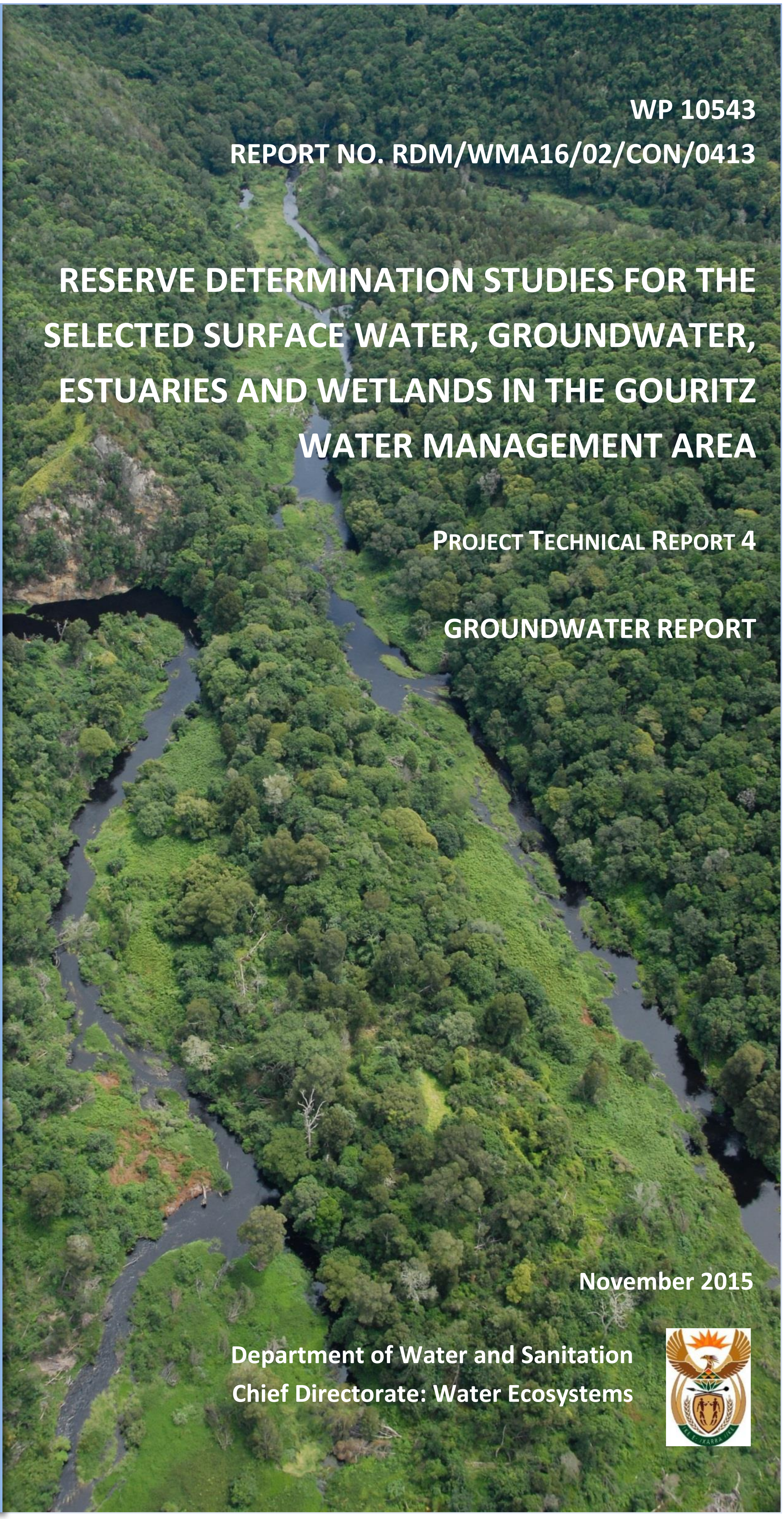







WP 10543

REPORT NO. RDM/WMA16/02/CON/0413

RESERVE DETERMINATION STUDIES FOR THE SELECTED SURFACE WATER, GROUNDWATER, ESTUARIES AND WETLANDS IN THE GOURITZ WATER MANAGEMENT AREA

PROJECT TECHNICAL REPORT 4

GROUNDWATER REPORT

November 2015

Department of Water and Sanitation
Chief Directorate: Water Ecosystems

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DOCUMENT INDEX

Reports as part of this project:

INDEX NUMBER	REPORT NUMBER	REPORT TITLE
Report Number 01	RDM/WMA16/00/CON/0113	Inception Report
Report Number 02	RDM/WMA16/00/CON/0213	Desktop EcoClassification Report
Report Number 03, Volume 1	RDM/WMA16/00/CON/0313, Volume 1	Delineation Report, Volume 1 (Groundwater, Estuaries and Wetlands)
Report Number 03, Volume 2	RDM/WMA16/00/CON/0313, Volume 2	Delineation Report, Volume 2 (Rivers)
Report Number 04	**RDM/WMA16/02/CON/0413**	**Groundwater Report**
Report Number 05	RDM/WMA16/03/CON/0513	Wetland Report
Report Number 06, Volume 1	RDM/WMA16/04/CON/0613, Volume 1	Estuaries RDM Report – Desktop Assessment
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Report Number 10	RDM/WMA16/01/CON/1013	Rivers RDM Report – Intermediate Assessment
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Report Number 13	RDM/WMA16/00/CON/1313	Main Report
Report Number 14	RDM/WMA16/00/CON/1314	Study Closure Report

Bold indicates this report.

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TITLE:	Reserve Determination Studies for the Selected Surface Water, Groundwater, Estuaries and Wetlands in the Gouritz Water Management Area: Groundwater Report
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REPORT SCHEDULE

Version	Date
First draft (internal review)	November 2014
Second draft (as preparation for January 2015 specialist groundwater meeting)	December 2014
Third draft (external review)	March 2015
Final report	November 2015

For management and improved governance reasons, South Africa's 19 water management areas have been consolidated into nine (9) WMAs. The Gouritz WMA (previously WMA16) now forms part of the Breede WMA (WMA8) and is known as the Breede-Gouritz WMA. It will be governed by the Breede-Gouritz Catchment Management Agency (CMA).

EXECUTIVE SUMMARY

INTRODUCTION

The Gouritz Water Management Area (WMA), a coastal WMA that is situated primarily in the Western Cape Province, is the second largest WMA in SA (old WMA delineation) covering ±53 000 km^2 and spans the southern coast of South Africa. The Gouritz WMA has increasingly received Water Use Licence Applications (WULA) for developments over the past few years. In some catchments current water supply and water demand are close to being equal (in balance), meaning the volume of water that can currently be supplied is almost completely used up by water users. Some areas of the WMA even operate at a water supply deficit and are under stress. Given these circumstances, the Department of Water Affairs (DWA) in 2011 initiated a tender process for a preliminary Reserve determination of selected water resources within the Gouritz WMA.

OBJECTIVES

The objectives of the study were to:

- *Perform a Desktop-Rapid level groundwater Reserve determination for the entire Gouritz WMA to identify hotspots/areas of water resource concern and areas in the WMA where limited groundwater is available after the Reserve is allocated;*
- *Perform Intermediate groundwater Reserve determinations for selected catchments/ Groundwater Resource Units (GRUs) that are classified as stressed based on the classification of the Desktop Reserve; and*
- *Report on groundwater Reserve figures and findings for the WMA and selected GRUs and make recommendations on where more detailed future studies should be performed.*

RESULTS

After evaluation of existing literature and data, a Desktop/Rapid level Reserve was performed for the Gouritz WMA using primarily the Groundwater Resource Assessment Phase II (GRA II) raster datasets and the new Groundwater Reserve Determination Methodology (GRDM) software database (Dennis et al., 2012). Vector overlay and raster extraction of the GRA II data was performed and compared to the new GRDM software database reference values for flow balance components such as recharge, baseflow and groundwater abstraction.

These results were used in conjunction with known problem or groundwater hotspot[1] areas (as stated during the October 2013 stakeholder meeting) as well as Reserve studies already performed in the Gouritz WMA, to identify groundwater hotspots and selected/priority GRUs (see map on following page and GRU table thereafter).

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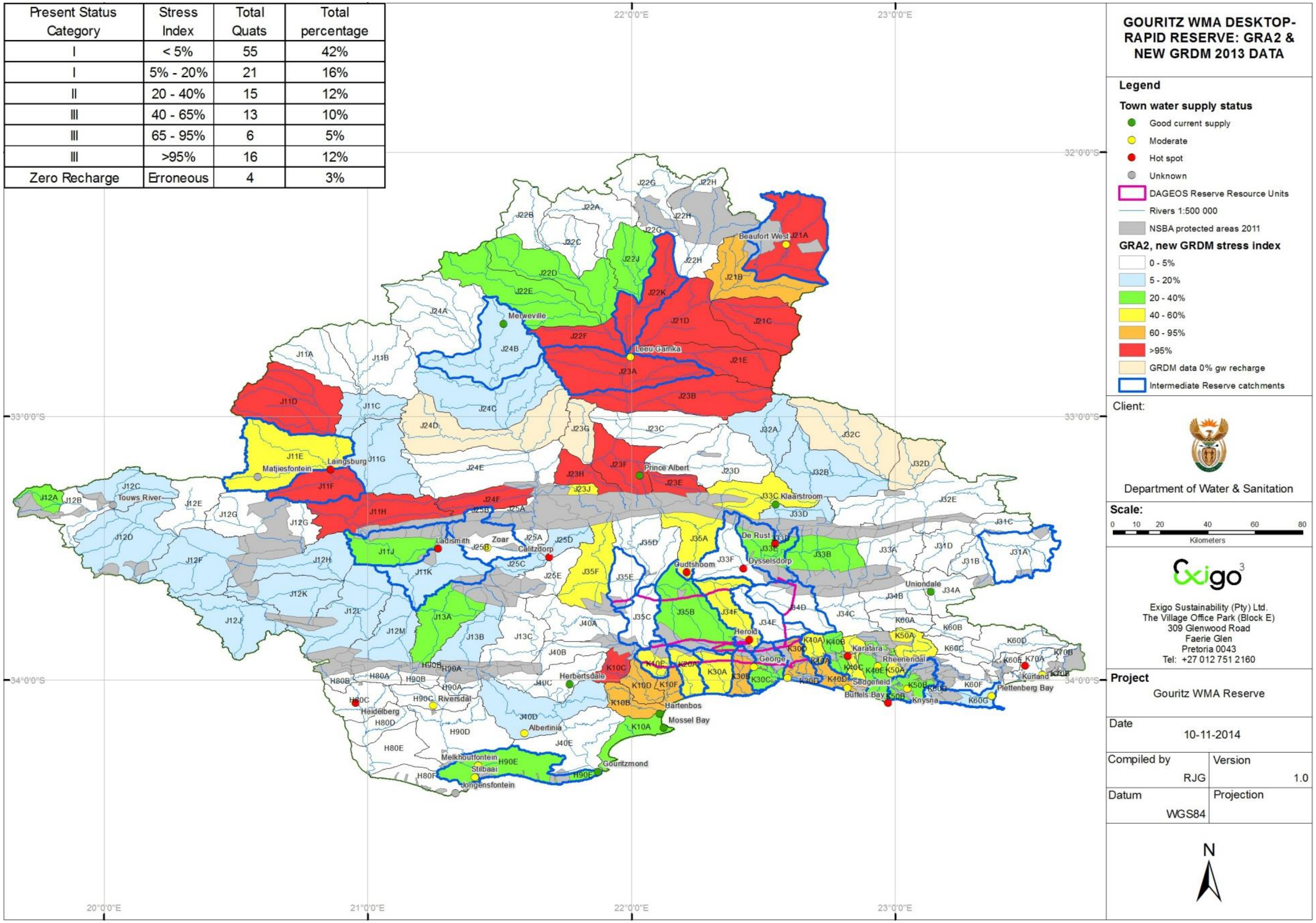
[1] A groundwater hotspot can be an area or town where large groundwater abstraction takes place, can be an ecologically sensitive area where environmental impact is expected due to groundwater abstraction, or is an area where groundwater is of strategic importance to many stakeholders and its shared use can potentially create conflict.

Present Status Category	Stress Index	Total Quats	Total percentage
I	< 5%	55	42%
I	5% - 20%	21	16%
II	20 - 40%	15	12%
III	40 - 65%	13	10%
III	65 - 95%	6	5%
III	>95%	16	12%
Zero Recharge	Erroneous	4	3%



Desktop-Rapid Reserve results for average conditions (P_{50}) and hotspots

Final selected quaternary catchments for Intermediate Reserve GRUs

Secondary Catchment Rivers	***Quaternary Catchment (28 catchments)***
Goukou River	*H90E*
Groot River	*J11E, J11F, J11J, J11K*
Gamka River	*J21A, J22K, J23A, J24B, J25B*
Olifants River	*J31A, J33E, J33F, J34D, J34E, J34F, J35B, J35C, J35E*
Klein-Brak River	*K10E*
Groot Brak River	*K20A*
Gwaing/Kaaimans/Touws Rivers	*K30A, K30B, K30C, K30D*
Sedgefield River	*K40D*
Knysna River	*K50B*
Keurbooms River	*K60G*
	***22%** of total (130) quaternary catchments*

HYDROCENSUS

An optimised hydrocensus was performed, guided by hotspot areas and the outputs of the Desktop-Rapid Reserve level results. A total of 97 geosites (boreholes and springs) were surveyed during the optimised hydrocensus in the Waboomskraal, southern Kammanassieberg, western Kammanassieberg and upper Olifants River areas. Accurate and recent groundwater level data is available for all actively monitored DWS boreholes in their monitoring network as shown in blue markers on the map in the report results section 2.4.2. A total of 86 groundwater levels were measured during the Gouritz hydrocensus, depending on where they could be accessed. For the dataset, the shallowest water level was 0.21 metres above ground level (magl), the deepest water level was 100 metres below ground level (mbgl) (actual >100 m, dip meter limitation) and mean groundwater level was calculated to be at 16.32 mbgl.

INTERMEDIATE RESERVE DETERMINATION

*The Desktop-Rapid level groundwater Reserve determination indicated that 28 of the 130 quaternary catchments are potentially stressed. In the Intermediate level Reserve, these 28 catchments were modelled in more detail to take account of storage and transient variability in rainfall (**Section 2.1.5**). Results from the Intermediate level Reserve determination are shown in the two maps below. It shows that under normal (mean annual precipitation) rainfall conditions, eight out of the 28 GRUs or quaternary catchments potentially show a groundwater deficit if the Reserve requirements are to be met. Under drought conditions 22 of the 28 Intermediate GRUs will have a groundwater balance deficit for drought years.*

FINDINGS (RECOMMENDATIONS)

The following summarises some of the main findings of this study:

1. *Groundwater forms an important part of the water resources in the Gouritz WMA. In the semi-arid areas north of the Outeniqua Mountains, the Klein Karoo and north of the Swartberg Mountains, groundwater is the dominant water resource. This is especially true during drought cycles, as groundwater becomes the sole water source when dams dry up. Groundwater supports water supply to local communities, towns and farms.*

2. The Intermediate Reserve results indicated that 1) alien vegetation has the potential to reduce groundwater recharge/groundwater potential significantly and 2) irrigation also has one of the biggest influences on the groundwater balance. When irrigation land use and typical irrigation water use is considered, the volumes are so large that it was concluded that there must be large surface water dams, river abstraction or irrigation canals present to justify these volumes. An assumption was made that 10 - 15% of all irrigation comes from groundwater.
3. There is a good correlation between catchments indicated as stressed and deeper groundwater levels. This may indicate that catchments highlighted as stressed are in fact experiencing groundwater stress. Further study is however required to verify this.
4. The Gouritz WMA is indicated to be stressed in a number of areas, more specifically in the Great Karoo basin as well as the Klein Karoo area and H90E. In the coastal areas further east, like K50B and K60G less groundwater stress is experienced due to the availability of surface water.
5. In the present day (status quo) scenario, using Mean Annual Precipitation (MAP), eight catchments (29%) of the 28 selected catchments show a groundwater deficit.
6. In 1 in 50 year drought conditions (Scenario 2), with rainfall at a 98 % level of assurance, 22 of the 28 selected quaternary catchments show a groundwater deficit. This shows that the methodology declassified the high stress status of six catchments that were analysed too conservatively in the Desktop-Rapid level Reserve iteration.
7. The groundwater quality of the regional area is generally good but influenced by the local geology. Certain lithologies within the Table Mountain Group (TMG) aquifers have a high iron content that exacerbates borehole clogging during abstraction when oxygen enters the system. The Bokkeveld- and Witteberg-Groups and the Dwyka Group in the Karoo generally have salinity problems. Most of the groundwater quality problems can be overcome with the latest water treatment technologies.
8. The deep confined Peninsula Aquifer (Resource Unit (RU) 2) is recharged by inflow from RU 1 (Conceptual Models 2-1 to 2-3).
   a. A conceptual numerical model was developed for the shallow and deep aquifers (RU1 and RU2) to determine the regional groundwater flow balance (Exigo, 2015). The potential flow from the shallower semi-confined aquifer (RU 1) to RU 2, under conditions of abstraction would in time reduce the baseflow contribution of RU 1.
   b. From the groundwater modelling, it is expected that it would take 15 - 20 years for the planned abstraction of Phase 1 at 3.8 million m^3/a (120 ℓ/s) to affect the northern reaches of the shallow semi-confined aquifer along the Doring River (Exigo, 2015). Increased leakage from surface streams due to abstraction may negate the partial dewatering of the deep confined aquifer but with an impact on the surface water streams.
   c. Based on this assessment, the combined yield of RUs 1 and 2 is 8.2 million m^3/a, for average conditions (P_{50}) and the assured yield (P_{98}) is 5.2 million m^3/a. It is estimated that a yield of 1.5 million m^3/a, during average conditions and 1.0 million m^3/a during drought conditions, may be applicable for RU 2, the deep confined aquifer. This will however need to be proven with more detailed follow-up monitoring and modelling. There is a Regional Bulk Infrastructure Grant (RBIG) study for Oudtshoorn deep groundwater development and aquifer modelling currently underway that should take the above flags that were raised into consideration, and provide updated estimates on aquifer parameters and Deep Artesian Groundwater Exploration for Oudtshoorn Supply (DAGEOS) scheme(s) allocable volumes.

d. An option for long-term sustainable use of the deep confined aquifer is to utilise storage which can be replenished via surface water artificial recharge during flood peaks. If this is a management option, it will have to be evaluated in more detail through a detailed feasibility study.

9. Long term monitoring data from the Klein Karoo Rural Water Supply Scheme (KKRWSS) indicates that yield and recharge of the Vermaaks River valley TMG is lower than initially estimated (GEOSS, 2014). It is also possible that abstraction from agricultural users around the Kammanassie Mountain could be causing a decline in hydraulic head in the vicinity of these abstractions.

10. Groundwater development potential is possible in ±70% of the catchments. The allocable groundwater potential is between a minimum of 31 million m^3/a, and 60 million m^3/a. An additional 25 million m^3/a could be available if advantage can be taken from reducing losses.

11. Conjunctive use between surface water and groundwater and artificial recharge are two future water use strategies that would be important to explore. Artificial recharge during times of flood or surplus flow conditions into deep aquifers could be a useful future strategy to store water for drought conditions.

RECOMMENDATIONS

The following summarises some of the recommendations made:

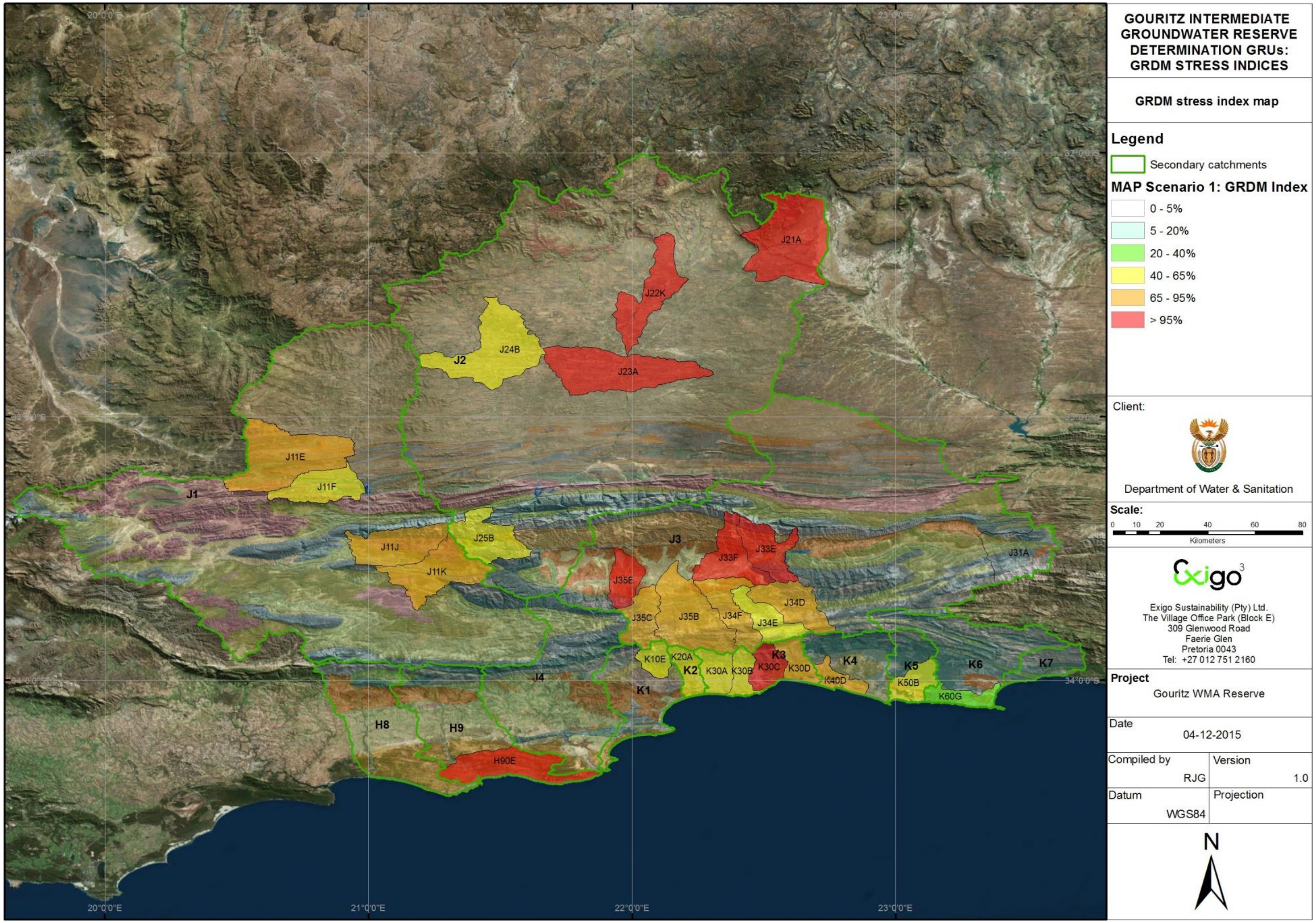
1. *Alien vegetation must be monitored and eradicated as far as possible in the WMA. The catchments that classified as the highest GRDM index should be targeted first. Alien vegetation should preferably be removed first in riparian-, spring- and wetland-areas. The water gained from Working for Water alien vegetation eradication programmes as well as the financial input for such programmes need to be justified, hence estimates of alien vegetation water use must be accurate (Mallory et al., 2011).*
2. *Groundwater monitoring should be performed across the WMA but with preference in the hotspot areas and catchments that classified with high GRDM stress indices.*
3. *The general authorisations in the 28 potentially stressed catchments must be reviewed and reduced to sustainable levels and in some cases it may be zero.*
4. *Detailed groundwater investigations and numerical flow management models using models such as MIKE SHE and FEFLOW, should be developed to characterise catchments H90E, J33E and J33F to verify the role that groundwater storage can play in the buffering of dry cycles. It will be important to verify the water use quantities. The deep Peninsula Aquifer will require a detailed three dimensional numerical groundwater flow model to refine and verify the yield.*
5. *The yield of the semi-confined shallow aquifer (RU 1) and the deep confined Peninsula Aquifer (RU 2) must be quantified using detailed 3D numerical groundwater flow models based on the latest data sets. The potential constraints of protected areas and surface water features e.g. streams and dams must be evaluated and environmental impacts qualified. It will be important to manage the groundwater abstraction from both RU 1 and RU 2 so as to ensure that the environmental flow requirements are met.*
6. *The groundwater contribution to baseflow should be verified in the catchments that flagged with a high GRDM index rating. Sampling of the water quality changes and parameter tracing based on hydrogeochemical mixing models can be considered to achieve this. The environmental flow requirement should also be refined.*

7. *Detailed field investigations and models should be used to determine a buffer zone to mitigate saline water intrusion. This aspect should be further investigated at K40D, K50B, K40E and K10A.*
8. *More research is required to determine under which conditions more groundwater may be available if losses can be reduced.*
9. *Additional groundwater development in the hotspot- and stressed-areas should be prevented if the stressed situation is verified. Options to regionally distribute groundwater abstraction to alleviate local concentrated abstraction should be investigated.*
10. *The Intermediate Reserve EWR must be refined in the next phase of the study as it could be less than the volumes that were conservatively estimated in this phase of the study.*
11. *Conjunctive use strategies between surface water and groundwater should be investigated and a guideline document be compiled that would account for the constraints in each catchment.*
12. *Artificial recharge should be considered as a future water management option. For aquifer types suitable for artificial recharge as well as artificial recharge methods that can be applied, please see the National Artificial Recharge strategy DWAF (2007b). Also see report by Murray et al. for DWA (2010b) of case studies where artificial recharge has been successfully applied. Notably artificial recharge case studies include Prince Albert and Plettenberg Bay that fall within the Gouritz WMA study area.*
13. *The water management strategy for the deep confined TMG aquifers should be reviewed and a guideline document be compiled to ensure sustainable development and utilisation of the deep groundwater systems.*
14. *Shale gas exploration (fracking) in the Karoo formations should be done with due diligence and care should be taken not to adversely affect the groundwater quality and supplies. The level of information on the hydrogeology of the deep Karoo Aquifers is currently too limited to make informed decisions on this aspect. Progress has been made in improving knowledge on the processes of deep groundwater circulation in Karoo aquifers and their flow mechanisms, notably the study performed by the KGEG (Steyl et al., 2012b) and more recently a study performed by Murray et al. (2015). Detailed groundwater investigations and baseline monitoring data must be collected before exploratory work is done.*

Summary table of the Groundwater Yield Model for the Reserve (GYMR) results for Scenario 1: Present Day with MAP rainfall

No	Quaternary catchment	Total surface area (km^2)	BHNR (million m^3/a)	Total inflow MAP (million m^3/a)	Total outflow before losses (million m^3/a)	Evapotranspiration streamflow loss (million m^3/a)	GYMR GW[1] contribution to baseflow (million m^3/a)	Ecological Water Requirement (EWR) (million m^3/a)	GYMR GW contribution to EWR (m^3/a)	GW allocation (million m^3/a)	GRDM Index	GRDM Present Status Category
1	H90E	498.43	-0.14	12.07	-22.94	-0.28	-11.15	-1.46	0.00	0.00	190%	III
2	J11E	811.58	-0.10	4.44	-3.56	-0.91	-0.04	0.00	0.00	0.00	80%	III
3	J11F	344.14	-0.02	2.12	-1.03	-0.45	0.65	0.00	0.00	0.65	48%	III
4	J11J	449.48	-0.03	5.07	-3.84	-0.48	0.75	0.00	0.00	0.75	76%	III
5	J11K	515.49	-0.26	3.71	-3.15	-0.57	-0.02	0.00	0.00	0.00	85%	III
6	J21A	854.17	-0.76	6.70	-6.81	-1.14	-1.24	-1.48	0.00	0.00	102%	III
7	J22K	478.81	0.00	2.10	-2.64	-0.70	-1.25	0.00	0.00	0.00	126%	III
8	J23A	761.62	-0.05	2.60	-7.19	-1.27	-5.86	0.00	0.00	0.00	276%	III
9	J24B	767.16	-0.03	3.15	-1.32	-1.10	0.72	0.00	0.00	0.72	42%	III
10	J25B	396.57	-0.09	5.42	-2.85	-0.79	1.79	-1.46	-1.46	0.33	53%	III
11	J31A	447.04	0.00	6.99	-1.40	-1.59	4.00	0.00	0.00	4.00	20%	I
12	J33E	328.67	-0.30	6.07	-7.56	-1.15	-2.64	-1.17	0.00	0.00	125%	III
13	J33F	365.63	-0.75	5.07	-10.57	-1.04	-6.54	-1.22	0.00	0.00	209%	III
14	J34D	354.20	-0.04	5.73	-5.10	-0.95	-0.31	-0.69	0.00	0.00	89%	III
15	J34E	257.99	-0.03	3.75	-1.53	-0.62	1.61	-0.76	-0.76	0.84	41%	III
16	J34F	319.97	-0.06	4.36	-3.93	-0.88	-0.45	-1.59	0.00	0.00	90%	III
17	J35B	651.14	-0.13	9.93	-8.93	-1.78	-0.78	-0.47	0.00	0.00	90%	III
18	J35C	264.48	-0.08	3.06	-2.89	-0.50	-0.33	-0.99	0.00	0.00	94%	III
19	J35E	215.16	-0.03	1.70	-2.87	-0.46	-1.64	-1.78	0.00	0.00	169%	III
20	K10E	132.50	-0.09	3.57	-2.24	-0.54	0.79	-0.79	-0.79	0.01	63%	III
21	K20A	168.94	-0.21	4.41	-1.91	-0.42	2.08	-1.98	-1.98	0.11	43%	III
22	K30A	196.60	-0.15	5.15	-3.13	-0.35	1.67	-2.27	-1.67	0.00	61%	III
23	K30B	139.65	-0.14	3.68	-2.38	-0.62	0.69	-2.40	-0.69	0.00	65%	III
24	K30C	190.68	-3.22	5.24	-6.66	-0.64	-2.06	-6.63	0.00	0.00	127%	III
25	K30D	178.79	-0.22	5.13	-3.52	-0.96	0.65	-0.82	-0.65	0.00	68%	III
26	K40D	131.21	-0.44	4.49	-3.77	-0.40	0.33	-1.03	-0.33	0.00	84%	III
27	K50B	203.97	-0.32	6.77	-3.43	-0.57	2.77	-3.07	-2.77	0.00	51%	III
28	K60G	168.89	-0.50	6.54	-2.11	-0.46	3.97	-2.39	-2.39	1.57	32%	II
	Total	**10 593**	**-8.19**	**139.04**	**-129.26**	**-21.64**	**-11.86**	**-34.47**	**-13.47**	**8.98**	**93%**	

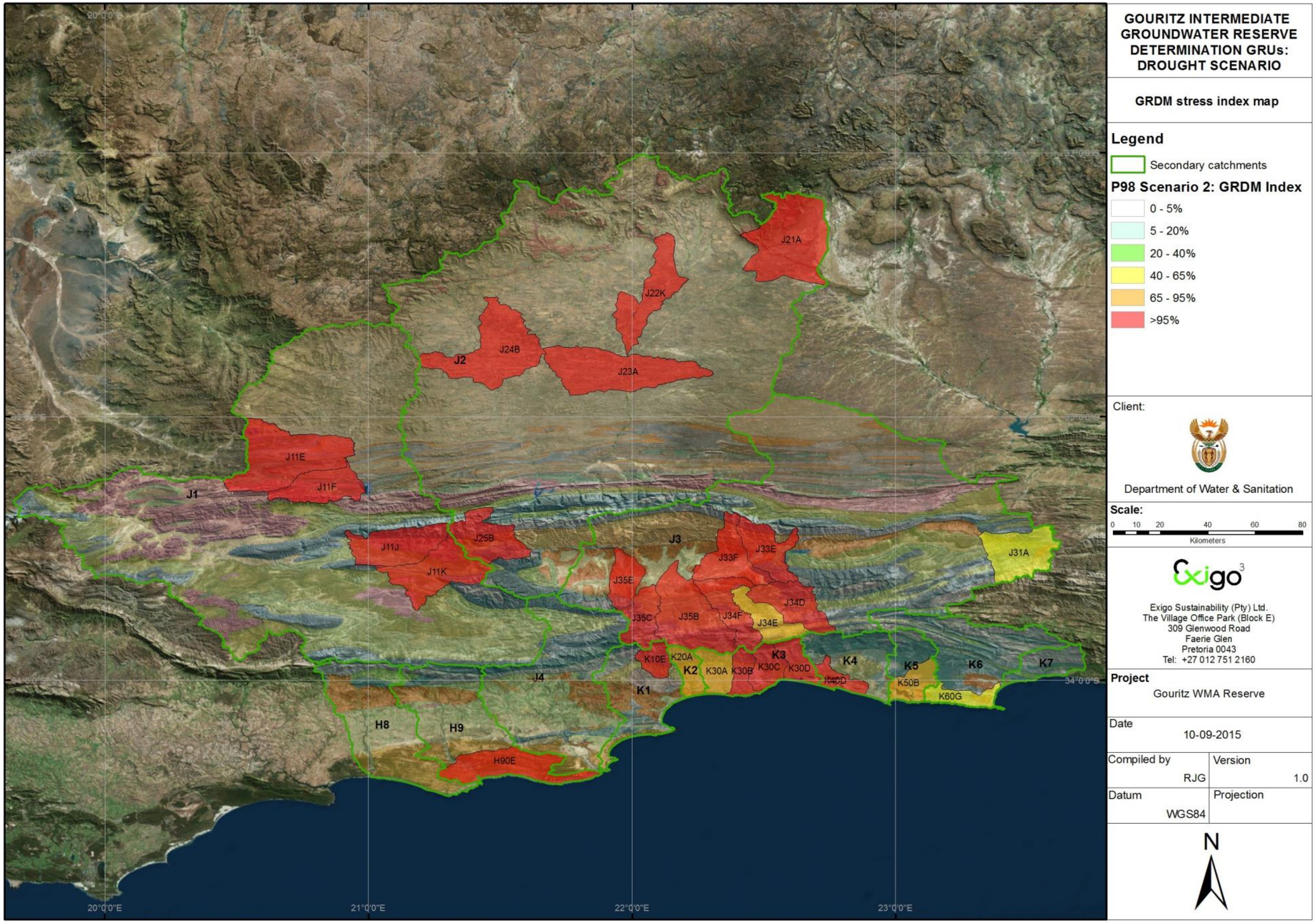
1 Ground water



Present day MAP scenario showing GRDM stress index per Intermediate Reserve selected catchment in the Gouritz WMA

Summary table of GYMR results for Scenario 2: Present day with 98% assured rainfall for drought cycles

No	Quaternary catchment	Total surface area (km^2)	BHNR (million m^3/a)	Total inflow 98% assured (million m^3/a)	Total outflow before losses (million m^3/a)	Evapotranspiration streamflow loss (million m^3/a)	Net baseflow before EWR (million m^3/a)	EWR (million m^3/a)	GYMR GW contribution to EWR (m^3/a)	GW Allocation (million m^3/a)	GRDM Index	GRDM Present Status Category
1	H90E	498.43	-0.14	7.57	-22.94	-0.28	-15.65	-1.46	0.00	0.00	303%	III
2	J11E	811.58	-0.10	2.08	-3.56	-0.91	-2.39	0.00	0.00	0.00	171%	III
3	J11F	344.14	-0.02	1.00	-1.03	-0.36	-0.39	0.00	0.00	0.00	103%	III
4	J11J	449.48	-0.03	2.76	-3.84	-0.48	-1.56	0.00	0.00	0.00	139%	III
5	J11K	515.49	-0.26	2.02	-3.15	-0.57	-1.71	0.00	0.00	0.00	156%	III
6	J21A	854.17	-0.76	2.81	-6.81	-1.14	-5.13	-1.48	0.00	0.00	242%	III
7	J22K	478.81	0.00	0.90	-2.64	-0.70	-2.45	0.00	0.00	0.00	295%	III
8	J23A	761.62	-0.05	0.98	-7.19	-1.27	-7.48	0.00	0.00	0.00	735%	III
9	J24B	767.16	-0.03	0.75	-1.32	-1.10	-1.68	0.00	0.00	0.00	177%	III
10	J25B	396.57	-0.09	2.94	-2.85	-0.79	-0.70	-1.46	0.00	0.00	97%	III
11	J31A	447.04	0.00	3.36	-1.40	-1.59	0.37	0.00	0.00	0.37	42%	III
12	J33E	328.67	-0.30	3.18	-7.56	-1.15	-5.53	-1.17	0.00	0.00	238%	III
13	J33F	365.63	-0.75	2.77	-10.57	-1.04	-8.84	-1.22	0.00	0.00	382%	III
14	J34D	354.20	-0.04	3.44	-5.10	-0.95	-2.61	-0.69	0.00	0.00	148%	III
15	J34E	257.99	-0.03	2.16	-1.53	-0.62	0.02	-0.76	-0.02	0.00	71%	III
16	J34F	319.97	-0.06	2.56	-3.93	-0.88	-2.25	-1.59	0.00	0.00	154%	III
17	J35B	651.14	-0.13	5.88	-8.93	-1.78	-4.83	-0.47	0.00	0.00	152%	III
18	J35C	264.48	-0.08	1.84	-2.89	-0.50	-1.56	-0.99	0.00	0.00	158%	III
19	J35E	215.16	-0.03	0.85	-2.87	-0.46	-2.49	-1.78	0.00	0.00	339%	III
20	K10E	132.50	-0.09	2.10	-2.24	-0.54	-0.67	-0.79	0.00	0.00	106%	III
21	K20A	168.94	-0.21	2.79	-1.91	-0.42	0.46	-1.98	-0.46	0.00	69%	III
22	K30A	196.60	-0.15	3.30	-3.13	-0.35	-0.19	-2.27	0.00	0.00	95%	III
23	K30B	139.65	-0.14	2.38	-2.38	-0.62	-0.62	-2.40	0.00	0.00	100%	III
24	K30C	190.68	-3.22	3.36	-6.66	-0.64	-3.94	-6.63	0.00	0.00	198%	III
25	K30D	178.79	-0.22	3.34	-3.52	-0.96	-1.14	-0.82	0.00	0.00	105%	III
26	K40D	131.21	-0.44	3.00	-3.77	-0.40	-1.16	-1.03	0.00	0.00	126%	III
27	K50B	203.97	-0.32	4.87	-3.43	-0.57	0.86	-3.07	-0.86	0.00	70%	III
28	K60G	168.89	-0.50	4.68	-2.11	-0.46	2.10	-2.39	-2.10	0.00	45%	III
	Total	**10 593**	**-8.19**	**79.66**	**-129.26**	**-21.55**	**-71.16**	**-34.47**	**-3.44**	**0.37**		



Map showing GRDM stress index per Intermediate Reserve catchment – Scenario 2: 98% assured rainfall (drought)

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ACRONYMS

AGEP	Average Groundwater Exploitation Potential
AGES	Africa Geo-Environmental Services
BHN	Basic Human Needs
BID	Basic Information Document
CD: RDM	Chief Directorate: Resource Directed Measures
CD: WE	Chief Directorate: Water Ecosystems (Name change from CD: RDM)
CFB	Cape Fold Belt
CMA	Catchment Management Agency
CMB	Chloride Mass Balance
CSIR	Council for Scientific and Industrial Research
DAGEOS	Deep Artesian Groundwater Exploration for Oudtshoorn Supply
DM	District Municipality
DMR	Department of Mineral Resources
DTM	Digital Terrain Model
DWA	Department of Water Affairs (Name change from DWAF applicable after April 2009)
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation (Name change from DWA applicable after May 2014)
EC	Electrical Conductivity
EIS	Ecological Importance and Sensitivity
EWR	Ecological Water Requirements
GA	General Authorisation
GDE	Groundwater Dependent Ecosystem
GEOSS	Geohydrological & Spatial Solutions International
GIS	Geographical Information System
GRA II	Groundwater Resource Assessment Phase II
GRDM	Groundwater Reserve Determination Methodology
GRDS	Gouritz Reserve Determination Study
GRUs	Groundwater Resource Units
GW	Groundwater
GYMR	Groundwater Yield Model for the Reserve
HGM	Hydrogeomorphic
IFR	Instream Flow Requirement
IWRM	Integrated Water Resource Management
K	Hydraulic Conductivity (m/d)
KGEG	Karoo Groundwater Expert Group
KKRWSS	Klein Karoo Rural Water Supply Scheme
$[L^2]$	Unit with dimensions of Length(L) squared
[L/T]	Unit with dimensions of Length(L)/Time(T)
Ma	Mega-annum or million annums
MAE	Mean Annual Evaporation
Magl	Metres above ground level
Mamsl	Metres above mean sea level
MAP	Mean Annual Precipitation
Mbgl	Metres below ground level
MAP	Mean Annual Precipitation
MPA	Marine Protected Area
NEMA	National Environmental Management Act
NGA	National Groundwater Archive
NGDB	National Groundwater Database

NGI	National Geospatial Information: Department of Rural Development and Land Reform
NSBA	National Spatial Biodiversity Assessment
NWA	National Water Act
OCWSS	Outeniqua Coast Water Situation Study
ORDS	Outeniqua Reserve Determination Study
PES	Present Ecological State
RBIG	Regional Bulk Infrastructure Grant
REC	Recommended Ecological Category
RDM	Resource Directed Measures
RO	Reverse Osmosis
RQO	Resource Quality Objective
RU	Resource Unit
SANBI	South African National Biodiversity Institute
SC&A	Scherman Colloty and Associates
T	Transmissivity (m^2/d)
TCF	Trillion Cubic Feet
TDS	Total Dissolved Solids
TMG	Table Mountain Group
UGEP	Utilisable Groundwater Exploitation Potential
WAAS	Water Availability Assessment Study
WARMS	Water Authorisation and Management System
WMA	Water Management Area
WR2005	Water Resources of South Africa, 2005 Study
WRC	Water Research Commission
WULA	Water Use Licence Application

GLOSSARY

Advection is the process by which solutes are transported by the bulk motion of the flowing groundwater.

Anisotropy is an indication of some physical property varying with direction.

Cone of depression is a depression in the groundwater table or potentiometric surface that has the shape of an inverted cone and develops around a borehole from which water is being withdrawn. It defines the area of influence of a borehole.

A ***confined aquifer*** is a formation in which the groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations; confined groundwater is generally subject to pressure greater than atmospheric.

The ***darcy flux***, is the flow rate per unit area (m/d) in the aquifer and is controlled by the hydraulic conductivity and the piezometric gradient.

Dispersion is the measure of spreading and mixing of chemical constituents in groundwater caused by diffusion and mixing due to microscopic variations in velocities within and between pores.

Drawdown is the distance between the static water level and the surface of the cone of depression.

Effective porosity is the percentage of the bulk volume of a rock or soil that is occupied by interstices that are connected.

Groundwater Resource Unit A groundwater body that has been delineated or grouped into a single significant water resource based on one or more characteristics that are similar across that unit.

Geosite "A naturally occurring or artificially excavated or constructed or improved underground cavity which can be used for the purpose of a) intercepting, collection or storing of water in, or removing water from an aquifer, b) observing and collecting data and information on water in an aquifer, or c) recharging an aquifer" (Xu *et al.*, 2003).

Groundwater table is the surface between the zone of saturation and the zone of aeration; the surface of an unconfined aquifer.

A ***fault*** is a fracture or a zone of fractures along which there has been displacement.

Hydrodynamic dispersion comprises of processes namely mechanical dispersion and molecular diffusion.

Hydraulic conductivity *(K)* is the volume of water that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured perpendicular to the area [L/T]. Hydraulic conductivity is a function of the permeability and the fluid's density and viscosity.

Hydraulic gradient is the rate of change in the total head per unit distance of flow in a given direction.

Heterogeneous indicates non-uniformity in a structure.

Karstic topography is a type of topography that is formed on limestone, gypsum, and other rocks by dissolution, an is characterised by sinkholes, caves and underground drainage.

Mechanical dispersion is the process whereby the initially close group of pollutants are spread in a longitudinal as well as a transverse direction because of velocity distributions.

Molecular diffusion is the dispersion of a chemical caused by the kinetic activity of the ionic or molecular constituents.

Observation borehole is a borehole drilled in a selected location for the purpose of observing parameters such as water levels.

Permeability is related to hydraulic conductivity, but is independent of the fluid density and viscosity and has the dimensions [L^2]. Hydraulic conductivity is therefore used in all the calculations.

Piezometric *head* is the sum of the elevation and pressure head. An unconfined aquifer has a water table and a confined aquifer has a piezometric surface, which represents a pressure head. The piezometric head is also referred to as the hydraulic head.

Porosity is the percentage of the bulk volume of a rock or soil that is occupied by interstices, whether isolated or connected.

Pumping tests are conducted to determine aquifer and borehole characteristics.

Recharge is the addition of water to the zone of saturation; also, the amount of water added.

Reserve "means the quantity and quality of water required to:

a) to satisfy basic human needs by securing a basic water supply, as prescribed under the Water Services Act, 1997 (Act No 108 of 1997), for people who are now or who will, in the reasonably near future, be:
    i. relying upon;
    ii. taking water from; or
    iii. being supplied from,
    the relevant water resource; and
b) to protect aquatic ecosystems in order to secure ecologically sustainable development and use the relevant water resource."

[Source: National Water Act (Act No. 36 of 1998)].

Sandstone is a sedimentary rock composed of abundant rounded or angular fragments of sand set in a fine-grained matrix (silt or clay) and more or less firmly united by a cementing material.

Shale is a fine-grained sedimentary rock formed by the consolidation of clay, silt or mud. It is characterised by finely laminated structure and is sufficiently indurated so that it will not fall apart on wetting.

Specific storage *(S_s)*, of a saturated confined aquifer is the volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head. In the case of an unconfined (phreatic, watertable) aquifer, specific yield is the water that is released or drained from storage per unit decline in the watertable.

Static water level is the level of water in a borehole that is not being affected by withdrawal of groundwater. Also known as a "rest water level"

Storativity is the two-dimensional form of the specific storage and is defined as the specific storage multiplied by the saturated aquifer thickness.

Total dissolved solids (TDS) is a term that expresses the quantity of dissolved material in a sample of water.

Transmissivity (T) is the two-dimensional form of hydraulic conductivity and is defined as the hydraulic conductivity multiplied by the saturated thickness.

An ***unconfined***, ***water table*** or ***phreatic aquifer*** are different terms used for the same aquifer type, which is bounded from below by an impermeable layer. The upper boundary is the water table, which is in contact with the atmosphere so that the system is open.

Vadose zone is the zone containing water under pressure less than that of the atmosphere, including soil water, intermediate vadose water, and capillary water. This zone is limited above by the land surface and below by the surface of the zone of saturation, that is, the water table.

Water table is the surface between the vadose zone and the saturated zone (i.e. groundwater). The water table is the surface of an unconfined aquifer at which the pressure is equal to that of the atmosphere.

1 INTRODUCTION

The Gouritz Water Management Area (WMA) is a coastal WMA that is situated primarily in the Western Cape Province and spans the southern coast of South Africa from the Duiwenhoks River mouth in the west (36 km west of Still Bay) to the Bloukrans River mouth to the east (near Nature's Valley). The Gouritz WMA has increasingly received Water Use Licence Applications (WULAs) for developments over the past few years. In some catchments current water supply and water demand are close to being equal (in balance), meaning the volume of water that can currently be supplied is almost completely used up by water users. Some areas of the WMA even operate at a water deficit and are under stress. Given these circumstances, the Department of Water and Sanitation (DWS) in 2011 initiated a tender process for a preliminary Reserve determination for the Gouritz WMA. It has been recognised that some parts of the WMA are severely affected by invasive alien vegetation. Working for Water programmes aim to eradicate these invasive alien plants, but the water gain as well as the financial input for such programs needs to be justified, hence estimates of alien vegetation water use must be accurate (Mallory *et al.*, 2011).

Groundwater is an important source of water supply in the arid and semi-arid areas north of the Outeniqua Mountains where it is the predominant source of water to farms, livestock and communities. South of the Outeniqua Mountains, groundwater is an important source of water to farms, livestock and some of the wetlands and riparian zones in low flow or drought periods.

1.1 TERMS OF REFERENCE

Exigo Sustainability (Pty) Ltd., hereafter referred to as Exigo, was appointed by Sherman Colloty and Associates cc. (SC&A) to perform a preliminary[2] Reserve determination of the groundwater component, for selected groundwater resources in the Gouritz WMA for the DWS. The approach was to perform a Desktop-Rapid level Reserve determination on the total of 130 quaternary catchments and an Intermediate level Reserve determination on the groundwater component for selected catchments that had a high (i.e. stressed) classification (Groundwater Reserve Determination Methodology ((GRDM) index) from the Desktop Reserve. Full details of the groundwater resources sub-task and scope of work are provided in the Gouritz WMA Reserve Inception Report (DWA, 2014a). The following summary is provided for the groundwater resources component of the study.

1.2 OBJECTIVES

The objectives of the groundwater study were:

- Perform a Desktop-Rapid level groundwater Reserve determination for the entire Gouritz WMA and Intermediate Reserve determinations for selected catchments that are classified as stressed based on the classification of the Desktop Reserve.
- Screening of the entire WMA for potential groundwater Reserve deficit areas.

[2] Under the National Water Act (No.36, 1998) (NWA) provision is made for preliminary determinations of class and resource quality objectives of a water resource before formal classification is made. Formal classification is legally binding on all authorities and institutions when exercising powers or duties under the NWA (1998).

- The study resolution and management unit was based on surface water quaternary catchments with hydrogeological units differentiated within the quaternary catchments.

1.3 SCOPE OF WORK

The scope of work for the Gouritz preliminary Reserve determination is summarised as follows from the Inception report (DWA, 2014a):

- Provide the groundwater inputs for the compilation of a project inception report, outlining the final planning and scope of the Gouritz Reserve study.
- Groundwater Rapid level Reserve determination: The Desktop-Rapid level Reserve determination is the first task to be completed for the groundwater component of the Reserve assessment and its purpose is to identify hot spots and areas in the WMA where limited groundwater is available after the Reserve is allocated. It was performed based on existing information with the outputs being a classification and maps with the Rapid Reserve results for all 130 quaternary catchments in the WMA. It also serves to guide the selected field hydrocensus surveys to hot spots and areas classified as priority through the Reserve, within the WMA.
- Delineation report inputs – preliminary Groundwater Resource Unit (GRU) delineation: This task has four components of contribution:
  - Use the Desktop-Rapid Reserve to flag problematic (i.e. stressed) catchments and aquifers;
  - Evaluate geological and geohydrological data and delineate GRUs based on geohydrology, aquifer units and boundaries.
  - Evaluate hydrological data and based on groundwater level distributions, delineate GRUs based on surface water quaternary catchment boundaries.
  - Evaluate merits for surface water quaternary catchment boundaries and hydrogeological boundaries and perform final GRU delineation.
- Hydrocensus field survey: The groundwater field survey (early 2014) forms an integral part of the data collection to be used as input information to the Intermediate groundwater Reserve determinations for selected GRUs, and entails the following: A hydrocensus and field survey on selected catchments that were identified during the Desktop-Rapid Reserve. A maximum of 10 quaternary catchments were selected to do a hydrocensus. This aspect was decided on in conjunction with the DWS.
- Development of conceptual groundwater flow models for both the shallow and known deep aquifers. These components would include all recharge- and discharge-components that are relevant to the Reserve such as rainfall-recharge, dam seepage, boreholes, springs, wetlands, riparian vegetation, irrigation, forestry and evaporation losses.
- Based on the Desktop-Rapid Reserve outcomes and identified groundwater hotspots, quaternary catchments and GRUs were selected to perform more detailed (Intermediate) qualitative and quantitative Reserve determinations on, and will be done using the Groundwater Yield Model for the Reserve (GYMR) (DWA, 2010) method. The method includes the following tasks:
  - Statistical rainfall analysis: From the rainfall analyses, it will be important to determine assurance levels and the potential impacts of droughts on groundwater availability.

    - Update the conceptual groundwater flow models from the Rapid Reserve that would take the required flow components into account. These components will include all groundwater recharge and discharge components important to the Reserve such as rainfall-recharge, dam seepage, boreholes, springs, wetlands, riparian vegetation, irrigation, forestry and evaporation losses.
    - Qualitative and quantitative groundwater volume modelling using the GYMR method for the present day case. This is based on the minimum groundwater balance approach (Vivier, 2013).
    - Development scenarios and scenario modelling to reflect the pristine and potential future cases.
    - Specific reference will be given to the Basic Human Needs Reserve (BHNR).
    - Groundwater quality consideration and influence of groundwater quality on the Reserve. Selected samples will be taken during the hydrocensus for groundwater quality analyses.
    - Surface water-groundwater interaction and integration to determine groundwater outputs to baseflow and the Ecological Water Requirements (EWRs).
- An assessment of groundwater monitoring data in the WMA will be performed and monitoring conclusions and recommendations will be developed as part of the groundwater deliverables of the WMA study.
- Capacity building forms an integral part of the groundwater Reserve assessment. Both field training during the hydrocensus as well as training on the Intermediate Groundwater Reserve determination methodology followed will be provided.
- Review of groundwater Reserve study and results.

1.4 STUDY AREA

The Gouritz WMA (WMA 16) is a coastal WMA that is situated primarily in the Western Cape Province with smaller parts extending into the Eastern and Northern Cape Provinces respectively (**Figure 1.1**). The WMA spans the southern coast of South Africa from the Duiwenhoks River mouth in the west (36 km west of Still Bay) to the Bloukrans River mouth in the east (8 km east of Nature's Valley). Three primary drainage regions form part of the Gouritz WMA: the J primary drainage region of the Gouritz River, covering 86% of the surface area, part of the K drainage region covering 9% of the area and the H drainage region covering 6% of the area.

The Gouritz River is the main drainage of the J primary drainage region as well as the Gouritz WMA. The H and K primary drainage regions are drained by other coastal rivers of the first or second strahler order. The major rivers of the entire Gouritz WMA are the Gouritz, Olifants, Kammanassie, Gamka, Buffels, Touws, Goukou and Duiwenhoks Rivers. The main cities and towns within the Gouritz WMA are George, Mossel Bay, Knysna, Oudtshoorn and Beaufort West. Approximate coordinates (WGS84, decimal degrees) for the centroid of the WMA are:

Latitude: -33.320393 Longitude: 21.796533.

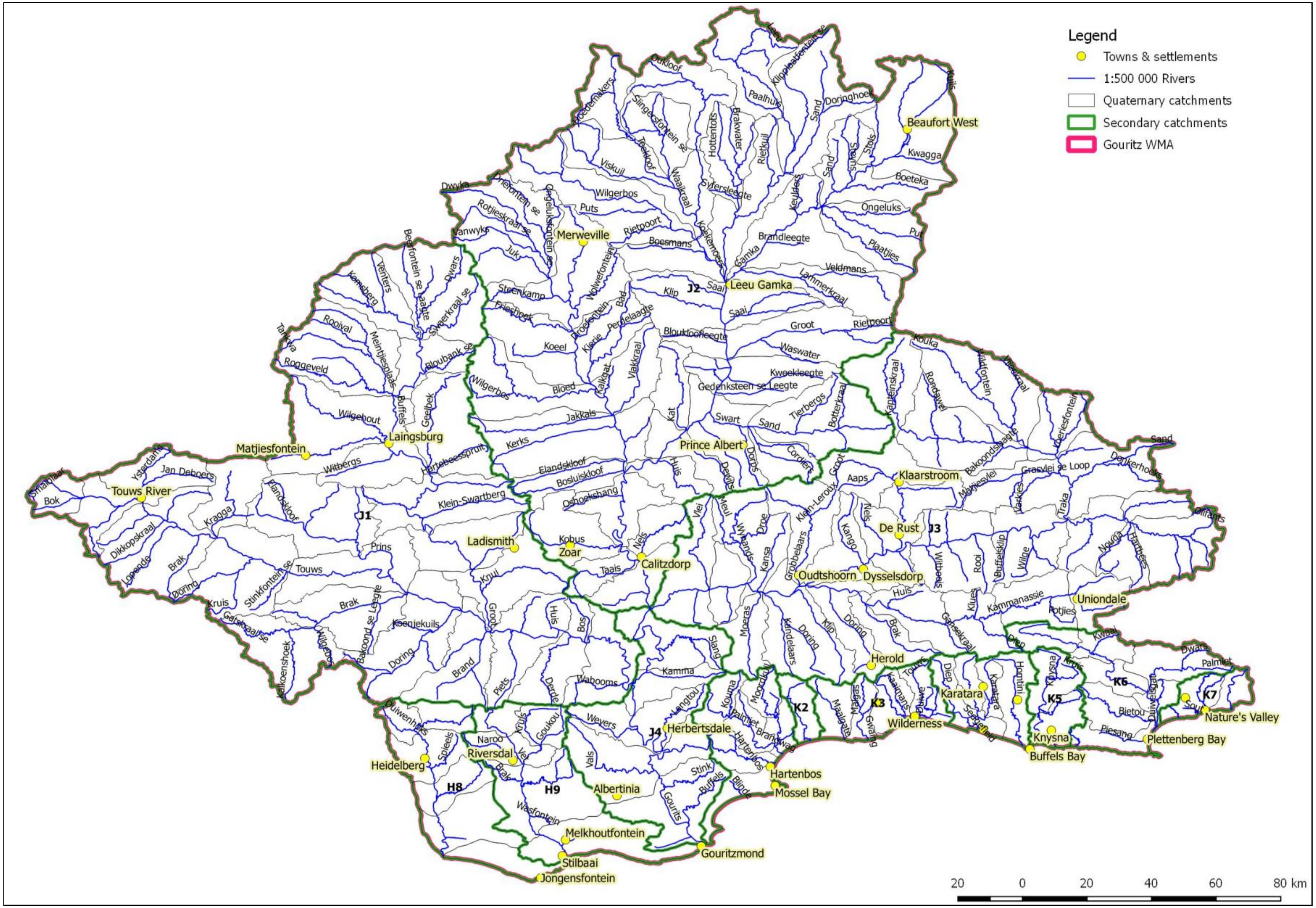


Figure 1.1 Map of Gouritz WMA (WMA16)

2 GROUNDWATER COMPONENT OF THE RESERVE

2.1 METHODOLOGY

2.1.1 Delineation approach

To provide effective groundwater Reserve determination assessments on selected/priority GRUs, a selection and delineation process is required. This section reports on the methodology followed for the selection of priority/hot spot locations for hydrocensus as well as determining selected GRUs for Intermediate Reserve determination.

There are two main approaches to GRU delineation (See **Section 2.1.4.1**):

- Surface water and catchment boundaries: The quaternary catchment is the primary unit of analysis based on the most recent version of the Groundwater Resource Directed Measures manual since groundwater must also be considered in terms of an integrated water resource (Dennis *et al.*, 2012). Following this approach, it is important to make provision for the main hydrogeological zones within the quaternary catchment, as recharge can vary substantially across a GRU, based on the geographic and geological setting.
- GRU boundaries based on the geology and hydrogeology: This approach assumes that hydraulic head (groundwater level) follows the hydrogeological zones with similar parameters such as recharge and transmissivity. Boundaries are thus based on contacts between the different geological formations/closed faults and differences between the hydraulic parameters of the strata.

A three-step delineation process was followed as described in the Outeniqua Reserve Determination Study (ORDS; DWA, 2010) and the new Groundwater Resource Directed Measures (GRDM) manual (Dennis *et al.*, 2012).

2.1.2 Desktop study of existing literature

A review of existing literature was performed to evaluate and obtain initial estimates of the inflow and outflow components as well as Desktop/Rapid level Reserves in the Gouritz WMA, based on a quaternary catchment and GRU approach. Results from the ORDS groundwater study (DWA, 2010) that obtained Reserve results for 19 quaternary catchments within the Gouritz WMA, were incorporated. A list of the other data sources are shown in **Appendix B**.

The Reserve determined for the deep confined Peninsula Aquifer used in the Deep Artesian Groundwater Exploration for Oudtshoorn Supply (DAGEOS) project by Riemann and Blake (2010) was evaluated and redone independently. This is the first deep Table Mountain Group (TMG) Aquifer planned to be developed and the first deep (500+ m) groundwater component of the Reserve that has been done in South Africa. The Reserve for the semi-confined aquifer within the quaternary catchments above the confined aquifer is also important and these quaternary catchments have been flagged as potentially sensitive as approximately 40% of the recharge area is underlain by South African National Biodiversity Institute (SANBI) protected areas.

2.1.3 Primary delineation: Data comparison, GIS overlay analysis and catchments

After evaluation of existing literature and data, a Desktop/Rapid level Reserve was performed for the Gouritz WMA using primarily the Groundwater Resource Assessment Phase II (GRA II) raster datasets and the new GRDM software database (Dennis *et al.*, 2012). Vector overlay and raster extraction of the GRA II data was performed and compared to the new GRDM software database reference values for flow balance components such as recharge, baseflow and groundwater abstraction.

Data from the newly improved GRDM (Dennis *et al.*, 2012) and GRA II (DWAF, 2006) databases were used to determine the groundwater use, recharge, EWR and Basic Human Needs (BHN) per quaternary catchment for the Desktop-Rapid Reserve. The EWR was assumed to be 40% of the quaternary baseflow estimate, which was obtained from the GRDM software database v.2.3.2.0 (Dennis, 2013). This assumption was conservatively made until the more accurate volumes become available from the other components of this study. The precautionary principle and minimax approach (Vivier, 2011; Von Neuman, 1928) is followed whereby conservative assumptions are made when uncertainty is dealt with. As more data is collected and uncertainty is reduced, the groundwater volumes available for use should increase (Vivier, 2011).

The National Spatial Biodiversity Assessment (NSBA) 2011 of formally protected areas GIS layer for the country was obtained from the South African National Biodiversity Institute (SANBI) website. Formally protected areas are protected against any further abstraction as well as any reduction in baseflow, thus they cannot be included in further calculations of allocable groundwater. NSBA Formally protected areas were subtracted from the quaternary catchment areas to obtain effective areas for the Desktop-Rapid Reserve determination. Recharge and baseflows were scaled based on the new effective areas.

These results were used in conjunction with known problem or hotspot areas (as stated during the October 2013 stakeholder meeting) as well as Reserve studies already performed in the Gouritz WMA, to identify groundwater hotspots and selected/priority GRUs. Existing groundwater Reserve studies in the Gouritz WMA include:

- Outeniqua coast water situation study. Groundwater resources, 2007 (DWAF, 2007a).
- Reserve determination studies for selected surface water, groundwater, estuaries and wetlands in the Outeniqua catchment: Technical component – Knysna and Swartvlei, 2010 (DWA, 2010).
- WULA – Geohydrological Assessment: Beaufort West Municipality, Beaufort West, 2012 (GEOSS, 2012a).
- Groundwater Reserve determination for current and potential wellfield development of TMG aquifers, 2010 (Riemann and Blake, 2010).
- Assessment of environmental impacts of groundwater abstraction from the TMG aquifers on ecosystems in the Kammanassie Nature Reserve and Environs, 2003 (Cleaver *et al.*, 2003).

2.1.4 Scale of the study

Scale is an important aspect in the study. The objective of the study is to determine the amount of water required for the groundwater Reserve as well as the amount of groundwater that can safely be allocated to current/future groundwater developments. For the purpose of this study, the resolution that is used is the quaternary catchment scale, which is typically tens of kilometres in dimension. Should assessments be done on a smaller scale, such as the wellfield scale that ranges from hundreds of metres to kilometres or borehole scale that ranges between sub-metres to several hundreds of metres or a couple of kilometres, then different conclusions may be reached. It is important to note that the scale of the assessment will have an influence on the assessments – a complex challenge that is associated with hydrogeology, especially in fractured aquifers (DWA, 2010; Bear, 1979; Steyl *et al.*, 2012a and Neuman, 2005).

Selected inferred hotspot areas were evaluated in more detail where deemed necessary.

2.1.4.1 Surface water catchments versus GRUs

The approach in this study is to use mainly quaternary catchments as the resolution for the study. The reason for this is that in previous studies and in this study there are good correlations between groundwater head elevation and topography for the shallow aquifers (**Section 2.2.10**). This is not necessarily the case for deeper aquifers. The importance of geology is acknowledged and allowance is made for up to ten hydrogeological sub-units within a quaternary catchment.

Another reason why this approach is preferred is because it is the legal boundaries within which Integrated Water Resource Management (IWRM) is done (National Water Act (NWA) no. 36 of 1998) (South Africa, 1998a) and data such as rainfall, baseflow, etc. are available at this scale for the whole country (Middleton and Bailey, 2011; DWAF, 2006). Should a geological unit be used as a resource boundary, it should be done as a secondary assessment. If the TMG quartzitic sandstone is to be considered as a GRU, which stretches across tens of kilometres, it must be considered that the rainfall and hence recharge will change across the length and breadth of the GRU and add uncertainty in terms of how to quantify the inflow and outflow of the GRUs.

2.1.4.2 Shallow and deep groundwater

The study primarily focuses on shallow aquifers as these are the predominant aquifers from which current groundwater use is taking place in the Gouritz WMA as well as the predominant source that meet EWRs from the groundwater Reserve side within the WMA. Of the 3 395 boreholes used in the assessment, the mean borehole depth is 74.1 m and the upper 95th percentile 160 m. The zone shallower than 160 m is the focus of this study.

The deep confined Peninsula Aquifer at Oudtshoorn (DAGEOS) was evaluated as a separate component in this study as it is the only deep confined groundwater system in the study area that is being developed and it receives inflow from the surface outcrop area in the Outeniqua Mountains.

2.1.5 Approach to quantification of the groundwater component of the Reserve

Several Water Availability Assessment Studies (WAAS) were done for the DWS: Directorate Water Resources Planning on a regional, primary catchment scale since 2005 (AGES, 2005; AGES, 2007 and AGES, 2008 and DWA, 2010). When the projects were initiated, it was realised that the application of numerical flow models could not be applied as the scale was too large to address the project objectives. A list of specific projects that were done for the DWS are:

- 2005 Crocodile River (West) regional groundwater quantification. In conjunction with AECOM (BKS at the time of this study).
- 2007 Olifants River regional groundwater quantification. In conjunction with Royal Haskoning DHV (SSI Engineers at the time this study).
- 2007 Upper Vaal regional groundwater quantification project (for DWS).
- 2010 Reserve determination studies for selected surface water, groundwater, estuaries and wetlands in the Outeniqua catchment: Technical component – Knysna and Swartvlei. In conjunction with Scherman Colloty & Associates.

During these projects, several shortcomings of the existing methods (GRDM, 2007) were identified as they vastly overestimated the allocable groundwater component and the groundwater component of baseflow. The main reason for this is (DWA, 2010):

- It used recharge as a function of Mean Annual Precipitation (MAP) (i.e. P_{50}) and not an assured lower recharge that could take account of drought conditions (i.e. P_{95} or P_{98}).
- Did not account for groundwater flow losses due to evapotranspiration in the riparian zone.
- Utilised too high recharge values when the system was up-scaled from wellfield to regional areas – known as wellfield bias.
- Did not sufficiently account for environmental groundwater components such as wetlands, alien vegetation, forests etc., which can use up significant quantities of groundwater.

The GRDM method was revised and updated in part due to the project performed to determine the groundwater component of the Reserve for the Outeniqua Catchment (K) (Dennis *et al.*, 2012; DWA, 2010). The GRDM, 2012 method entails most of the important principles used in the GYMR method (DWA, 2010). The GYMR method was subsequently updated to produce monthly as opposed to annual groundwater volumes for both average and dry cycles for selected quaternary catchments based on stochastic simulations of groundwater volumes available.

2.1.5.1 Minimum groundwater balance approach

In line with the precautionary principle as described in the National Environmental Management Act No 107 of 1998 (NEMA); in this Preliminary Reserve a minimum groundwater balance approach is followed (South Africa, 1998b; Vivier, 2013). From the minimum amount of groundwater available one can always increase for example the percentage groundwater recharge from rainfall or decrease existing abstraction as more evidence and information becomes available to prove the yield of the resource and more confidence is built in the available volumes. If on the other hand the water availability is over-estimated and these volumes are used for national planning, it is very difficult to reverse the planning and development time and cost spent on a resource if that resource later proves to be much less than expected. It is accepted that the uncertainty and data limitations on the scale of the assessment is of such a nature that the actual groundwater balance will never be known as it will be transient. The objective is therefore not to determine the actual groundwater balance as it cannot be known without long-term monitoring data. A minimum groundwater balance approach also ensures that aquatic ecosystems (EWR) and the BHNR are duly protected from precluded initial over-estimations.

2.1.5.2 A note on the application of conservatism

The proposed minimum groundwater balance approach can be perceived as being overly conservative. This is not the case as will be shown in the results. Even if the approach weighs in on the conservative side of the scale, only 28 (21.5%) of the 130 quaternary catchments were flagged as potentially stressed during the first iteration which is the Desktop-Rapid Reserve. If the approach is overly conservative, this figure would in reality be expected to be much lower. The 28 potentially stressed catchments are modelled in the second iteration, the Intermediate Reserve level, at a higher confidence level with rainfall probability and groundwater storage taken into account. The Rapid Reserve iteration was also used to focus not only on which catchments should be used for more detailed modelling but also where the hydrocensus field surveys should be focused. This Intermediate Reserve or second iteration indicated that there are eight quaternary catchments which require more detailed studies.

The chosen approach is that if any potential developer can prove with field data that, e.g. wetlands that were conservatively flagged as being potentially supported by groundwater are in fact not, then the additional groundwater can be allocated to that developer if it can be shown that the groundwater yields are sustainable. This leaves the burden of proof on the potential water user and not on the regulator.

The philosophy of *all models are wrong but some are useful* (Poeter, 2006) is acknowledged and the chosen decision-making method is to be *wrong on the right side*. The effects of uncertainty mean that the environment and the Reserve would receive the benefit of the doubt, which is much better than the other way around.

2.1.6 Ecological Water Requirement (EWR) – groundwater component

The volume of groundwater available for future use, known as the allocable groundwater is constrained by the requirements of the riverine EWR. The EWR is the volume, quality and timing in which water is required in a stream or river to sustain the system in a particular state so as to support ecosystem function and other users. The riverine EWR may be a fraction of baseflow. Baseflow consists of a combination of surface water low flow and groundwater inflow. It is often difficult or impossible to distinguish which fraction of baseflow constitutes groundwater although baseflow separation techniques (Hughes *et al.*, 2003) and chemical mixing models can be used to obtain a qualified estimate (Steyl *et al*., 2012a).

In a natural system un-impacted by any anthropogenic effects, the groundwater component of baseflow is equal to recharge minus losses due to spring flow, losses via deep groundwater flow from geothermal springs if in area or upward leakage of deep groundwater (and if hydraulic conductivity at depth allows appreciable flow/lithostatic pressure) and evapotranspiration in riparian zone. It is expected that the groundwater component of baseflow will increase relative to runoff and interflow during drought or low flow periods. It may even be that there could be no actual flow in a surface stream while groundwater seepage continues to support the riparian vegetation along drainages and downstream wetlands that are supported by springs. It must be recognised that the total EWR volume consists of surface water runoff, periodic flow releases from dams, maintenance low flow and drought low flow. It is thought that only the drought low flow EWR volume is actually applicable to the groundwater contribution to EWR volume.

2.1.7 Desktop-Rapid Reserve

The Desktop-Rapid level Reserve was based on desktop and literature data taken from the available databases (Dennis *et al.*, 2012). It is a first- or high-level approach on the regional 130 quaternary catchments in the Gouritz WMA. The approach is conservative which means that more groundwater will be available than the calculated volumes as it follows a minimum groundwater approach (Vivier, 2013; **Appendix C**). The reason for this is that recharge rates that are used are scaled down and storativity, which is a regionally unknown parameter, is neglected at this level. The Desktop or Rapid level groundwater balance assessments are done on a steady-state basis. This approach is in line with the precautionary principle outlined in the NEMA Act no. 107 of 1998 (South Africa, 1998b), as the environment benefits where there is uncertainty.

The modelling and decision-making approach is based on a Bayesian method, which is iterative and as more data becomes available, so more groundwater volumes would be allocable as conservative assumptions are replaced with measured or acquired field data (DWA, 2010; Vivier and van der Walt, 2011a; Vivier and van der Walt; 2011b).

During the Desktop-Rapid Reserve, the catchments which classify as high[3], will be or should be reviewed at a more detailed level in the Intermediate Reserve. Only 28 or 22 % of the 130 regional catchments were classified as stressed during the Desktop-Rapid Reserve. These catchments warranted more detailed field investigations and modelling in the Intermediate phase of the Reserve determination process. The Desktop-Rapid level Reserve was therefore used to screen out the catchments that have surplus groundwater potential and those that are at potential risk due to overexploitation. Groundwater in the remaining 102 catchments can be allocated at a lower risk to the water use licence applicant and the regulator due to the conservative nature of the Desktop-Rapid Reserve determination. Cognisance should however be given to hotspot areas where over abstraction takes place on a local scale.

2.1.8 Intermediate Reserve

In the Intermediate phase of the GRDM, a hydrocensus was completed on selected quaternary catchments and GRUs to determine the borehole locations, springs, groundwater levels, groundwater use and groundwater quality. The purpose of the hydrocensus is to verify the data used for the Intermediate Reserve determination.

[3] The GRDM classification is done based on a "stress index", which is determined by recharge divided by groundwater use. It must be noted that in the Rapid phase, it could classify certain catchments as "stressed" even though it may not be the case in reality. This is due to the conservative approach that is followed in cases where data is limited and associated with a high degree of uncertainty. The benefit of the doubt is always given to the environment.

The 28 catchments that classified as groundwater-stressed during the Desktop-Rapid Reserve phase are modelled on a more detailed transient basis where groundwater storativity is now taken into account. Groundwater storage acts as a buffer to the volume of groundwater available in the aquifer during drought conditions. The transient simulations are done for periods that range from 50-100 years, which is typically a simulation of current discharge zones vs. past rainfall. The recharge is non-linear as provision is made for a simple power function that reduces recharge for below average rainfall seasons and increases it for above average seasons. Monthly rainfall (r_m) is multiplied by the recharge percentage of MAP specific to the geology, as well as a recharge factor (Re_F) which is determined by:

$$If\ (r_m > r_{cut-off})\ Then\ Re_F = \left(\frac{r_m}{r_{mean}}\right)^x\ Else\ \ Re_F = 0$$

Where $r_{cut\text{-}off}$ is the monthly rainfall cut-off in mm below which no recharge occurs; r_{mean} is the arithmetic mean monthly rainfall and x is the power exponent controlling the magnitude of recharge escalation or depreciation compared to the r_{mean}.

The simulations are done on a stochastic basis which will produce an average groundwater volume, represented by a simulated representative water level. The sustainability of the groundwater resource is then observed in terms of the number of failures of the system compared to the deepest groundwater level constraint allowed for a given assurance level, which is typically to a 1:50 year drought (P_{98}).

2.2 STUDY AREA DESCRIPTION

2.2.1 Climate

The Gouritz WMA can be divided into two major climatic zones based on two inland areas and a coastal belt. These three areas are divided by the two major east-west extending mountain ranges, namely the Swartberg Mountain Range and the Outeniqua Mountain Range. These mountain ranges were created by the Cape Fold Belt orogeny and causes orographic rain on the southern slopes which is an important source of groundwater recharge. The northern and central inland areas are semi-arid to arid with summer rainfall areas with most of the rainfall occurring in the months November up to end of April. MAP for the inland areas ranges between 127 mm/a, for the central Great Karoo basin catchment J23A and 471 mm/a for the J34D catchment located closer to the coastal belt north of Sedgefield. The coastal belt rainfall and humidity is markedly higher and as such it is defined as the other major climatic region in the WMA. The coastal belt is subject to an orographic precipitation setting due to the Outeniqua Mountain Range. The coastal belt receives appreciable amounts of rain all year round but most of its rain falls from October to April. The MAP per coastal catchment where orographic rain occurs, ranges between 679 mm/a, and 882 mm/a. **Figure 2.1** shows the rainfall distribution across the Gouritz WMA, obtained from the Water Resources of South Africa, 2005 Study (WR2005) dataset (Middleton and Bailey, 2008; 2011). The inland areas are subject to temperature extremes with hot days and cold nights due to land surface thermal radiation during the nights. The coastal belt in the Gouritz WMA on the other hand is classified as a temperate climate with small temperature differences between day and night on average.

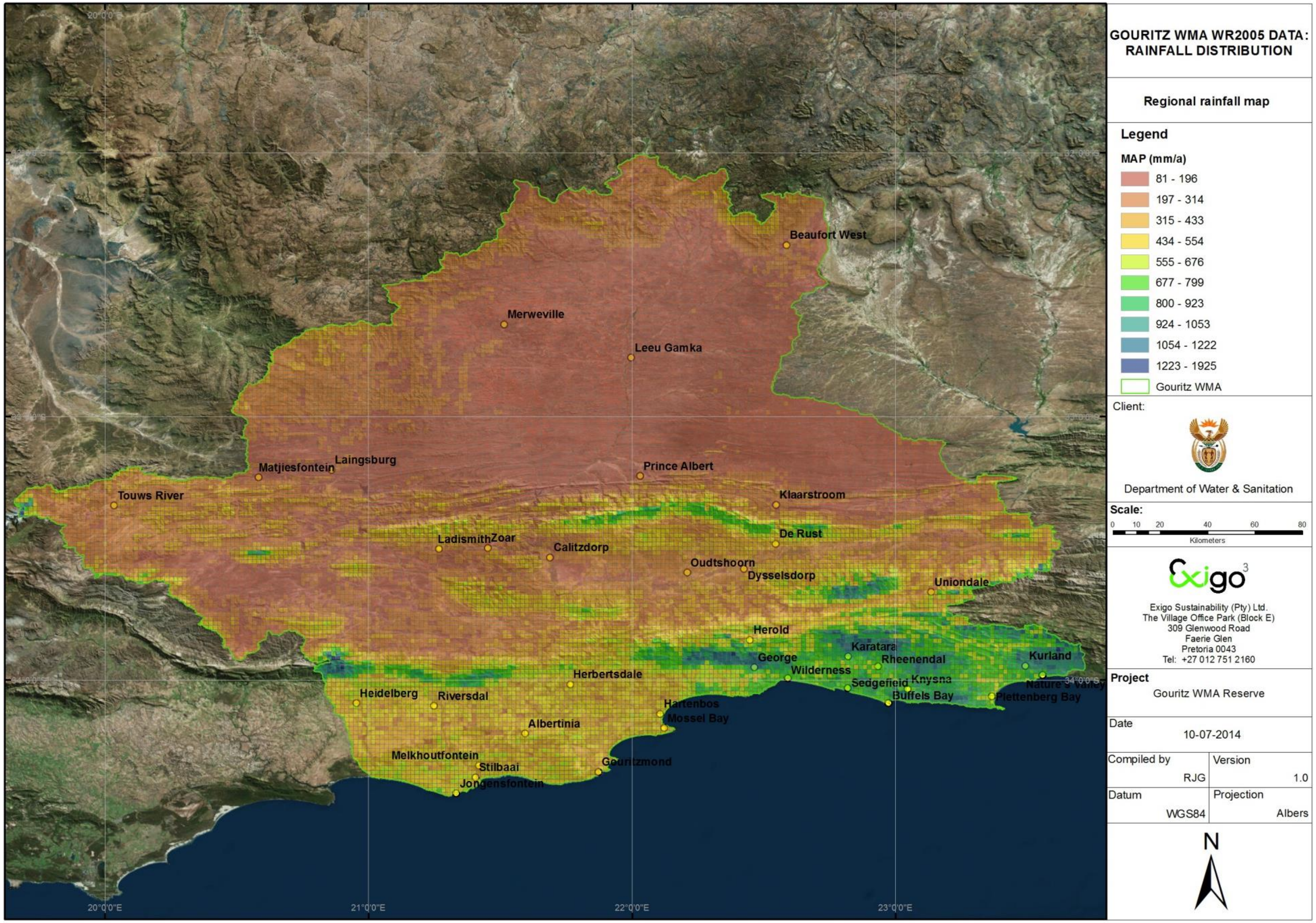


Figure 2.1 Annual rainfall distribution (mm/a) across the Gouritz WMA

Groundwater becomes more important as a water resource towards the northern areas of the WMA where it is drier and surface water is largely absent.

2.2.2 Topography

The topography of the Gouritz WMA is distributed over a large elevation range compared to some of the other WMA's in South Africa. The lowest elevation in the WMA is found at sea level along the coast on the beaches and in the estuaries. The highest elevations in the WMA are located in the second major east-west mountain chain found inland, i.e. the Swartberg Mountains. The highest elevations in this mountain range are at approximately 2 332 metres above mean sea level (mamsl) (**Figure 2.6**).

Spatially the topography of the WMA has zones of distinctly different elevation profiles controlled by geomorphology. Three main areas can be distinguished:

- The northern part of the WMA where the main Karoo Basin is present has a relatively flat topography compared to other areas in the WMA. This area is known as the Great Karoo. The basin is bounded to the south by the east-west extension of Swartberg Mountain Range for the entire width of the WMA. This area is very dry and mostly dependant on groundwater as a sole source of water supply.
- The Cape Fold Belt (CFB) mountains and associated Klein Karoo area: The Klein Karoo area is characterised by a series of valleys and surrounding mountains, with some pediplain and floodplains present. These are not nearly as extensive as the Great Karoo basin. The Klein Karoo is bounded to the north by the east-west extension of the Swartberg Mountain Range and is bounded to the south by the east-west extension of the Outeniqua Mountain Range. Long linear valleys were created by the Cape Fold Belt mountain building event associated with the breakup and reuniting of Gondwana and crustal plates. Subsequent erosion of softer geological strata enhanced the valleys formed, one example of such a long extensional valley being the Langkloof. This area is very dry and is dependent on a number of rivers and groundwater resources for water supply.
- Coastal belt: The coastal belt within the Gouritz WMA is located to the south of the Outeniqua Mountains and shows a typical orographic setting with a dramatic reduction in topography from the east-west extension of the Outeniqua Mountains in the north to the oceans in the south. This area has a high rainfall and depends mostly on surface water for bulk water supply. Groundwater in this setting is important in supporting wetlands, baseflow and riparian vegetation.

2.2.3 Hydrology and drainage

The study area is delineated by the Gouritz WMA boundary of which the Gouritz River is the main drainage with a Strahler order of 5. The WMA consists predominantly of the primary drainage region J with 9 other secondary catchments along the coast, making up the rest of the WMA. The other secondary drainage regions form part of the H primary drainage region to the west and the K coastal drainage region to the east. The Gouritz WMA consists of the 13 secondary catchments and associated rivers summarised from upstream to downstream in **Table 2.1**.

Table 2.1 Secondary drainage regions and associated main rivers (Figure 1.1)

Secondary catchment	Major river(s) of catchment
J1	Groot River
J2	Gamka River
J3	Olifants River
J4	Lower Gouritz River
H8	Duiwenhoks River
H9	Goukou River
K1	Klein-Brak River
K2	Groot Brak River
K3	Gwaing/Kaaimans/Touws Rivers (all second order rivers)
K4	Sedgefield River
K5	Knysna River
K6	Keurbooms River
K7	Groot/Bobbejaan River

The hydrological catchment scale of choice for this groundwater Reserve assessment is the quaternary catchment (see **Section 2.1.4**). There are 130 quaternary catchments in the Gouritz WMA. The hydrology is further described in detail in the Desktop EcoClassification report (DWA, 2014b) of the GRDS and the reader is referred to it for more information on hydrology.

2.2.4 Geology

2.2.4.1 General

The study area is located within the CFB and the Karoo formations north of the CFB. The Karoo formations underlie the northern part of the Gouritz WMA, as far north as Beaufort West. The study area is underlain predominantly by sedimentary rocks, which were subjected to pressure from the south, resulting in a variety of structural features and deformational sequences (**Table 2.2**, **Figure 2.2**).

The Outeniqua Mountain Range, forms an important recharge zone of the CFB and, is the most prominent evidence of the structural deformation found in the study area. Formations strike in a general east-westerly direction, associated with the CFB axis. Dip directions and angles within the pre-CFB rocks vary due to the extensive folding. Sedimentary deposits, younger than the CFB-event are prominent in the south-east and south-west of the study area along the coastal zone where it has been deposited in predominantly fault-bounded basements. These formations are mostly horizontally orientated and layered. The relative occurrence of the main geological units is indicated in the geological map (**Figure 2.2**). The purpose of this section is to provide a regional overview of the geology and its control on groundwater. For a more complete description of the hydrogeology see Woodford and Chevallier (2002).

The regional hydrogeological groupings of main aquifers are formed by the following (**Table 2.2**, **Figure 2.2**, **Figure 2.6**):

- Quaternary sands and alluvium of recent deposits along drainages and the coast. These generally form permeable unconfined major aquifers.
- The CFB with the TMG fractured sandstone and quartzite that forms major aquifers, where folded and fractured. These aquifers are generally semi-confined or confined.
- The Karoo sandstone and shale aquifers form minor to major aquifers. Faulting and folding with associated fracturing in the south and dolerite sill intrusions in the northern parts of the study area are important as it created permeable minor to major aquifer zones. The Karoo aquifers are in general semi-confined or confined.

There are always exceptions to the main classifications of aquifer type and classification as indicated in **Table 2.2.** Major aquifers can have low yields where fracturing is absent and aquitards like the Dwyka can form major aquifers where significantly folded and fractured in the south.

2.2.4.2 Lithostratigraphy

Geological formations occurring in the study area range between >500 Mega-annum or million annums (Ma) old sedimentary deposits of the Namibian Era to recent Quaternary age sandy deposits. The main tectonic events that have influenced the depositional and structural history of rocks in the study area are the Cape Granite intrusions that took place approximately 500 Ma ago, the CFB event that occurred approximately 300 Ma ago and the Karoo dolerite intrusions that took place 200 – 300 Ma ago. **Table 2.2** gives a graphical presentation of the lithostratigraphical sequence in the study area as initially compiled by Parsons and Veldtman (DWAF, 2007) and updated during this study to include the aquifer type and classification as well as the inclusion of the Karoo formations.

2.2.4.3 Kaaimans Group

The Kaaimans Group lithologies are the oldest in the study area. It consists mainly of phyllite, quartzite, hornfels and schist. These sediments were deposited some 800 – 700 Ma ago and were subsequently intruded by the Cape Granite Suite. The rocks have been intensely folded, both prior to and during the Cape Orogeny. The Kaaimans Group, whose thickness exceeds 2 550 m in places, outcrops in the south-central part of the study area and bounds the Cape Granite Suite (DWAF, 2007). The distribution and occurrence of the Kaaimans Group sediments is indicated in **Figure 2.2**.

These formations in general form minor aquifers but can have high yields where faults/fractures are intersected.

2.2.4.4 Cape Granite Suite

The Cape Granite Suite consists of two main plutons in the study area, namely the Woodville pluton north of Sedgefield and the George pluton west of the town of George. These intrusions took place approximately 500 Ma ago. The grain sizes of these rocks vary through fine-grained to medium and coarse-grained granites.

Table 2.2 Hydrogeological successions in the Gouritz WMA (also see Figure 2.2)

ERA	AGE (Ma)	SUPER GROUP	GROUP	SUB GROUP	Intru-sives	FORMATION	LITHOLOGY	Graphic	AQUIFER TYPE	AQUIFER CLASS	TECTONIC ACTICITY
Cenozoic	0 -1	Quaternary					semi to unconsolidated sands and alluvium		Unconfined primary	Major	
		Bredasdorp				Stranveld	dune sands	Bredasdorp	Semi-confined fractured	Minor/major	
						Waenhuis	calcified dune sand				
						Klein Brak	shelly sand, pebbles				
						Wankoe	calcranites, aeolian sandstone,calcrete				
	2					De Hoopvlei	shelly limestone, calcranites, conglomerates				
		Unconformity									
Mesozoic	65	Grahamstown				Grahamstown	silcrete, ferricrete		Semi-confined fractured	Minor	
	120	Uitenhage				Hartenbos	silt and mudstone	Uitenhage			
						Buffelskloof	conglomerate, sandstone				
						Kirkwood	sand, silt and mudstone				
						Enon	conglomerate, sandstone		Semi-confined fractured	Minor/major	
		Karoo	Beaufort	Tarka stad	Dolerite (dykes & sills)	Burgersdorp	mudrock, sandstone		Semi-confined fractured porous	Minor	Breakup of Gondwana
						Katberg	coarse sandstone		Semi-confined fractured porous	Major	Faulting intrusion of dolerite sills and dykes creating major aquifer zones
Palaeozoic	250			Adelaide		Balfour	mudrock, sandstone		Semi-confined fractured	Minor	
						Middleton	mudrock, sandstone				
						Koonap	mudrock, sandstone				
			Ecca & Dwyka	Ecca		Waterford	sandtsone, mudrock		Semi-confined fractured	Minor/major	
						Fort Brown	Mudrock, sandstone		Semi-confined fractured	Aquitard/minor	
						Ripon	sandstone and mudrock		Semi-confined fractured porous	Aquitard/minor	
						Collingham	Dark grey siliceous mudrock				
						Whitehill	black lamintated carbonaceous shale		Semi-confined fractured	Aquitard/minor	
						Prince Albert	dark grey to black carbonaceous shale		Semi-confined fractured	Aquitard/minor	
				Dwyka		Dwyka	tillite, shale		Confined fractured	Aquitard/minor	
	290	Unconformity									Cape Fold Belt
	330	Cape	Witteberg			Wagendrift	shale, quartzite		Semi-confined fractured	Minor/major	Folding and faulting
	370		Bokkeveld	Ceres			alternating shale and sandstone	Bokkeveld	Semi-confined fractured	Aquitard/minor	
	400		Table Mountain			Baviaanskloof	shale, sandstone	Table Mountain	Semi-confined fractured to fractured porous	Major/minor	
						Kouga	sandstone				
						Goudini	sandstone				
						Cedarberg	shale				
						Peninsula	quartzite, sandstone				
	500	Cape Granite			George pluton		granite and gneissic granite	Cape Granite	Semi-confined fractured	Minor/major	Pan African
					Woodville pluton		biotite-rich granite				
Namibian	545	Kaaimans				Homtini	phylite, feldspathic grit, quartzite	Kaaimans	Semi-confined fractured	Minor	
						Victoria Bay	feldspathic quartzite				
						Soetkraal	phylite,schist, quartzite				
						Skaapkop	gritty quartzite, phylite, schist				
						Sandkraal	quartz schist				
						Silver River	quartz schist				
						Saasveld	andalusite schist, hornfels				

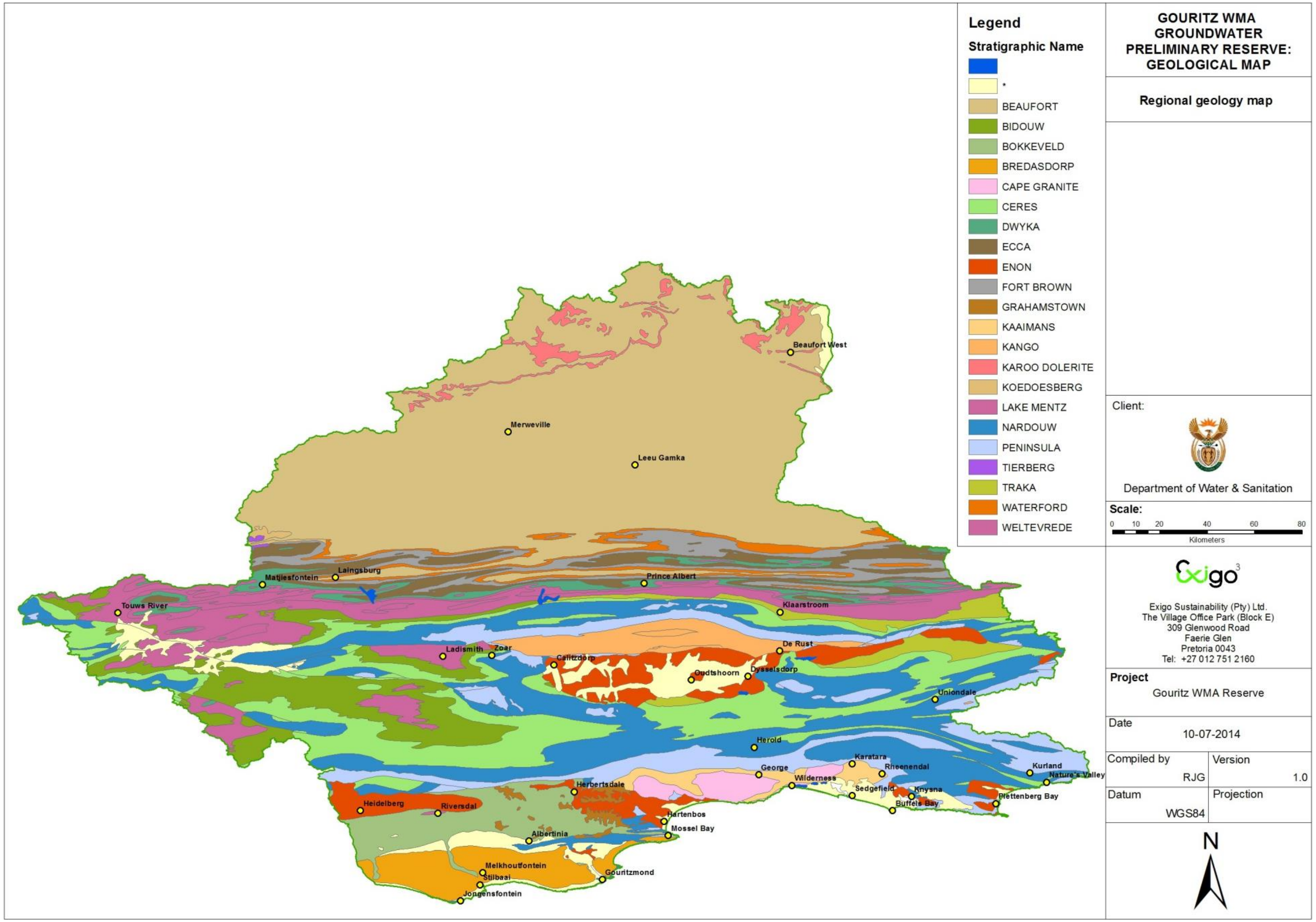


Figure 2.2 Regional hydrogeological map of the Gouritz WMA

As weathering patterns of granite are partly controlled by grain size, the hydrogeological properties of the different intrusives vary. Southwest and southeast striking dolerite dykes also intruded into the granites (Meyer, 1998) that could influence hydrogeological behaviour. The unweathered granite matrix would form an aquitard but can form minor to major aquifers where faulted and fractured or where weathered basins occur.

2.2.4.5 Table Mountain Group (TMG)

The presently exposed structure and thickness of the TMG rocks are the result of initial deposition within an east-trending basin (Rust, 1973) along the Southern and South-western Cape regions, which was modified by two major tectonic events, namely the Permo-Triassic Cape Orogeny and the fragmentation of south-western Gondwana during the Mesozoic. The TMG comprises of an approximately 4 000 m thick sequence of quartz arenite and minor shale layers deposited in a shallow, but extensive, predominantly east-west striking basin (Xu *et al.*, 2007).

The TMG was deposited directly on granites of the Cape Granite Suite and Namibian era sedimentary rocks. The Group comprises five principal units in the southern and eastern Cape, namely the Peninsula-, Cedarberg-, Goudini-, Kouga- and Baviaanskloof-Formations (DWAF, 2007). The TMG contains two regional major aquifers (the Peninsula- and Skurweberg-Formations) separated by a major aquitard (Goudini Formation). There are, however, zones in the TMG where lower yields occur; where there is absence of major fractures, or even aquitard formations where shale zones occur, that could separate sandstone (quartzitic) layers.

2.2.4.6 Bokkeveld Group

The Bokkeveld Group consists of alternating shale and sandstone. It forms, in general, a regional aquitard, but can have local permeable zones where faulted and fractured. The water quality in the Bokkeveld Group zones are in general poor with high salinity (Xu *et al.*, 2007).

2.2.4.7 Uitenhage Group

A major unconformity exists in the southern parts of the study area prior to the deposition of the Uitenhage Group. During this time the area underwent periods of folding, erosion and faulting due to the Cape Orogeny. The Uitenhage Group comprises four formations, namely the Enon, Kirkwood, Buffelskloof and Hartenbos Formations, with the Enon Formation being dominant in the study area. This formation was deposited in high energy environments directly adjacent to major faults. Consequently, the Enon Formation comprises of conglomerates (predominantly Table Mountain or Bokkeveld Group clasts in a sandy matrix) and coarse-grained sandstones. Down-gradient of the high energy environments, sediments were deposited on extensive floodplains (Kirkwood Formation) and in deltas and shallow marine environments (Buffelskloof- and Hartenbos-Formations).

Sandstones, fine-grained siltstones and mudstones dominate the latter formations. The strata inter-finger laterally with each other (DWAF, 2007).

The Uitenhage formations in general forms minor aquifers but can have higher yields where faulted and fractured. The Enon (conglomerate) Formation is known to be an aquitard.

Outcrops are limited to three areas in the study area, namely in the west, near Mosselbay, as well as directly north of the Knysna lagoon and around Plettenberg Bay in the east (**Figure 2.2**). The Formation attains a thickness of approximately 200 m in the Knysna area (Meyer, 1998).

2.2.4.8 Bredasdorp Group

The Bredasdorp Group is the youngest deposits in the study area. It occurs along the coast between Swartvlei in the central part of the study area towards the east of the Knysna Lagoon in the east of the study area. Small portions of the Bredasdorp formations occur near the extreme south-western boundary of the study area on the coastal plains near Mossel Bay.

The Bredasdorp Group comprises the De Hoopvlei, Wankoe, Klein Brak and Strandveld Formations. The sediments were generally deposited on wavecut platforms under marine transgression and regression conditions, with at least three major transgression – regression episodes being recognised.

The De Hoopvlei Formation is a laterally discontinuous conglomerate horizon including shelly limestones and calcarenites. Toens *et al.* (1994) noted that where this horizon is well developed, large quantities of good quality groundwater could be obtained. The Wankoe Formation comprises calcarenite with aeolian cross-bedding and calcrete lenses. Extensive outcrops are found on the coastal plains west of Mossel Bay and the coastal plains east of Wilderness. In place, this unit is capped by a calcrete cover (Toens *et al.*, 1994) or covered by light grey to pale red sandy soil (DWAF, 2007).

2.2.4.9 Karoo Supergroup

The Karoo Aquifers occur in the northern part of the WMA, north of the CFB Mountain Ranges of the Klein Karoo. Laterally, there are two main zones that influence the hydrological properties of the Karoo aquifers. The southern part is intensely folded and faulted which creates permeable zones and major aquifers (**Figure 2.2**, **Figure 2.6**, and **Table 2.2**). The northern part consists mainly of sub-horizontal layered sandstone, mudrock and shale of the Beaufort Subgroup. The most important controlling factor is the intrusion of dolerite dykes that form permeable minor and major aquifer zones in these areas (Vivier, 1996, Woodford and Chevallier, 2002).

2.2.4.10 Quaternary Deposits

During the last 10 000 years, climatic changes and sea level movements gave rise to dune fields along the coast. Sea levels rose from some 130 m below present sea level to about 2 m above present sea level 5 000 years ago. Sea levels settled at the present level 3 700 years ago. Younger aeolian sand deposits are found in the area between Sedgefield and Knysna. Most of these deposits are unconsolidated, but may be semi-consolidated in places.

Coastal sands consist of a matrix of well sorted, well rounded fine- to medium-grained sands and beach sediments with occasional clay lenses. Sand thicknesses vary between 5m and 20m (Meyer, 1998). Groundwater discharges from the quaternary deposits to the sea (Jia, 2007).

In the Karoo formations towards the north and in the CFB area, north of the cost, primary aquifers are formed by recent alluvial deposits that occur mainly along drainages.

These formations in general form unconfined major aquifers that have a localised lateral extent.

2.2.5 Structural geology and neo-tectonics

The most important structural events are the folding and faulting associated with the CFB in the south and the intrusion of dolerite into the northern parts of the WMA (**Figure 2.2**, **Figure 2.6**, and **Table 2.2**). Structural geology is the single most important geological feature that influences the transmissivity and usability of aquifers. Most of the groundwater development takes place on fault and dyke zones where fracturing creates preferential pathways for groundwater to flow towards a borehole.

The neo-tectonic principal stress direction in the CFB was determined to be from a west-northwest to east-southeast to a north-northwest and south-southeast direction (Andreoli *et al.*, 2013). This means that fracture orientations perpendicular to this direction would be expected to be either closed or less permeable than the other fracture orientations.

Neo-tectonic movement may occur due to tectonic stresses in the crust that causes minor earthquakes. The Gouritz WMA is located over parts of the Cape seismic province and the Senqu-seismic provinces (Woodford and Chevallier, 2002). It is inferred that although seismicity can change hydraulic parameters over time, it does not have a significant influence on groundwater in the study area during recent times (Woodford and Chevallier, 2002).

2.2.6 Deep groundwater and hot springs

Although deep groundwater is not the main topic of this study, it will become more important in the future as shallow aquifers become over-exploited and with abstractions from the deep aquifer as well as fracking and exploration of unconventional gas resources on the horizon (**Section 2.2.9**).

Evidence of deep circulation of groundwater is mainly from hot springs and artesian conditions from deep boreholes drilled by Soekor and the DAGEOS project (Jia, 2007; Rosewarne *et al.*, 2013; Umvoto 2005; Hartnady *et al.*, 2014). The hot springs are formed along major fault and/or dyke zones and represent old groundwater that could have a higher salt load, especially in the Karoo formations. It usually supports a downstream wetland and associated eco-system that is relevant to the groundwater component of the Reserve. Any utilisation of deep aquifers must take the potential impacts on hot springs into account.

2.2.7 Cold springs

Cold springs are formed when groundwater from shallow surface aquifers intersects the topography. These springs usually forms at fault/fracture, dyke and geological contact zones. Cold springs usually also support a down gradient wetland zone and are therefore of significance to the groundwater component of the Reserve. Most of the cold springs in this study area occurs at geological contact zones and/or faults for the CFB formations and on dyke contact zones in the Karoo formations.

2.2.8 Conceptual models

Conceptual models are important as they represent the analyst's representation of the real world aquifer system and how it interacts with the boundaries (Botha, 1996). Conceptual models were developed for the general shallow surface aquifers and the deep aquifer systems to demonstrate how it was used in the groundwater resource quantification for the Reserve components. In cases where the hydrogeological conditions are complex and uncertain, more than one conceptual model was developed to illustrate the impact on the groundwater component of the Reserve. This is important as the most conservative option or conceptual model was applied in cases where there is uncertainty (DWA, 2010; Vivier, 2011).

2.2.8.1 Conceptual model for localised shallow surface aquifers

The conceptual model for the shallow surface aquifers consists of a simple model with no aquifer compartments and no evapotranspiration losses (Conceptual Model 1-1, **Figure 2.3**) and a more complex Conceptual Model 1-2 with aquifer compartments and groundwater flow losses (**Figure 2.4** and **Figure 2.5**).

Conceptual Model 1-1 considers a local (e.g. quaternary) catchment where it accounts for the recharge from rainfall and borehole abstraction, with the resultant volume being (incorrectly) assumed to be the groundwater component of baseflow in steady-state for a natural system as follows (**Figure 2.3**, **Section 2.1.4.1**):

$$Q_R – Q_{GBF} = 0$$

Where Q_R is groundwater recharge and Q_{GBF} is the groundwater component of baseflow. In a natural groundwater system, this approach can be used to determine the regional aquifer transmissivity by typically using steady-state flow models during the calibration process for recharge and transmissivity (**Table 2.3**). By following this approach, it was found that the groundwater component of baseflow is overestimated as it does not make provision for flow losses mainly in the riparian zone (DWA, 2010) or, often more importantly, any other outflows from the catchment.

The model was adapted to allow for groundwater flow losses as follows (**Figure 2.5**):

$$Q_R – Q_{GBF} - Q_{GFL} = 0$$

Where Q_{GFL} represents the groundwater flow losses due to evaporation and transpiration, which can be significant. It was found that 70% to >90% of the groundwater recharge could be lost in the evapotranspiration zone along stream drainages (DWA, 2010) on the scale of consideration, which could be local wellfield or quaternary catchment scale.

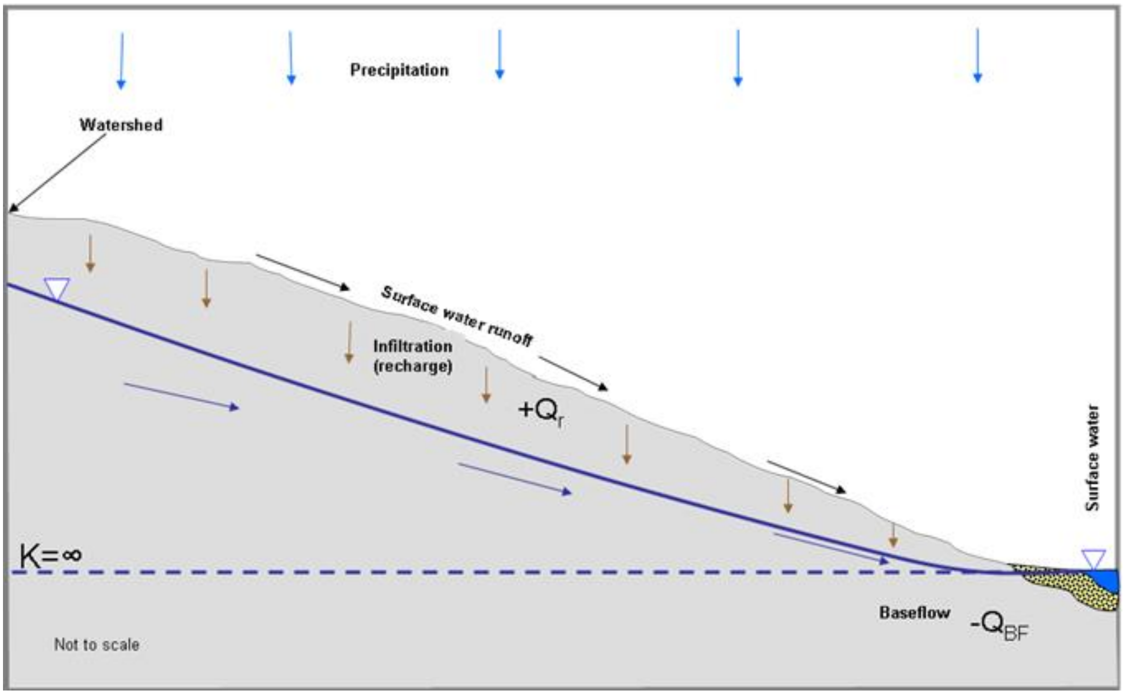


Figure 2.3 Gouritz groundwater – shallow surface aquifers Conceptual Model 1-1

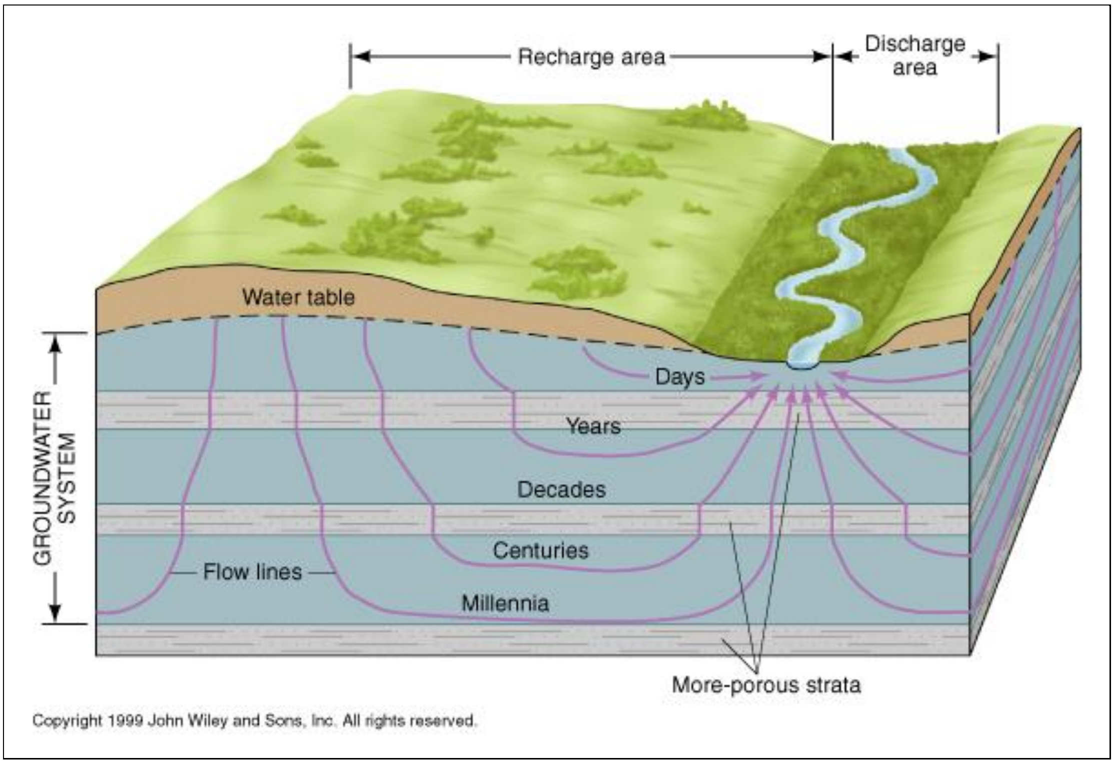


Figure 2.4 Illustration of flow lines (streamlines) through strata and towards drainage (river) – discharge boundary condition

Table 2.3 Steady-state calibration of regional groundwater flow modes to determine transmissivity and recharge (Figure 2.5)

In natural steady-state conditions, the net groundwater inflow from recharge is balanced by baseflow and losses (+spring flow if springs exist). The groundwater balance is given by $+Q_r - Q_{BF} - Q_{GFL} = 0$. The piezometric gradient, which can be measured from site characterization and monitoring boreholes is known and the boreholes can be aquifer tested to determine the transmissivity and hydraulic conductivity ranges. The outflow per unit length (L) of aquifer is given by Darcy's law as, $q = (K^{dh}/_{dl}) \times D$, where q is the Darcy flux in m/d (or $m^3/m^2/d$), K is the hydraulic conductivity (m/d), D the aquifer thickness (m) and $^{dh}/_{dl}$ the piezometric gradient (- or m/m). Since K, D and the head gradient can be measured from field tests (i.e. aquifer tests), a steady-state model can be calibrated by changing the recharge value until the measured and simulated head gradients have a small (or acceptable) error. An acceptable error is usually less than 10 % of the aquifer thickness. If the aquifer is for example 40 m thick, then an error of less than 4 m between the measured and simulated head elevations could be considered as acceptable. Note that in a steady-state flow model, the term for aquifer storativity disappears making it easier to calibrate the model with less variables. A perfectly flat head gradient of 0, will e.g. imply an infinite hydraulic conductivity. This process can be used to calibrate a regional steady-state model for recharge and transmissivity where a groundwater head distribution (i.e. head gradient) is known from field measurements. If e.g. transmissivity ranges are known from field tests, recharge can be quantified.

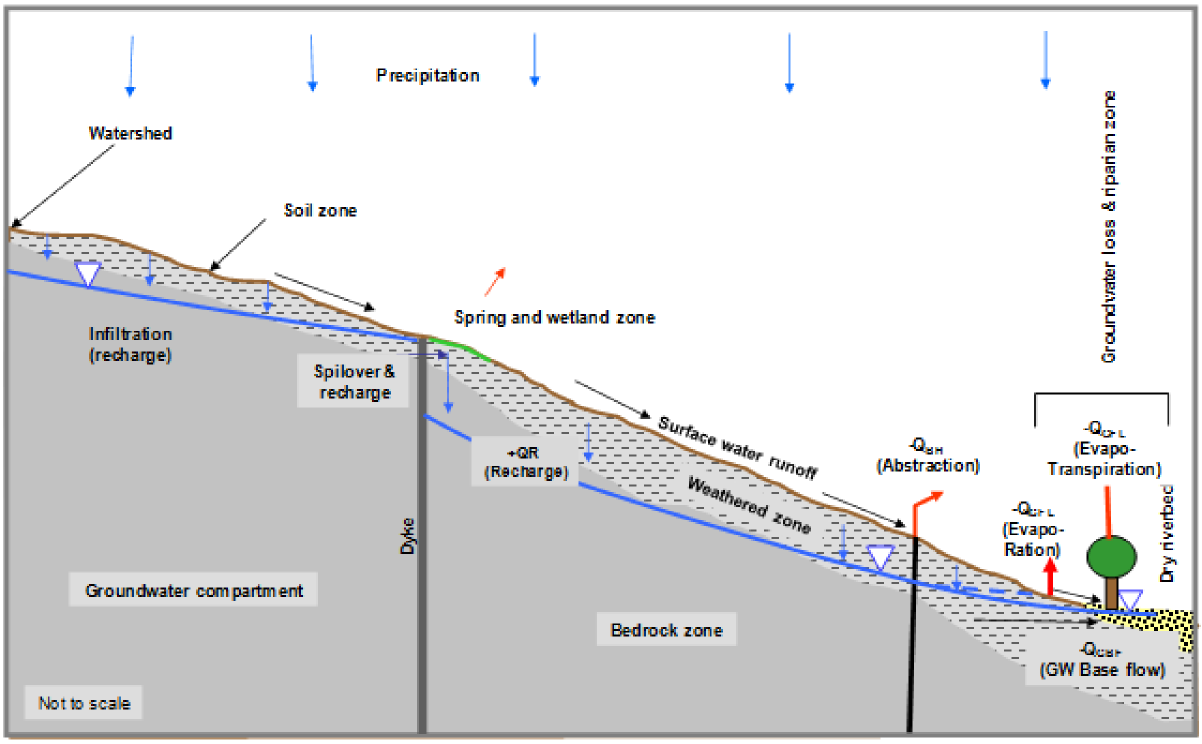


Figure 2.5 Gouritz groundwater – shallow surface aquifers Conceptual Model 1-2

2.2.8.2 Regional shallow and deep aquifer systems

The conceptual models that are described in this section are more complex than the previous models that were developed on a smaller study area (DWA, 2010). The models represent the areas just north of the coastline in the George area and reach the Karoo aquifers towards Beaufort West (Chevallier *et al*., 2004; **Figure 2.8**). The conceptual models were developed based on a south-north cross-section. An east-west cross section was also developed for the mountainous outcrop area of the Peninsula Formation aquifer, where the recharge areas are. The differentiated groundwater flow balances were also included which add important information to the concepts. From this, four separate conceptual model scenarios were developed from simple to more complex to show the effect of the different models on the groundwater component of the Reserve. The models were then narrowed down on which of these are physical possible and which are not. In the sections that follow, the groundwater conceptual models are illustrated by graphic representations with the steady-state groundwater flow balances to indicate how it would influence the resource quantification and Reserve components.

2.2.8.2.1 Conceptual Model 2-1: Simple model with shallow flow only, no deep outflow via fault zones

This model shows the shallow semi-confined surface weathered/fractured aquifers with the deep confined fractured aquifers below. It is a simple first approach that considers shallow flow[4] only (**Figure 2.7**)[5].

- Recharge driven by orographic rain mainly takes place on the seaward side of the Outeniqua Mountains, south of the watershed where part of the Peninsula Aquifer outcrops.
- The groundwater flow gradient is controlled by the topographic gradient with most of the shallow groundwater flowing to the south. There is also a secondary flow component to the north that is maintained by rainfall and recharge north of the watershed. The groundwater shed mimics the surface watershed (Blauvelt and Fullmer, 2011).
- Surface springs (cold water) would be expected on the contact with the Peninsula Aquifer with the Goudini Aquitard to the north and the granite minor aquifers to the south that constrains flow (See Figure 2.8).
- Subsurface flow is also expected from the Peninsula Aquifer to the granite minor aquifers to the south via weathered and faulted zones. The weathered zone is an inclusion that could have important influences on groundwater flow in the shallow semi-confined surface aquifers. Also see Conceptual Model 2-4 for the importance of lateral flow (E-W) to the surface drainages.
- The steady-state[6] groundwater flow balance is given by:

$$Q_R - Q_{SSF} - Q_{SP} - Q_{ET} - Q_{SGBF} = 0$$

---

[4] These are typically shallower than 150 m and represent the area where most of the boreholes and hence groundwater abstraction takes place.

[5] Due to the limited space allowed in the document and the detail, the graphics will be supplied separately as PowerPoint or pdf files that allow the reader to zoom in. The figures are included here for reference purposes.

[6] To change the equation to transient, the zero would be replaced by *d*S/*d*t, which is the change in storage over time.

- where Q_R is recharge, Q_{SSF} shallow spring flow, Q_{SP} pumping from shallow boreholes, Q_{ET} is evapotranspiration losses in the riparian zone and Q_{SGBF} is shallow groundwater base flow into the surface streams. Due to the assumption that there is no deep groundwater baseflow or outflow component, there can be no groundwater flow into the deep confined Peninsula Aquifer. This scenario is partially depicted in Riemann and Blake (2010, Table 4-6) where no allowance was made for any outflow mechanisms from GRU 2 (confined deep Peninsula Aquifer) to justify through flow. All the recharge has to be balanced by losses, groundwater baseflow and abstraction in the shallow semi-confined surface aquifers.
- In the case where there is outflow (Conceptual Model 2-2), the yield and Reserve must decrease and in the case where there is no outflow (Conceptual Model 2-1), then no recharge can flow into the deep aquifer via the shallow aquifer. These two conceptual models cannot be true at the same time.

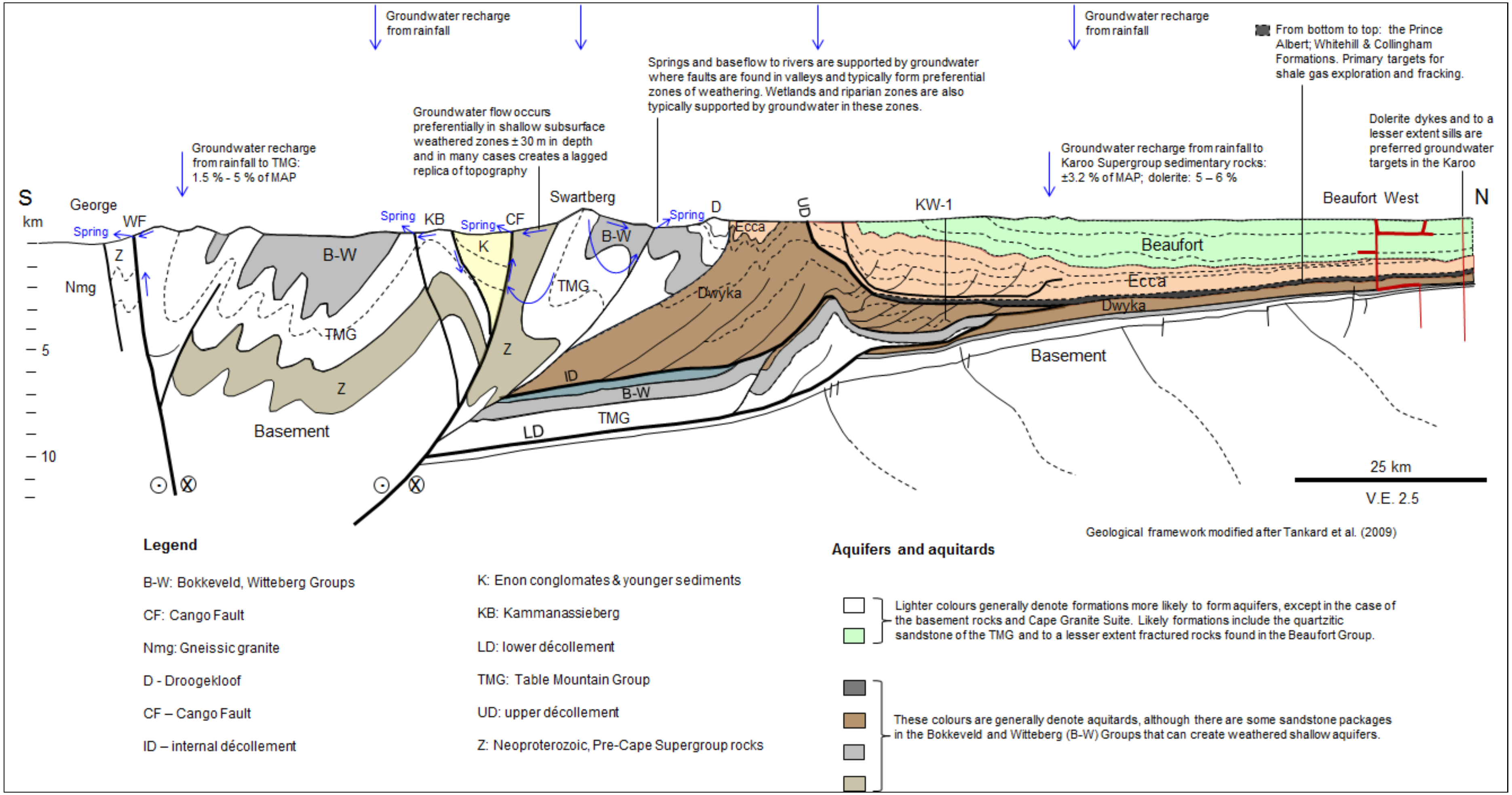


Figure 2.6 Gouritz groundwater – regional hydrogeological cross-section C (modified after Tankard *et al.*, 2009)

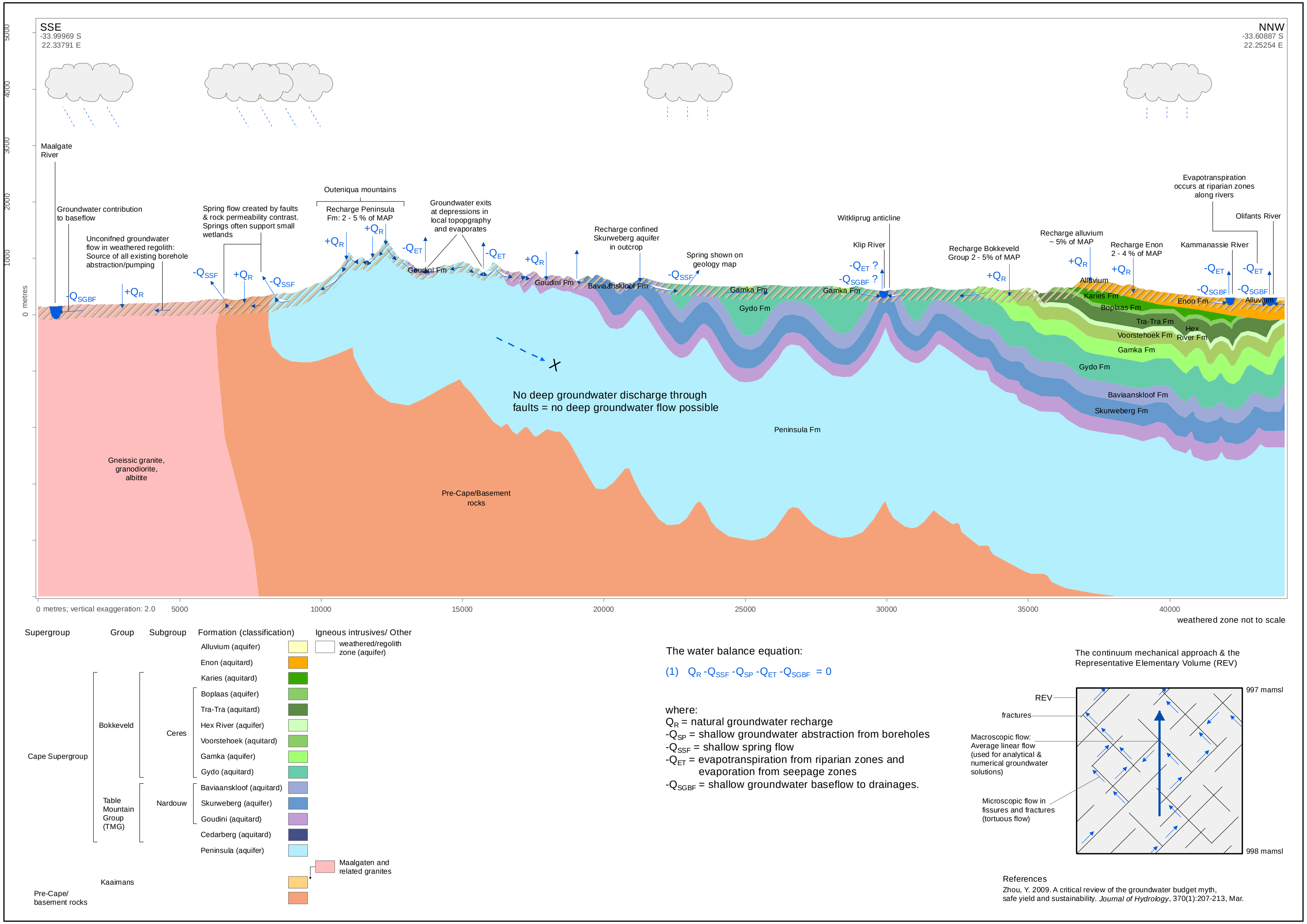


Figure 2.7 Gouritz groundwater – Conceptual Model 2-1

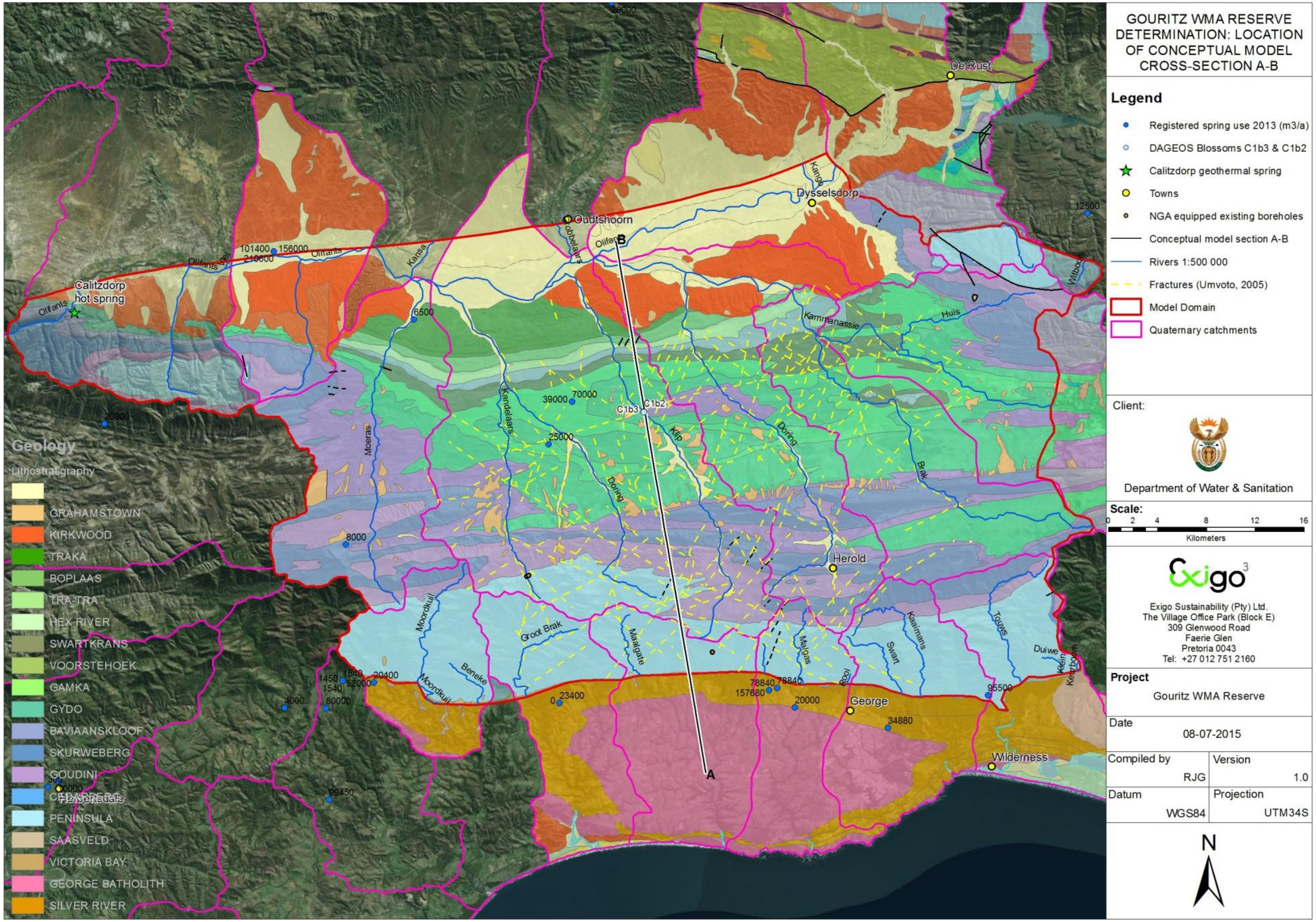


Figure 2.8 Map showing conceptual model cross-section A-B

2.2.8.2.2 *Conceptual Model 2-2: Conceptual Model 2-1 with deep flow*

This model is similar to Conceptual Model 2-1 but with deep groundwater baseflow possible under natural non-stressed conditions (**Figure 2.9**). The other outflow components are the same and limited to the shallow semi-confined surface aquifers. Deep groundwater baseflow or outflow via springs would be possible via fault zones that link the deep confined Peninsula Aquifer with surface streams as it would be inferred that the surface streams would follow or at least cross deep-seated fault zones. Most of the surface streams north of the watershed flow north-west and the large fault zones strike in a west-northwest to east-southeast direction (Umvoto Africa, 2005), so this is a possible but maybe improbable scenario, except for the Calitzdorp hot spring. The groundwater head gradient from boreholes developed in the deep aquifer did indicate a northwards natural gradient (Hartnady *et al.*, 2014). In the absence of prior abstraction there must be a flow component that would be controlled by the natural discharge rate (e.g. hot springs), given that the deep discharge is smaller than the total recharge to RU2 due to lateral outflow constraints. In other words, if the deep discharge was larger than the shallow recharge, the deep confined aquifer would not have an artesian hydraulic head where it starts to outcrop and becomes RU1.

- For this model, the steady-state groundwater flow balance now changes to:

$$Q_R - Q_{SSF} - Q_{SP} - Q_{ET} - Q_{SGBF} - Q_{DGBF} = 0$$

- Where Q_{DGBF} is the deep groundwater baseflow component. No deep abstraction was assumed as it is a pre-development or natural, steady-state scenario. Let's call it Scenario 2-2a for the deep aquifer(s). In this case the deep groundwater flow from the shallow semi-confined surface aquifer (Resource Unit 1 to Resource Unit 2) is controlled by Q_{DGBF}, it cannot be greater.
- If abstraction from the deep aquifer is included in a sub Scenario 2-2b, the balance is given by:

$$Q_R - Q_{SSF} - Q_{SP} - Q_{ET} - Q_{SGBF} - Q_{DGBF} - Q_{DP} = 0$$

- where Q_{DP} is pumping from the deep aquifer. In the case that, $Q_{DGBF} + Q_{DP} > Q_R$ let's call it Scenario 2-2b1, then Q_{SSF}, Q_{SP}, Q_{ET} and Q_{SP} would eventually decrease with time and cease as the deficit can only be balanced by the confined storativity of the aquifer. The magnitude of the transmissivity and storativity and specific setting in elevation will determine the time that it would take for the depletion to occur. This aspect can only be quantified using numerical groundwater flow models. If Scenario 2-2b1 is likely, then the strategy would be to deplete the aquifer over the long-term and the time to depletion should be quantified as it will have an impact on the Reserve and sustainable management of the aquifer. This scenario excludes potential direct inflow from surface streams to the shallow aquifer, which could also supplement the deep aquifer, and will be included in Conceptual Model 2-4. In the case that $Q_{DGBF} + Q_{DP} < Q_R$, which we call Scenario 2-2b2, then Q_{SSF}, Q_{SP}, Q_{ET} and Q_{SP} would still decrease over time, but the impact would be much lower. The magnitude and timing of the impacts will be determined by Q_{DP}.
- Under stressed conditions induced by pumping, the natural flow fields can be changed to force the flow northwards (Riemann and Blake, 2010). This means that the other groundwater components of the Reserve would eventually be impacted on with time.

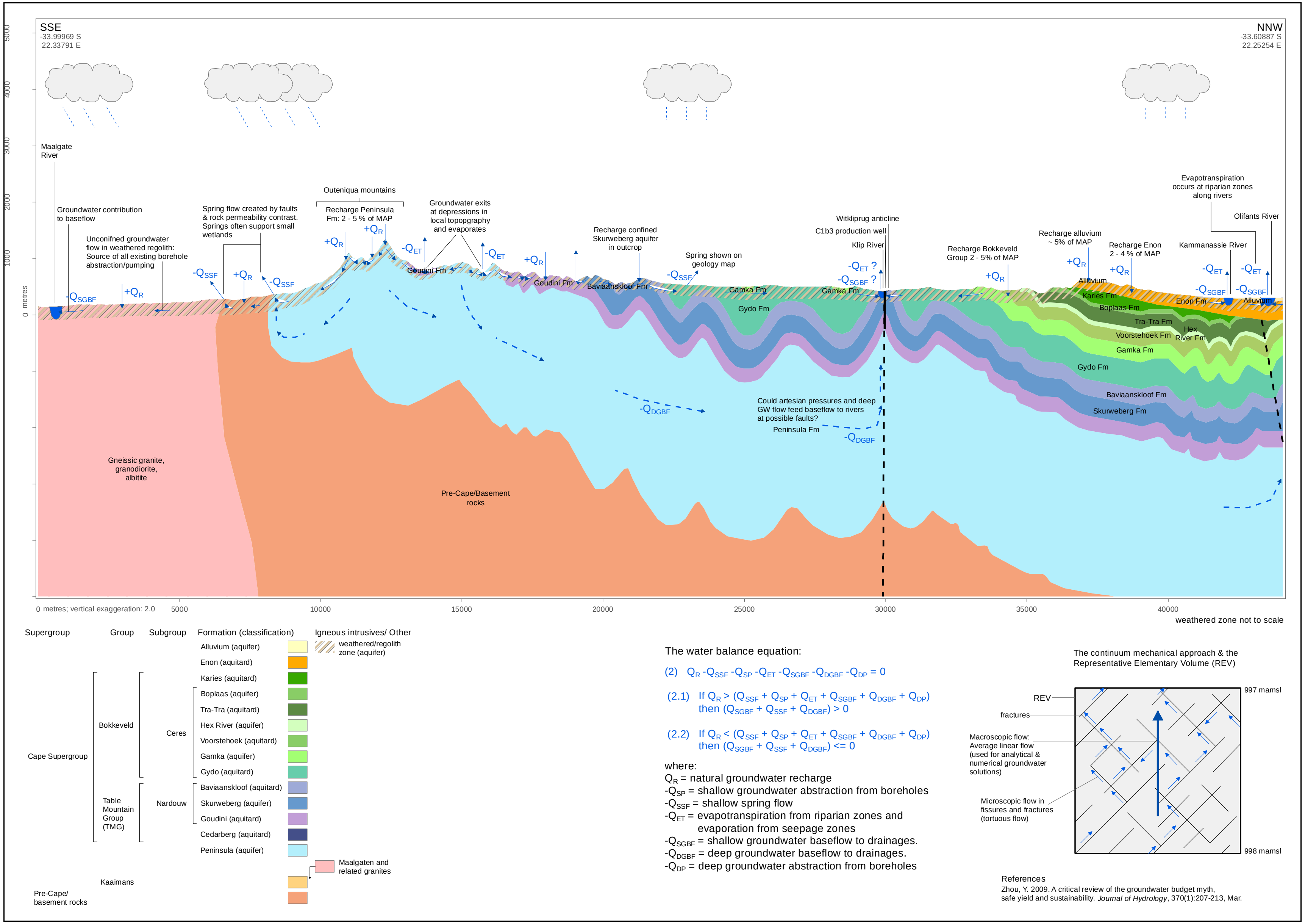


Figure 2.9 Gouritz groundwater – Conceptual Model 2-2

2.2.8.2.3 Conceptual Model 2-3: Conceptual Model 2-2 with deep flow and upward leakage

This model is similar to Conceptual Model 2-2 but with the inclusion of inferred large sub-horizontal fault zones that would link the deep confined Peninsula Aquifer to the shallower, confined Skurweberg Aquifer and even the surface weathered/fractured Gydo minor aquifer as well as the surface streams (**Figure 2.10**):

- The steady-state groundwater balance is given by:

$$Q_R - Q_{SSF} - Q_{SP} - Q_{ET} - Q_{SGBF} - Q_{DGBF} - Q_{DP} - Q_{LF} - Q_{DSF} = 0$$

  where Q_{LF} is upwards leakage via fault zones and Q_{DSF} is spring flow due to deep seated fault zones that daylights. A combination of Q_{LF} and Q_{DSF} is also possible or Q_{LF} could add up to Q_{SGBF} via the shallow surface aquifers. In this case, the pumping from the deep aquifer could impact on shallow spring discharges, shallow baseflow from groundwater as well as the other balance components like potentially increased recharge (Q_R) (which has a certain maximum value and is a major constraint on the availability of groundwater resources).
- The concept of determining the impacts on the groundwater component of the Reserve is important in this scenario. It was agreed at a technical meeting (January 2015) that this scenario is unlikely. There is also currently little evidence for this being a widespread/common occurrence.

2.2.8.2.4 Conceptual Model 2-4: Conceptual Model 2-2 with lateral outflow to rivers and streams under natural conditions

The layering of the Peninsula Aquifer is approximately east-west which is in the same direction as the largest and most prominent regional fault zones and syncline/anticline hinges (Umvoto Africa, 2005). It will be expected that under natural conditions, surface streams and rivers would act as drains to the regional groundwater system. This would mean that the groundwater recharged in the Outeniqua Mountains would by preference discharge laterally to the west and east towards the surface water streams that cuts into the mountains and act as drains (**Figure 2.11**). The surface water streams form the local topographic lows (i.e. head gradient control) and the transmissive fault zones would act as conduits taking flow towards the topographic lowest points. The approximately west-east layering and main direction of faulting would support this scenario.

- The natural steady-state groundwater balance is given by the same variables as in Conceptual Model 2-2 while highlighting the groundwater component of shallow baseflow, is given by:

$$Q_R - Q_{SSF} - Q_{SP} - Q_{ET} - \left(Q_{SGBF}\right) - Q_{DGBF} - Q_{DSF} = 0$$

- The deep groundwater flow component would be equal to (Q_{DGBF} + Q_{DSP}).
- Under stressed conditions introduced by pumping from the deep Peninsula Aquifer when (Q_{DP}>Q_R), the groundwater balance changes to:

$$Q_R - Q_{SSF} - Q_{SP} - Q_{ET} - Q_{SGBF} - Q_{DGBF} - Q_{DP} - Q_{DSF} + Q_{RDL} = 0$$

  where Q_{RDL} is river and dam leakage. Supplementary to Conceptual Model 2-2, Scenario 2-2b1 where (Q_{DP}+Q_{DGBF})>Q_R, it is expected that the groundwater in storage would be depleted over time or could be balanced by leakage from rivers and dams (Q_R). Several important surface streams and dams such as the George Dam are located on the southern slopes of the

Outeniqua Mountains. In the case that the surface streams are dry or the zone of impact is far from surface sources, the groundwater in storage would be depleted first before leakage from surface streams would be able to supplement it. Should the surface streams contain water that could act as a leakage boundary, the reduction in surface water flow would be equalled by the deficit of recharge as follows: $Q_{RDL}=Q_{DP}+Q_{DSF}+Q_{DGBF}-Q_{R}$.

To summarise this point, no groundwater can be abstracted from either shallow or deep aquifers without an impact over time. The potential impacts may be insignificant and beyond the currently delineated RU2 but have to be quantified and demonstrated before the groundwater yield can be determined.

- The groundwater balance principle dictates that the water must come from somewhere. If it leads to a reduction in evapotranspiration losses or spring flow, it could be beneficial provided that there are no adverse impacts on e.g. wetlands or riparian vegetation. Whether the impact is significant or not or whether it would take e.g. 10 or 100 years to manifest must be quantified using appropriate conceptual models and numerical modelling in combination with monitoring data obtained under abstraction conditions. Following the principles of sustainability, the socio-economic-environmental and development potential or impacts needs to be determined on the Water Reserve before the sustainable yield of an aquifer can be determined (Vivier, 2013; NWA, 1998).

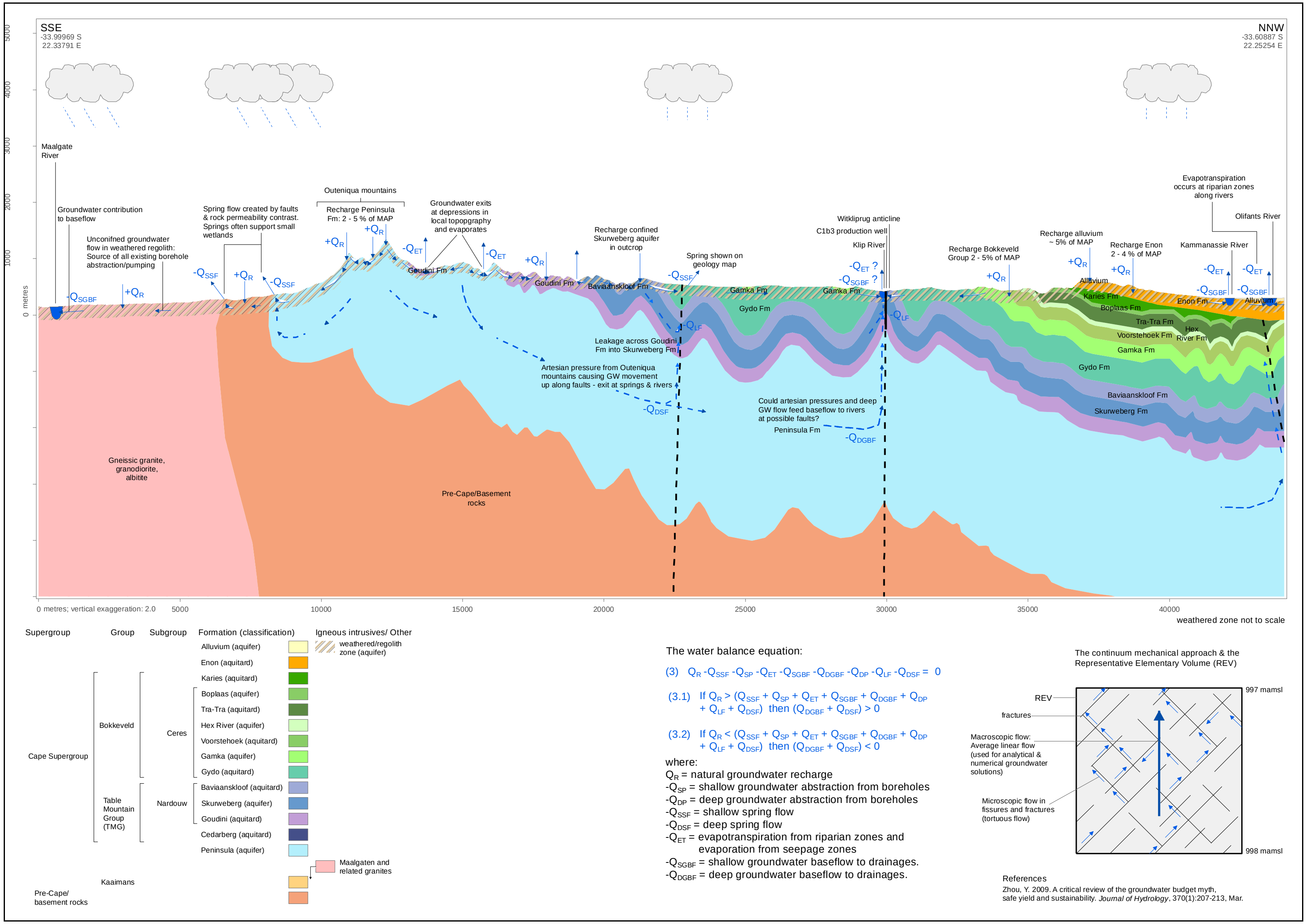
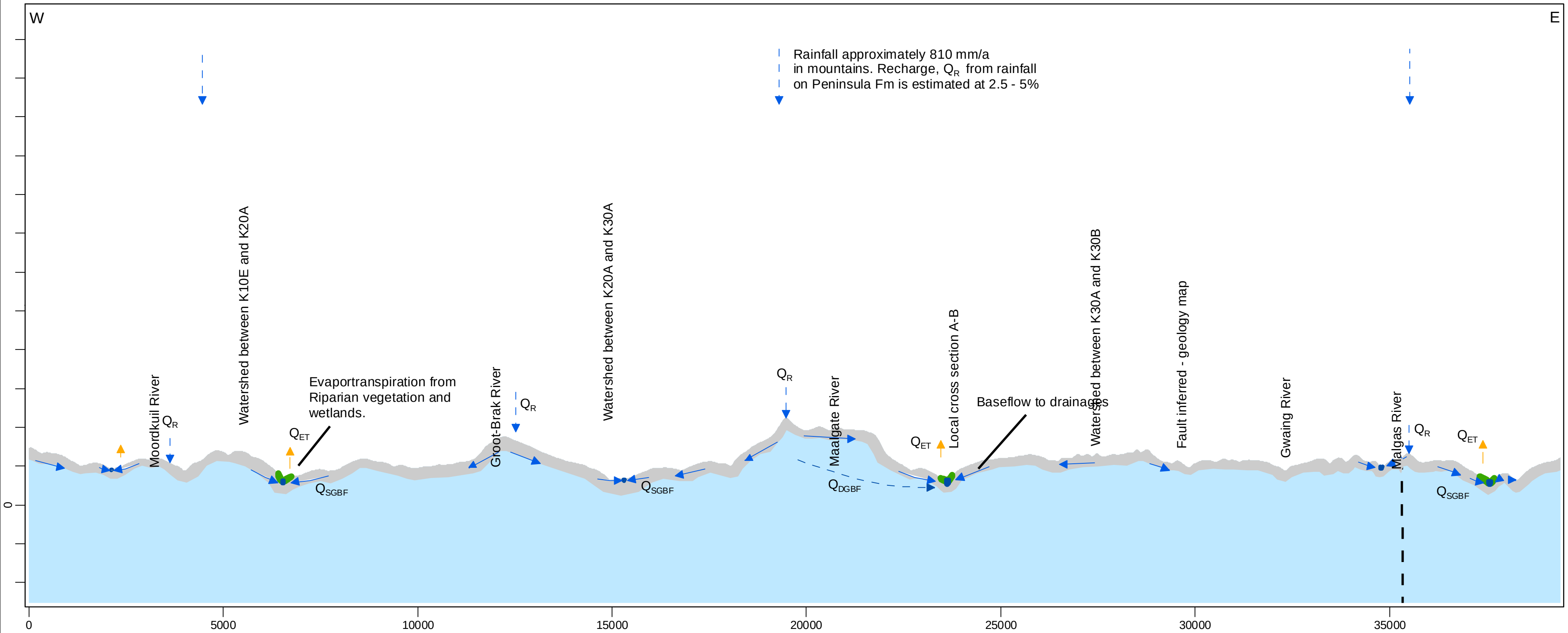


Figure 2.10 Gouritz groundwater – Conceptual Model 2-3



Legend

- Rainfall and recharge
- Groundwater flow
- Deep GW baseflow
- Evapotranspiration
- Rivers
- Wetlands & Riparian vegetation
- Weathered & fractured zone
- Faults
- Peninsula Formation

The water balance equation:

(4) $Q_R - Q_{SSF} - Q_{SP} - Q_{ET} - (Q_{SGBF}) - Q_{DGBF} - Q_{LF} - Q_{DSF} - Q_{RL} = 0$

where:

Q_R = natural groundwater recharge
$-Q_{SP}$ = groundwater abstraction from boreholes
$-Q_{SSF}$ = shallow spring flow
$-Q_{ET}$ = evapotranspiration from riparian zones and evaporation from seepage zones
$-Q_{SGBF}$ = shallow groundwater baseflow to drainages
$-Q_{DGBF}$ = deep groundwater baseflow to drainages
$-Q_{LF}$ = upwards leakage via fault zones
$-Q_{DSF}$ = deep spring flow
$-Q_{RL}$ = River leakage

Notes:

Conceptual model W-E cross section is drawn within the unconfined aquifer Resource Unit 1. All rivers crossed by this section line flow south.

Figure 2.11 Gouritz groundwater – Conceptual Model 2-4

2.2.9 Unconventional shale gas exploration and development in the Karoo formations – potential impacts on the groundwater component of the Reserve

The potential to exploit unconventional gas resources in the Karoo has been promulgated by potential developers. This has led to widespread debate as the prospects of hydraulic fracturing (fracking) and the potential impacts that it could have on the surface landscape and groundwater quality is unqualified at the moment. South Africa has an estimated 450 trillion cubic feet (TCF) of shale gas, which would be the fourth largest shale gas resource in the world (De Wit, 2012).

Regulations on fracking were gazetted (gazette no. 38855) by the Department of Mineral Resources (DMR) in June 2015 (South Africa, 2015). The regulations make provision for environmental impact assessments in which the geology, geohydrology and water resource assessments and impacts must be determined prior to exploration licences being issued. An important aspect of the assessment is to determine the prior or baseline groundwater and surface water quantity and quality (hydrocensus) against which future potential impacts can be measured, none of which have been done to a reasonable degree for groundwater fracking yet. The regulations provide a process through which exploration for shale gas can be done.

The aim of this section is not to do an in-depth investigation into fracking and also not to quantify the impacts. The purpose is to put the potential groundwater related risks and impacts into perspective with the groundwater component of the Reserve at a high- or initial-level.

2.2.9.1 Potential risks from hydraulic fracturing (fracking) on the groundwater component of the Reserve

It is well known that surface water is mostly absent for the western Karoo area in South Africa. The northern part of Gouritz WMA is underlain by Karoo formations which could form targets for fracking (see **Figure 2.12**, **Figure 2.6**). It must be noted that very limited information is available on the deep seated Karoo formations, at the depths where fracking is planned. Most of the data is obtained from hot springs and the Soekor boreholes that were drilled. The existing data was used by the Karoo Groundwater Expert Group (KGEG) to compile an initial hydrogeological conceptual model (Rosewarne *et al.*, 2013) and a Water Research Commission (WRC) research report (Steyl *et al.*, 2012b).

The main formations that will be targeted are the carbonaceous- or oil-shale of the Ecca Group, namely the Prince Albert-, Whitehill- and Colligham-Formations (**Table 2.2**, **Figure 2.12**, Rosewarne *et al.*, 2013). The Whitehill Formation will form the main target for shale gas exploration (Geel *et al.*, 2013). Fracking will be done at great depths of >1 km below surface. The shale gas will be accessed via vertical wells that will be drilled from surface to the orebody from where it is directionally drilled in a lateral direction and fracked under high pressure to create fissures along which the gas can escape and be tapped.

Based on the information available the following main risks due to fracking are flagged:

- The exploration phase should be preceded with detailed baseline groundwater quality- and quantity-hydrocensus surveys so that impacts can be measured against a reference quantity and quality. This should be followed by a detailed hydrogeological investigation so that the deep geology, hydrogeology and groundwater flow dynamics are understood to sufficiently determine the potential impacts related to the impacts of the drilling and fracking on subsurface processes, as well as on the surface processes.

- The fracking fluids that are currently used on an international scale contain toxic substances (Colborn *et al.*, 2011). The toxicity of the fracking fluids is the main concern should the deep seated contaminated fracking zone water find pathways upwards in the future, either via the imperfect borehole seals of geological structures such as faults and dykes. There is apparently research being conducted and patents filed for non-toxic fracking fluids.
- Methane can occur naturally and leak to the surface aquifers via natural geological pathways such as faults and dykes. One of the main pathways for methane gas and fracking fluids are imperfect well seals that degrade with time. It was determined that 1 - 3% of post-operational well seals leak. Although this is a small percentage, it is very difficult to guarantee the integrity of well seals into the future (Vidic *et al.*, 2013).
- Based on the limited data from hot springs and the Soekor boreholes, the Karoo Basin in the area where fracking exploration is planned may be artesian at some localities. This means that there is an inferred vertical driving force that could leak residual fracking fluid to the surface. The lateral extent of the artesian conditions and where it is likely to be prevalent must still be determined. The driving force for the artesian groundwater head conditions is uncertain as it could be either from recharge on the elevated CFB Mountains or compression from the CFB.
- The southern border of the Karoo formations close to the Swartberg Mountains would be inferred as high risk for fracking. This is due to the intense folding and faulting that could provide potentially (permeable) pathways through the confining layers. The northern part of the study area, closer to Beaufort West, contains numerous dolerite sills and dykes. The dolerite dykes could create vertical pathways for future potential upwards migration of fracking fluids.

The two main risks from fracking are toxic fracking fluids and the inferred artesian conditions in the Karoo Basin. These risks could potentially be mitigated if non-toxic fracking fluids are developed and fracking only occurs in higher elevation areas where the artesian conditions may not be prevalent. It has not yet been determined what the zone of influence of a leaking well would be. Depending in which formation it has been developed and what the conditions of the surface aquifer or aquitard are, the zone of influence could be localised or spread with time. Should wells be developed from surface aquitards, this risk can be reduced. Detailed investigations before, during and after the exploration phases will have to be done to prove the deep subsurface hydrogeological conditions.

Groundwater is the only water resource in many parts and towns of the Karoo. Unconventional gas development/fracking requires approval of a water use licence. WULAs (and applicable Environmental Impact Assessment (EIA) / geohydrology / specialist studies) should be more strictly evaluated in areas where the groundwater resource is stressed or over allocated or areas where groundwater Reserve determination studies have indicated stressed GRUs / catchments. Surplus / other- water resources in such areas will not be available to mitigate any loss of the groundwater resource. A licence will only be issued if adequate water is available for the activity (based on site specific hydrogeological report). Appropriate mitigation measures may form a part of such a licence application. This could include importing water to the “stressed” area or even future waterless fracking. The magnitude of impacts will be proven as EIA and applicable specialist studies are performed for the WULA.

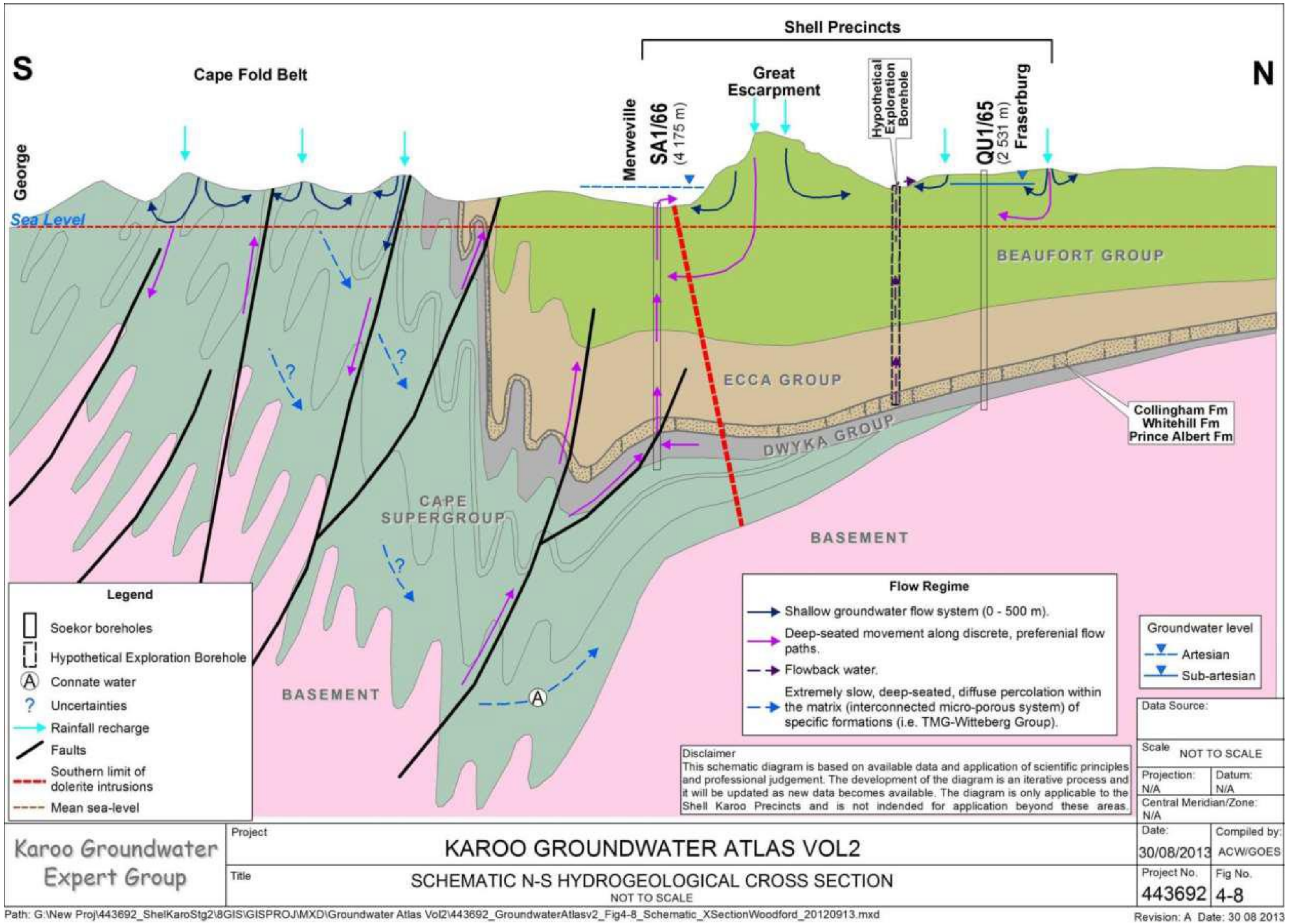


Figure 2.12 Regional south-north hydrogeological cross-section of the CFB and the Karoo Formations (Rosewarne *et al.*, 2013)

2.2.10 Groundwater in relation to topography

As part of the GRU delineation process, the correlation between hydraulic head and topography was evaluated to confirm whether it is suitable to use the quaternary catchment scale watersheds and boundaries as GRUs. What does the correlation between hydraulic head (water levels) and topography tell us? It tells us to what extent is the hydraulic gradient ($^{dh}/_{dL}$) and elevation related and does the hydraulic gradient in fact present a subdued replica of topography (Blauvelt and Fullmer, 2011; Haitjema and Mitchell-Bruker, 2005; Tóth, 1963). In other words groundwater flows from higher elevation areas to lower elevation areas (following from potential field theory). The strongest influence on groundwater flow is however found in the form of active boundary conditions (sources or sinks) that either add or remove appreciable quantities of groundwater from the applicable aquifer.

Hydraulic heads (groundwater levels) were obtained from the following datasets and processed for the comparison:

- DWS actively monitored boreholes across the Gouritz WMA.
- Gouritz WMA optimised hydrocensus for this study.
- National Groundwater Archive (NGA) groundwater levels.
- GRA II groundwater levels.

A 20 x 20 m cell size Digital Terrain Model (DTM) was created for the entire WMA using the National Geospatial Information (NGI) 20 m contours and spot heights. The data was interpolated using the Topo to Raster spatial processing tool to create a hydrologically acceptable DTM. The XY accuracy that can be expected from the DTM is 25 m, while the elevation is noted in the NGI standard operating procedure (QLAS.SD.3_v1) for DEM compilation to have a maximum vertical standard deviation of ± 10.5 m. The DTM was used to calculate the hydraulic head and was also used in the correlation comparison of the hydraulic head and topography for the different hydraulic head datasets. A sample of 33 quaternary catchments was randomly selected from the 130 quaternary catchments in the WMA for hydraulic head-topography comparison and to do statistically representative evaluations on.

Table 2.4 summarises the coefficients of determination or R-squared (R^2) for 33 randomly selected quaternary catchments as well as for the WMA. **Figure 2.13** shows a scatter plot of the hydraulic head and elevation of each NGA geosite in the Gouritz WMA with a measured groundwater level. The regression line was also drawn for the dataset indicating an R^2 of 0.99. This shows that groundwater head elevation is a subdued replica of topography.

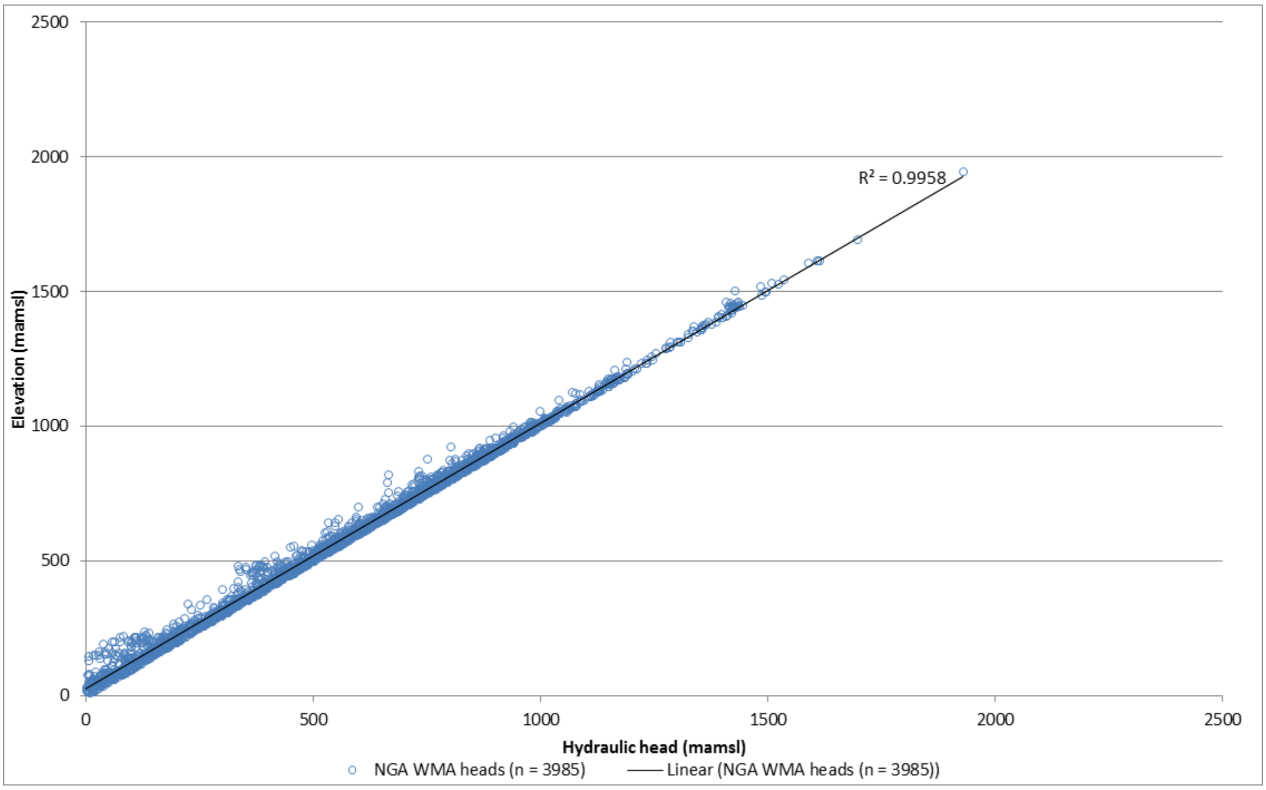


Figure 2.13 Hydraulic head and topography of Gouritz WMA NGA geosites plotted and regression line drawn (n = 3985)

Table 2.4 Quaternary catchment hydraulic head-topography correlations: 33 randomly selected quaternary catchments

No	Quaternary catchment	NGA R^2	Sample size	DWS active BHs R^2	Sample size	Gouritz Hydrocensus R^2	Sample size	GRA II 1x1 km R^2
1	H80A	-	-	-	-	-	-	0.9123
2	H80E	0.9659	6	-	-	-	-	0.8381
3	H90C	0.9969	4	-	-	-	-	0.8656
4	J11B	0.9851	12	-	-	-	-	0.9339
5	J11F	0.9936	16	-	-	-	-	0.9262
6	J11K	0.9898	16	-	-	-	-	0.9411
7	J12D	0.9826	45	-	-	-	-	0.8756
8	J12H	0.98	27	-	-	-	-	0.9097
9	J12M	-	2	-	-	-	-	0.9241
10	J21A	0.997	287	0.9828	6	-	-	0.9677
11	J21E	0.9981	9	-	-	-	-	0.9964
12	J22D	0.994	27	-	-	-	-	0.973
13	J22H	0.9938	29	-	-	-	-	0.9744
14	J23B	0.988	9	-	-	-	-	0.995
15	J23F	0.9894	49		2	-	-	0.9655
16	J24A	0.9984	142	0.9944	15	-	-	0.9708
17	J24E	0.9919	55	-	-	-	-	0.9671
18	J25C	0.9658	21	-	-	-	-	0.8899
19	J31B	0.9914	9	-	-	-	-	0.9163
20	J32A	0.9407	15	-	-	-	-	0.9716
21	J32E	0.969	41		2	-	-	0.9062
22	J33D	-	2	-	-	-	-	0.9305
23	J34B	0.9898	10	-	-	-	-	0.9017
24	J34F	0.9864	38	0.881	4	-	-	0.9027
25	J35D	0.9917	69	-	-	-	-	0.9525
26	J40B	0.9987	4	-	-	-	-	0.8238
27	K10A	0.9295	33	-	-	-	-	0.8558
28	K10E	0.5407	3	-	-	-	-	0.915
29	K30B	0.0054	7	-	-	-	-	0.9333
30	K40B	-	2	-	-	-	-	0.9171
31	K50A	-	-	-	-	-	-	0.8925
32	K60C	0.8564	6	-	-	-	-	0.8098
33	K60G	0.7446	24	-	-	-	-	0.8434
	Minimum	**0.0054**		**0.881**				**0.8098**
	Maximum	**0.9987**		**0.9944**				**0.9964**
	Mean	**0.9198**		**0.9527**				**0.9181**
	5th Percentile	**0.6121**		**0.8912**				**0.8324**
	95th Percentile	**0.9983**		**0.9932**				**0.9826**

For the NGA geosites, the following summary correlations were obtained: a minimum R^2 of 0.0054 (no correlation), a maximum R^2 of 0.9987 and a mean R^2 value of 0.9198 (good correlation) for quaternary catchments. The 5^{th} percentile of the data (95% of the correlations are higher) indicates a R^2 of 0.61, which is still a positive correlation. This means that there is in general a good correlation between topography and groundwater head elevation for 95% of the catchments in the population sample. The low correlation in catchment K30B indicates that groundwater does not always follow topography and deviations need to be taken into account. This catchment is classified as part of the 28 stressed catchments so it is expected that over-abstraction is the reason for the lower correlation. Similar results are obtained from the GRA II study's 1x1 km interpolated hydraulic head grid clipped from the national GRA II grid that was interpolated from a cleaned database of a

126 263 National Groundwater Database (NGDB) boreholes with measured groundwater levels (DWA, 2006).

The fact that only five of the 33 randomly selected catchments have DWS actively monitored boreholes in the WMA is not representative of the DWS monitoring programme efficiency in the WMA: There are DWS monitoring boreholes in most of the catchments where groundwater is intensively used and where groundwater monitoring is required. Even with only five catchments where DWS actively monitored boreholes occur in this random catchment evaluation and with sparse observation boreholes in each; the minimum R^2 obtained is 0.88.

None of the randomly selected quaternary catchments contain Gouritz hydrocensus Geosites. Given this outcome, the hydraulic heads of the Gouritz hydrocensus boreholes in the seven quaternary catchments where they are present were assessed. A minimum R^2 of 0.75 (n = 16), a maximum R^2 of 0.9965 (n = 5) and mean R^2 value of 0.88 was calculated for the seven quaternary catchments and 86 Geosites. It is however noted that the sample size for the former mentioned maximum correlation is too small to provide a statistically representative correlation.

All the hydraulic head observations used in all of the correlations performed are from the shallow unconfined to semi-confined aquifers situated in aquifers up to 160 metres below ground level (mbg)l.

2.3 DESKTOP-RAPID RESERVE DETERMINATION

A Desktop-Rapid groundwater Reserve determination was completed using available information and databases as a screening tool to flag problematic areas and catchments within the Gouritz WMA. The latest GRDM 2012 software was used for this analysis.

Selection of final GRUs for Intermediate GYMR Reserve determinations are based on known problematic or sensitive areas (hotspots), problematic Desktop Reserves (stress index > 60%) with less groundwater availability from the Desktop-Rapid Reserve taken into account.

Results from the evaluation of town hotspots and preliminary problem catchments are graphically portrayed and summarised in **Figure 2.14**.

Hotspots and selected GRUs are described in **Section 2.3.3**. Hotspots are aquifers or zones where over- abstraction is taking place, mostly in a localised area.

2.3.1 Secondary delineation: GRUs based on geology

The map in **Figure 2.15** represents the geology of the study area at an appropriate scale for the WMA, i.e. 1: 1000 000. For the Intermediate Reserve and for priority areas, 1: 250 000 geology was used which is currently the highest resolution geological spatial data publically available in raster/vector format for the country.

Aquifers can be classified according to the lithological character of a group of formations as well as the transmissivity (T) of the formations or larger groups of formations. Within the Gouritz WMA study area, some geological units have already been defined as aquifers and aquitards in the ORDS (DWA, 2010) as well as the Outeniqua Coast Water Situation Study (DWA, 2007).

Table 2.6 describes the geology based grouping and basic GRU delineation with details of geological formations, groups and subgroups as well as lithology. Aquifer classification is also provided according to Parsons (1995).

Figure 2.16 provides a map of the basic delineation of the different aquifer types and main GRUs in the study area based on geology. Colours show how the main geological units have been grouped.

The confined aquifer associated with the Peninsula Formation of the TMG is delineated as a GRU based on geological boundaries for comparison with the Reserve and balances of the quaternary catchments it underlies.

The final quaternary catchments selected as GRUs for Intermediate groundwater Reserve determination as well as geology defined GRUs are discussed in **Section 2.3.3**.

2.3.2 Results of Desktop-Rapid Reserve determination

The purpose of the Desktop-Rapid Reserve was to quantify the regional groundwater resources for the purpose of the Reserve and to focus the Intermediate Reserve on the expected stressed catchments. The Desktop-Rapid Reserve results indicated the following (Table 2.5, Figure 2.14, **Appendix A**):

- The minimum recharge in the WMA is estimated at 447 million m^3/a (8.5 mm/a), for average rainfall (398 mm/a) and 268 million m^3/a (5.1 mm/a) for assured recharge or drought conditions (98% assured). The average rainfall recharge of the shallow unconfined aquifers across the regional WMA has a minimum of 1.8% of mean annual precipitation.
- The groundwater component of baseflow is in the order of 54 million m^3/a (1 mm/a), for average conditions and 33 million m^3/a (0.6 mm/a), for dry cycles.
- The current groundwater use is in the order of 140 million m^3/a (2.7 mm/a), and the BHNR is in the order of 10 million m^3/a (0.2 mm/a).
- The allocable groundwater that is still available is 60 million m^3/a (1.1 mm/a), for average rainfall conditions and 31 million m^3/a (0.6 mm/a) for dry conditions. This means that additional groundwater development potential is available for 102 quaternary catchments which is more than 70% of the WMA. This potential is discussed in more detail in **Section 2.10**. It must be noted that this volume is conservative as it was assumed that the losses are a given. Once groundwater is used, losses would decrease. If only 10% of the losses are used, then another 25 million m^3/a, could be freed. More detailed studies will have to be done to substantiate the origin of the losses. Should it be due to riparian vegetation, then less volume would be available than e.g. if it is alien vegetation.
- A total of 28 of the 130 quaternary catchments classified with a high GRDM index under average conditions (P_{50}) which may be stressed. These catchments represent 20% of the total WMA and can be considered as potentially under stress based on the current assessment. When assured recharge is considered at 98% assured rainfall, then a total of 44 (34%)

catchments were flagged as stressed. This means that even under 1:50 year drought conditions, 65% of the groundwater would still be available. Given that storage was not taken into account, it is expected that the droughts would be partially buffered and the 28 catchments that did flag as stressed under average rainfall-recharge conditions (P50). These catchments were assessed in more detail in the Intermediate Reserve.

It must be noted that due to the conservative nature of the Desktop-Rapid Reserve methodology (**Section 2.1.5**) catchments that flag as "stressed" may declassify during the Intermediate and higher level Reserve iterations. It is acknowledged that the average regional values above will not be applicable on a local quaternary catchment or wellfield scale, but do provide a primary catchment or regional perspective. More detailed values for each quaternary catchment are listed in **Section 2.7** and **Appendix A**.

Table 2.5 Rapid Reserve determination summary of results

Catch-ment	Area (km^2)	P50 Recharge (Mm^3/a)	P98 Recharge (Mm^3/a)	P50 GW Base flow (Mm^3/a)	P98 GW Base flow (Mm^3/a)	GW Use (Mm^3/a)	P50 GW losses (Mm^3/a)	P98 GW losses (Mm^3/a)	BHN Reserve (Mm^3/a)	EWR (Mm^3/a)	P50 GW Alloctn (Mm^3/a)	P98 GW Alloctn (Mm^3/a)
		447	268	54	33	139	244	87	10	22	60	31
121	52 571	8.5	5.1	1.0	0.6	2.7	4.6	1.6	0.2	0.4	1.1	0.6

2.3.3 Selected GRUs, hotspots and focus areas for Intermediate Reserve determination

The following criteria were used to identify hotspots for hydrocensus as well as in final delineation of GRUs for Intermediate groundwater Reserve determination:

- Desktop-Rapid groundwater Reserve determination results.
- Existing studies information.
- DWS Gouritz WMA Stakeholder Meeting held 3 October 2013 (see **Table 2.7**);
- DWS All Towns Reconciliation Strategies (DWA, 2014c).
- Known aquifers of importance:
  - Vermaaks River catchment and Klein Karoo Rural Water Supply Scheme (KKRWSS).
  - Peninsula Formation confined aquifer associated with DAGEOS.
- Water Use Licence Applications as received per DWS Excel sheet (DWS, 2014).
- DWS existing groundwater monitoring borehole data to steer hydrocensus.
- Wetlands from National Freshwater Ecosystem Priority Area (NFEPA) spatial coverage.

Present Status Category	Stress Index	Total Quats	Total percentage
I	< 5%	55	42%
I	5% - 20%	21	16%
II	20 - 40%	15	12%
III	40 - 65%	13	10%
III	65 - 95%	6	5%
III	>95%	16	12%
Zero Recharge	Erroneous	4	3%

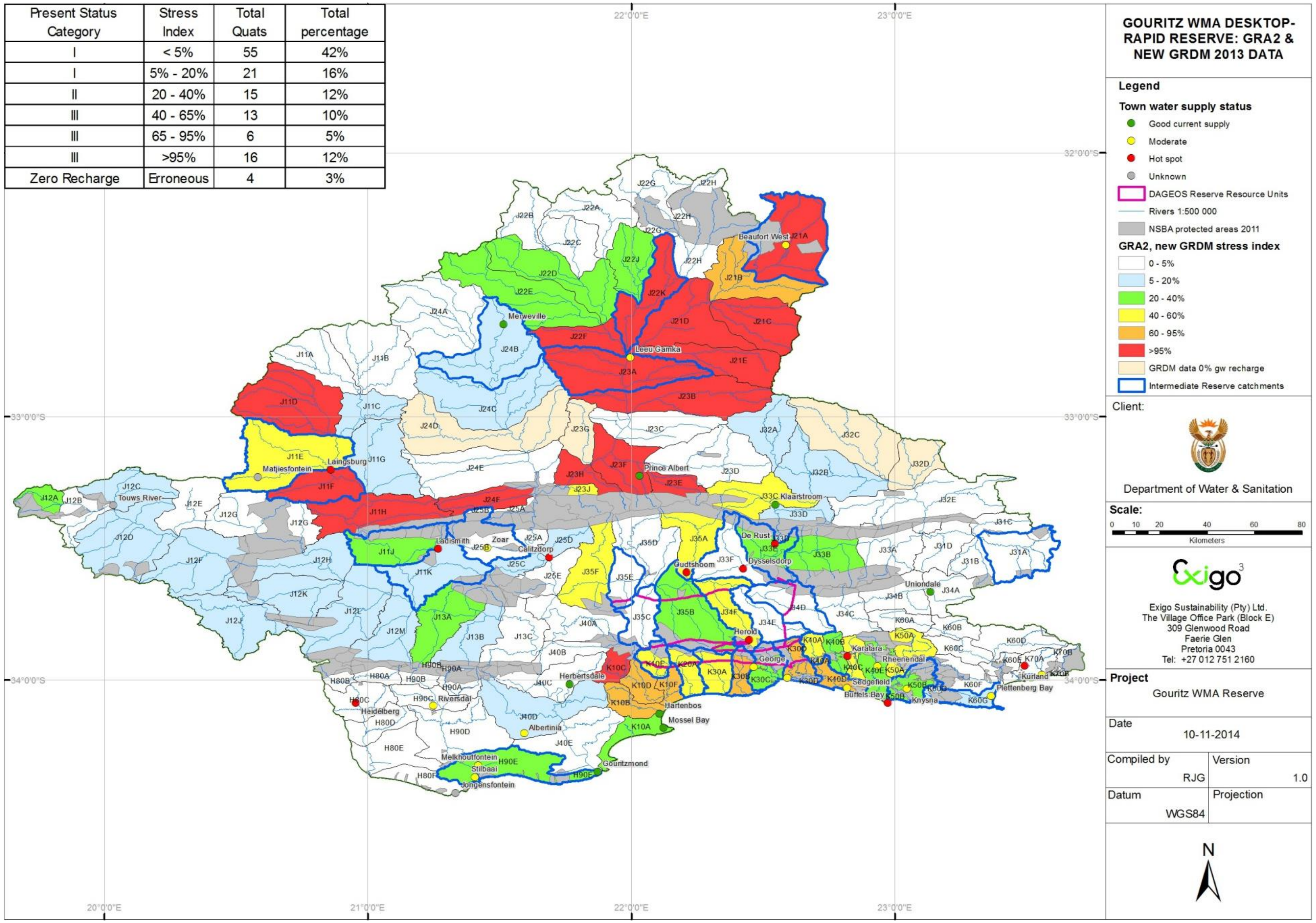


Figure 2.14 Rapid Reserve results for average conditions (P_{50}) and hotspots

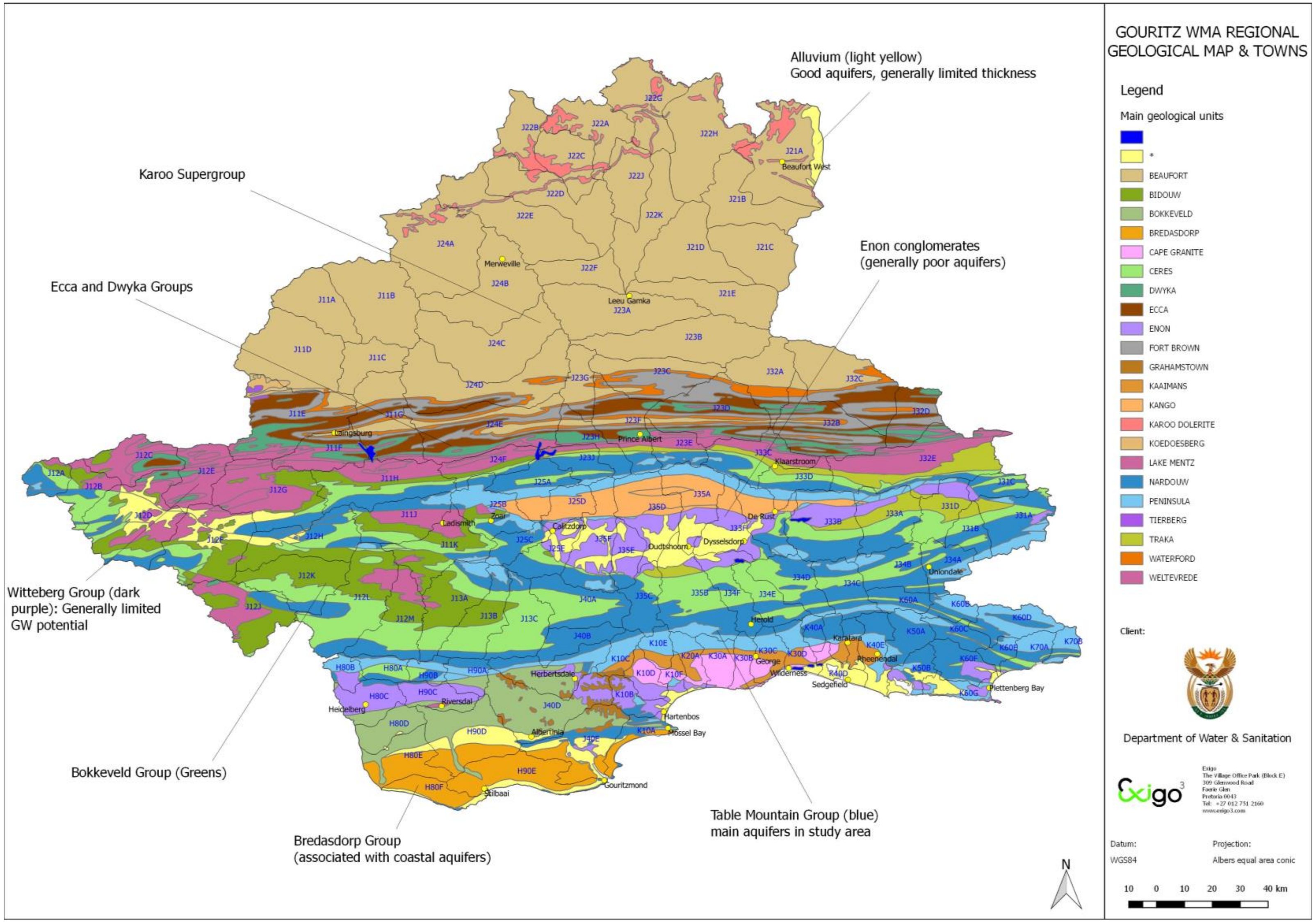


Figure 2.15 Geological map showing the major groups, subgroups and formations underlying the Gouritz WMA

Table 2.6 Summary table of geology, hydrogeology and GRUs based on geology

Main Unit	Aquifer type	Unit in map	Lithology	GRU	Comments
Alluvium	Major	Alluvium	Coastal sands, quaternary sediments	GRU2b	The updated regional scale geology map shows larger areas of porous/ intergranular aquifers, but thickness is unknown and critical to sustainability
Bredasdorp Group	Major	Bredasdorp	Conglomerate, shelly limestones, calcarenites and calcrete	GRU2a	Essentially regarded as coastal aquifers
Grahamstown Fm	Poor	Silcrete	Silcrete-sand grains to pebbles cemented in a hard secondary siliceous matrix	GRU11	Poor aquifer
Uitenhage Group	Poor	Enon Fm/ Kirkwood Fm	Conglomerate, sandstone and siltstone	GRU8	Poor aquifer
Karoo dolerite	Major/ Sole source	Karoo dolerite (Jd)	Hypabyssal dolerite, igneous rock	GRU4	Dolerite and contact zones major groundwater targets in the Karoo
Cape Granite suite	Poor	Cape Granite Suite	Plutonic igneous rock	GRU6	Massive igneous rock, limited GW potential in weatherd zone
Beaufort Group	Minor/ Sole source	Beaufort undifferentiated	Siltstone, mudstone and sandstone	GRU7a	Karoo Sedimentary rocks with approximately similar groundwater characteristics
Ecca Group	Minor/ Sole source	Ecca Group	Shale, mudstone and minor sandstone		
	Poor	Tierberg Fm	Predominantly argillaceous well-laminated dark grey to black shale		
	Minor/ Sole source	Waterford (previously Koedoesberg Fm)	Arenaceous very fine-grained lithofeldspathic sandstone and mudrock		
	Minor	Fort Brown Fm	Rythmite and mudrock, minor sandstone intercalations		
	Minor/ Sole source	Koedoesberg Fm	Fine- to medium-grained sandstone, siltstone, shale, rhytmite		
Dwyka Group	Poor	Dwyka Group	Diamictite	GRU11	Poor groundwater prospects; aquitard; ductile deformation
Witteberg Group	Poor	Lake Mentz Subgroup	Quartzites, mudrock and siltstone	GRU9	According to explanation abstract of 1:500 000 Port Elizabeth geohydrological map, poor aquifers in terms of quality
	Minor	Witpoort	Sandstone		
	Poor	Weltevrede Subgroup	Siltstone, shale and sandstone		
Bokkeveld Group	Poor	Bokkeveld undifferentiated	Feldspathic sandstone, shale and siltstone	GRU10	Generally poor aquifers due to abundant fine grained rock matrix
	Poor	Bidouw /Traka Subgroup	Shale, siltstone and sandstone	GRU10a	
	Minor	Ceres Subgroup	Feldspathic sandstone, mudrock and siltstone	GRU10b	Borehole yields vary widely
Table Mountain Group	Minor	Nardouw Subgoup	Feldspathic sandstone and siltstone, fractured quartzite, sandstone, siltstone and shale, tillite	GRU1b	Containing 1 aquifer unit, i.e Skurweberg Fm (400m) and two aquitards; the Baviaanskloof Fm (200m) and thicker Goudini Fm (300m)
	Major	Skurweberg Formation	Thick bedded sandstone	GRU1c	Skurweberg Fm (400m) aquifer
	Major	Peninsula Formation	Fractured quartzite	GRU1a	The major aquifer unit in the WMA
Schoemanspoort Fm	Minor	Schoemanspoort Fm	Conglomerate	GRU3	Conglomerate and sandstone
Cango Caves Group	Minor	Cango Caves	metasediments		Low - to medium-grade metamorphosed sedimentary rocks
Kansa Group	Minor	Kansa			Coarse clastic succession
Kaaimans Group	Poor	Kaaimans	Low grade metasediments	GRU5	Metamorphosed sedimentary rock

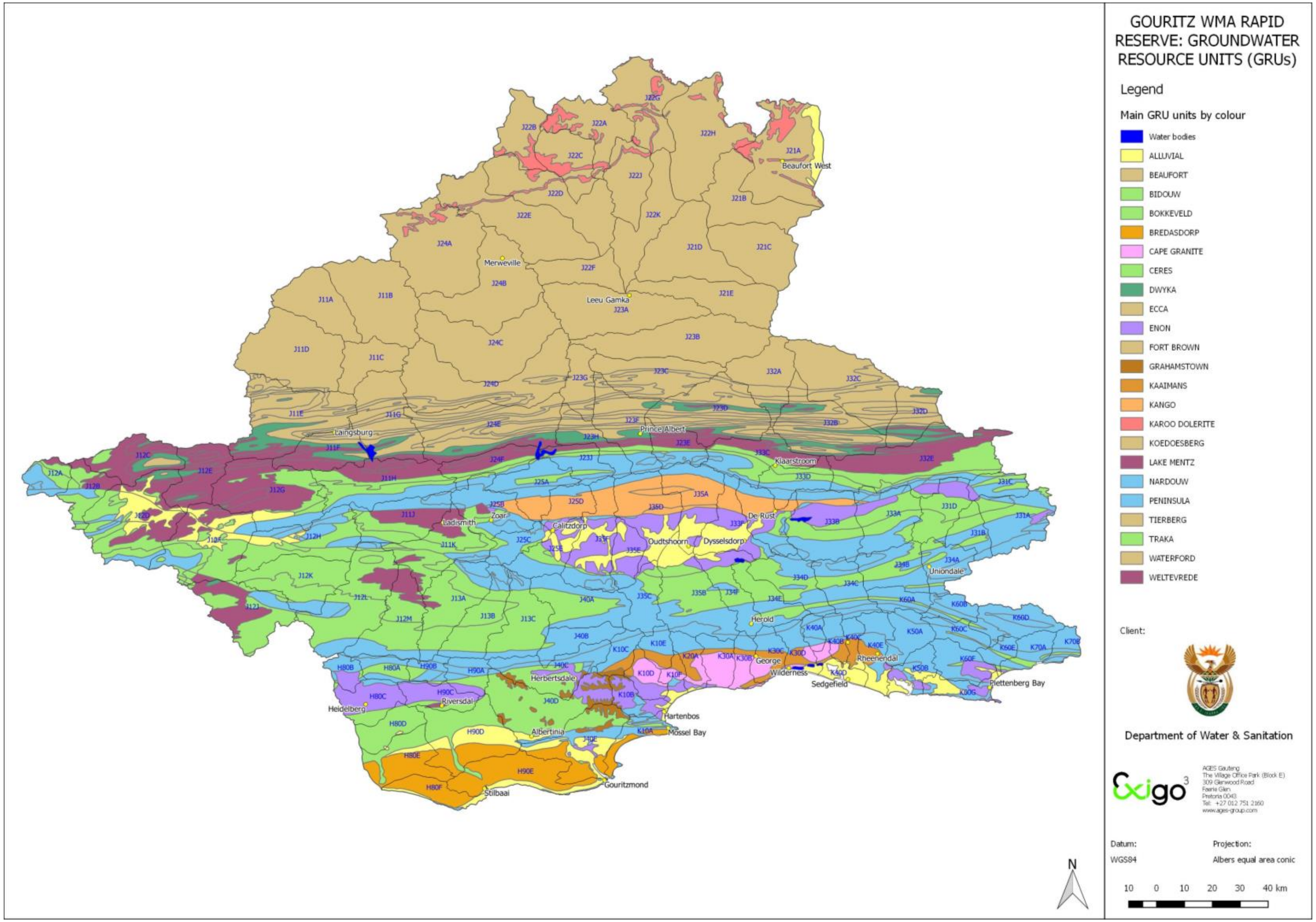


Figure 2.16 GRUs delineated based on geology shown in grouped colours

Table 2.7 Known or expected groundwater hotspots – Public Stakeholder Meeting October 2013

No	Name	Reason for hotspot	Source
1	Waboomskraal area	Intensive agricultural irrigation in the Waboomskraal area (Outeniqua mountain range north of George)	Mike Smart (DWS) - Gouritz Reserve Determination Public Stakeholder Meeting 3 October 2013
2	Western end of Kamanassie range	Groundwater abstraction for Klein Karoo scheme and agriculture	
3	Course of the Olifants River	Groundwater hotspot	
4	Ladismith groundwater abstraction	Groundwater abstraction	
5	Prince Albert groundwater abstraction	Groundwater abstraction	
6	Fracking in Karoo north of Swartberge		Piet Lodder (Agri Klein Karoo) Public Stakeholder Meeting 3 October 2013
7	Peninsula Formation confined aquifer	Confined aquifer and associated semi-unconfined aquifer/ Recharge areas	Exigo, Umvoto, DWS & GEOSS Groundwater specialist meeting: January 2014. Could affect the Waboomskraal unconfined/semi-confined Aquifer in the future.
8	Beaufort West	Historic droughts	Public knowledge
9	Albertinia		Henry Geldenhuys (Eden DM)
10	Swartvlei and flood lines		Henry Geldenhuys (Eden DM)
11	Reserve Determination for non-perennial systems	Select specific systems	Mike Smart (DWS) - Public Stakeholder Meeting 3 October 2013
12	Piesang River	Assess if only surface water issue	Christo Vlok (Plett Ratepayers)
13	Blinde River	Assess if only surface water issue	Benjamin Walton (CapeNature)
14	Keurbooms and Palmiet River systems	Assess if only surface water issue	Christo Vlok (Plett Ratepayers)

Figure 2.17 Example of one of the groundwater hotspots, namely Waboomskraal area which was delineated based on watersheds

Figure 2.17 shows an example of one of the important hotspots, namely the Waboomskraal area, delineated based on watershed GRU boundaries. Intensive hops irrigation takes place here supplied from groundwater abstraction in the unconfined aquifer.

Table 2.8 is compiled from the DWA All Town Strategies project (DWA, 2014c) and from a summary map received from Dr Kornelius Riemann from Umvoto Africa (Riemann, *pers. comm.*, 16 Jan. 2014).

Table 2.8 All Town Reconciliation Strategies: towns with higher risk of surface water or groundwater supply failure (DWA, 2014c)

Number	Town hot spots	Water supply failure risk
1	Laingsburg	High
2	Ladismith	High
3	Calitzdorp	High
4	Oudtshoorn	High
5	De Rust	High
6	Dysselsdorp	High
7	Herold	High
8	Heidelberg	High
9	Karatara	High
10	Kurland	High
11	Beaufort West	Medium
12	Leeu Gamka	Medium
13	Zoar	Medium
14	Riversdal	Medium
15	Albertinia	Medium
16	Melkhoutfontein	Medium
17	Stilbaai	Medium
18	Rheenendal	Medium
19	George	Medium
20	Wilderness	Medium
21	Sedgefield	Medium
22	Plettenberg Bay	Medium
23	Nature's Valley	Medium

Quaternary catchments within the study area from the previous ORDS are not re-evaluated unless it is required for the Peninsula Formation confined aquifer Intermediate Reserve determination.

The final GRUs and quaternary catchments for GRU delineation and Intermediate Reserve determination are graphically illustrated in **Figure 2.18** and selected quaternary catchments are shown in **Table 2.10**.

Water that is abstracted from groundwater resources within the Gouritz WMA is transferred via pipelines to Willowmore where legal action is currently underway regarding this matter. This area must be investigated in more detail to determine the status and groundwater risks.

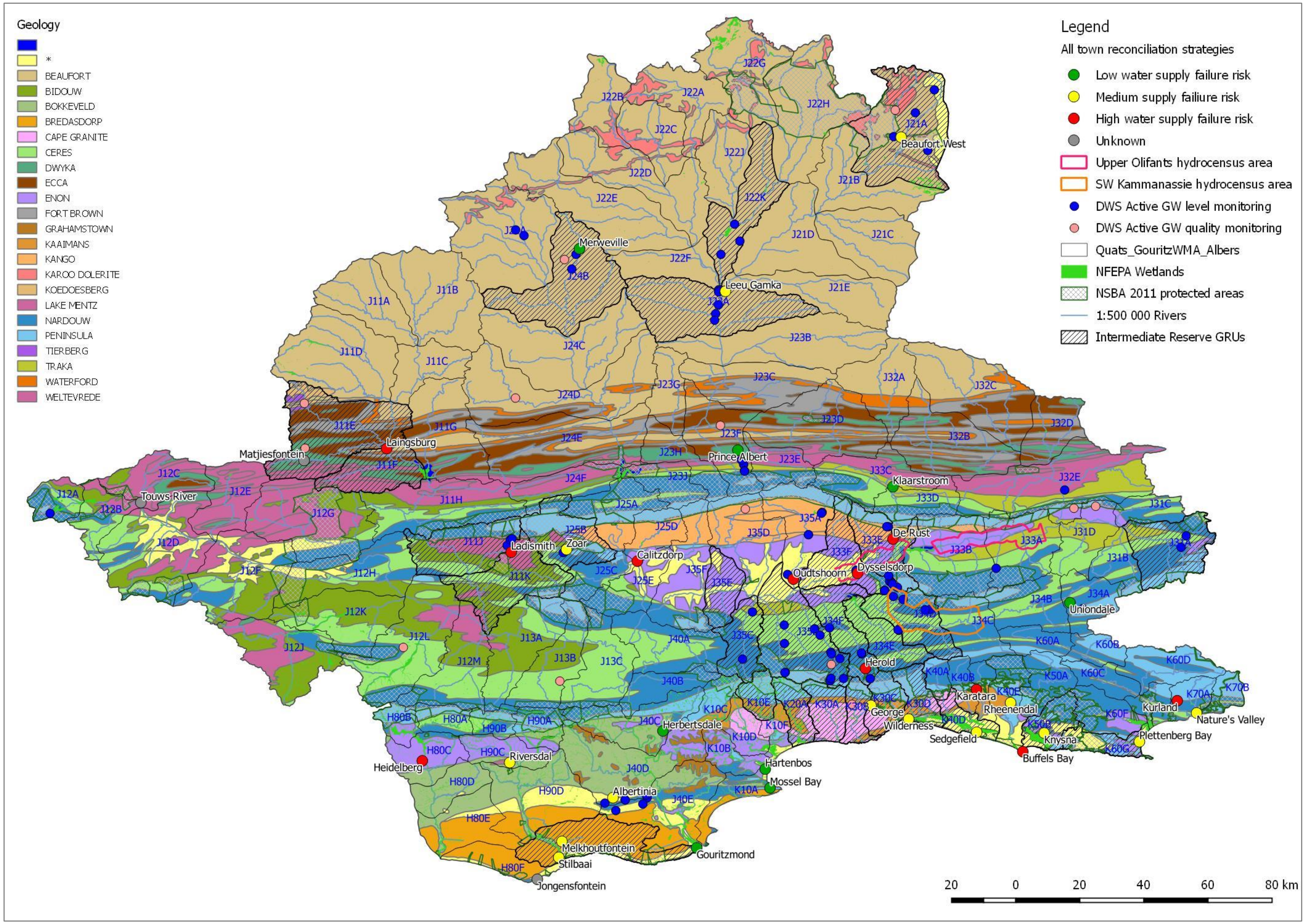


Figure 2.18 Quaternary catchments for GRU delineation with hotspots and areas of interest

Table 2.9 List of WULAs and groundwater hotspots or focus areas

Town /area hot spots or WULAs	Quaternary catchment / GRU
Beaufort West Municipality WULA GW; Sec 21(a); Hansrivier 196 / Steenrotsfontein 168	J21A
Knysna RO plant – according to WULA list GW implication; Section 21 (a) & (f, h) & (e & g)	K50B
Plettenberg Bay Municipality WULA Section 21 (g) groundwater?	K60G
Baviaans Municipality WULA GW section 21 (a); Wanhoop farm	J31A
Dreamworld Investments – WULA GW; Section 21 (a)	J21A
Knysna Municipality town WWTW WULA; Estuary. Section 21 (e, f, g) GW?	K50B
Beaufort West Municipality WULA; section 21 (a); Beaufort West 166	J21A
Oudtshoorn Municipality Blossoms wellfield; Section 21 (c, i)	J35B
Selected	
Dysselsdorp (KKRWSS), Vermaaks River catchment	J33E, J33F, J34D (hydrocensus)
Waboomskraal	J35B
Recharge areas of Peninsula aquifer applicable to DAGEOS confined aquifer	1: 250 000 geology maps; large area
DAGEOS Peninsula confined aquifer; Blossoms wellfield also section 21 (c, i)	J35B,J35C,J34E,J34F,K10E,K20A, K30A,K30B,K30C,K30D - GRU
Ladismith recent groundwater development WULA	J11J, J11K
Zoar – Hoeko valley – information from GEOSS	J25B
Sedgefield – new wellfield development	K40D
Stilbaai-Melkhoutfontein springs situation	H90E
Laingsburg-information from municipality	J11E, J11F
Leeu Gamka – abstraction attrition; look at River catchment (s); check whether groundwater Reserve was done.	J23A, J22K
Complaints of groundwater stress	J24B (Merweville catchment)

The confined aquifer associated with the Peninsula Formation of the TMG (DAGEOS) was also selected as a GRU based on geological boundaries for comparison with the Reserve and balances of the quaternary catchments it underlies. Quaternary catchments that form a major part of the surface water drainage basins above the DAGEOS aquifer were thus also included as GRUs for the Intermediate Reserve Determination. The Peninsula Formation confined aquifer GRU boundary (DAGEOS RU1 and DAGEOS RU2) for the first Peninsula Formation confined aquifer Reserve determination (Riemann and Blake, 2010), will be used in this Intermediate Reserve determination.

Priority GRUs and hotspots were reviewed by the DWS and finalised and the hydrocensus was optimised based on GRUs and DWS actively monitored boreholes.

In addition to the groundwater quantity limitation at Beaufort West, a hydrocarbon fuel spill that occurred (public meeting 2014) still impacts on the water supply from private boreholes in the town. Strict measures must be taken to prevent spillages of hydrocarbon fuel from depots.

Table 2.10 Final selected GRUs within quaternary catchments for Intermediate Reserve

Number	Quaternary catchment
1	H90E
2	J11E
3	J11F
4	J11J
5	J11K
6	J21A
7	J22K
8	J23A
9	J24B
10	J25B
11	J31A
12	J33E
13	J33F
14	J34D
15	J34E
16	J34F
17	J35B
18	J35C
19	J35E
20	K10E
21	K20A
22	K30A
23	K30B
24	K30C
25	K30D
26	K40D
27	K50B
28	K60G
22%	of total (130) catchments

2.4 HYDROCENSUS

2.4.1 Hydrocensus methodology

Due to the large size of the study area and for the purposes of selected groundwater resources, a hydrocensus survey was conducted for the Gouritz WMA. The hydrocensus was informed by the hotspot areas and the outputs of the Desktop-Rapid Reserve level.

The optimisation of the hydrocensus was steered by the aspects as noted in **Section 2.3.3**.

After priority areas for the hydrocensus had been identified the land owners and the regional agricultural council managers were contacted for site access and the agricultural associations such as Agri Klein Karoo received the Basic Information Document (BID) to publish on their websites for land owners.

In visiting the farms identified in priority areas, liaison with land owners took place regarding boreholes and springs on their farms and typical groundwater use as well as possible problems they experience with quantity and quality of the groundwater.

At an early stage during project, a hydrocensus was performed in the Waboomsrkaal area. The DWS Western Cape GZ borehole numbering system had not yet been discussed and the boreholes were simply sequentially numbered with a BH prefix. After a site meeting with DWS Western Cape the GZ numbering system was implemented and the geosites were marked in the field with this numbering system with yellow paint (see **Figure 2.19**). DWS assisted the project groundwater team with the hydrocensus field survey.

Figure 2.19 Photos of selected boreholes and springs visited during hydrocensus

2.4.2 Gouritz hydrocensus results

A total of 97 geosites (boreholes and springs) were surveyed during the optimised hydrocensus in the Waboomskraal, southern Kammanassieberg, western Kammanassieberg and Olifants River areas. Accurate and recent groundwater level data is available for all actively monitored DWA boreholes in their monitoring network as shown in blue markers on the map in **Figure 2.20**.

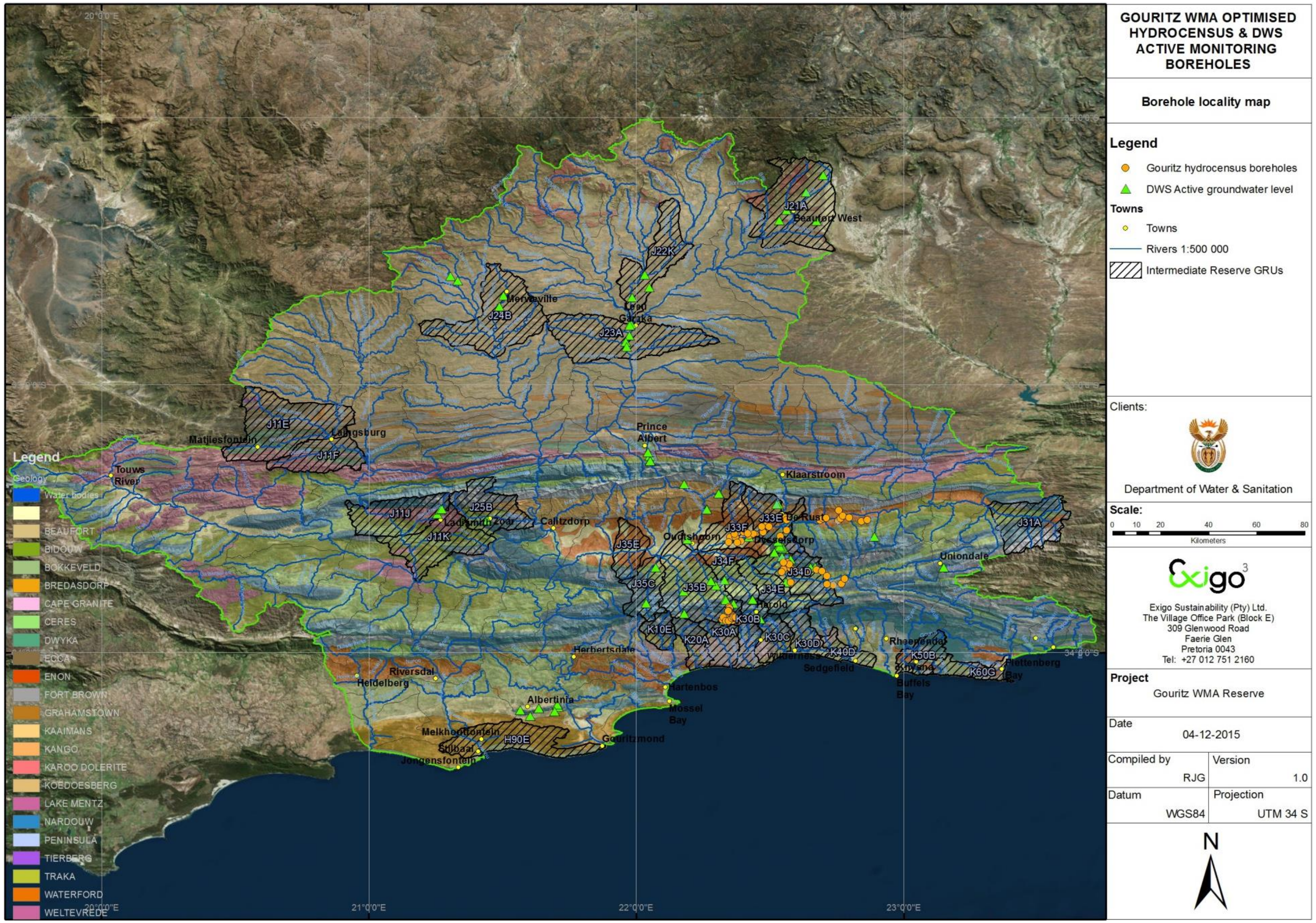


Figure 2.20 Gouritz hydrocensus and DWS actively monitored boreholes

Table 2.11 Gouritz hydrocensus water quality results for selected representative samples

Catchment	Overall Water Quality Class	pH	EC mS/m	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	CO_3 mg/l	HCO_3 mg/l	Cl mg/l	SO_4 mg/l	F mg/l	N mg/l	Fe mg/l	Mn mg/l
BH16	Class 0	7.1	14.5	110.0	1.6	4.3	21.8	0.8	LoD	0.9	38.1	11.2	0.11	0.6	LoD	0.00
BH17	Class 0	6.9	17.1	124.0	1.2	7.2	25.1	1.0	LoD	15.0	38.5	2.3	0.12	3.7	LoD	0.00
BH23	Class 0	7.5	28.7	204.0	4.8	8.7	44.3	2.9	0.1	18.4	78.8	4.2	0.14	0.4	LoD	0.00
BH29	Class 1	6.3	44.2	256.0	6.4	10.3	73.3	2.4	LoD	25.0	122.0	2.8	0.08	1.1	LoD	0.00
GZ00644	Class 0	6.9	10.0	64.0	1.5	1.7	16.2	1.1	LoD	6.9	23.8	1.8	0.08	0.3	LoD	0.00
GZ00646	Class 0	8.0	18.8	122.0	5.5	7.2	16.6	16.4	0.4	50.4	31.1	4.4	0.17	0.3	LoD	0.00
GZ00446	Class 3	8.4	415.0	2274.0	191.0	62.7	682.0	10.3	6.9	272.0	1144.0	424.0	0.50	1.2	LoD	0.00
GZ00655	Class 4	8.6	260.0	2072.0	129.0	147.0	341.0	5.9	16.6	462.0	237.0	872.0	3.96	5.1	LoD	0.00
GZ00663	Class 2	8.3	183.0	1154.0	36.6	42.6	341.0	29.8	2.8	153.0	539.0	140.0	0.31	0.3	LoD	0.00
GZ00666	Class 2	8.6	215.0	1402.0	103.0	80.3	341.0	4.6	16.2	433.0	514.0	111.0	0.32	0.3		
DWA drinking WQ guidelines 1998																
Class 0: Ideal water quality		*5.0<pH<9.5*	*70*	*450*	*80*	*70*	*100*	*25*	*N/A*	*N/A*	*100*	*200*	*0.7*	*6*	*0.5*	*0.1*
Class 1: Good water quality		*5.0>pH>9.5*	*150*	*1000*	*150*	*100*	*200*	*50*			*200*	*400*	*1*	*10*	*1*	*0.4*
Class 2: Marginal water quality		*4.5>pH>10.0*	*370*	*2400*	*300*	*200*	*400*	*100*			*600*	*600*	*1.5*	*20*	*5*	*4*
Class 3: Poor water quality		*4.0>pH>10.5*	*520*	*3400*	*300+*	*400*	*1000*	*500*			*1200*	*1000*	*3.5*	*40*	*10*	*10*
Class 4: Unacceptable water quality		*3.0>pH>11.0*	*520+*	*3400+*		*400+*	*1000+*	*500+*			*1200+*	*1000+*	*3.5+*	*40+*	*10+*	*10+*

LoD - Lower than detection limit

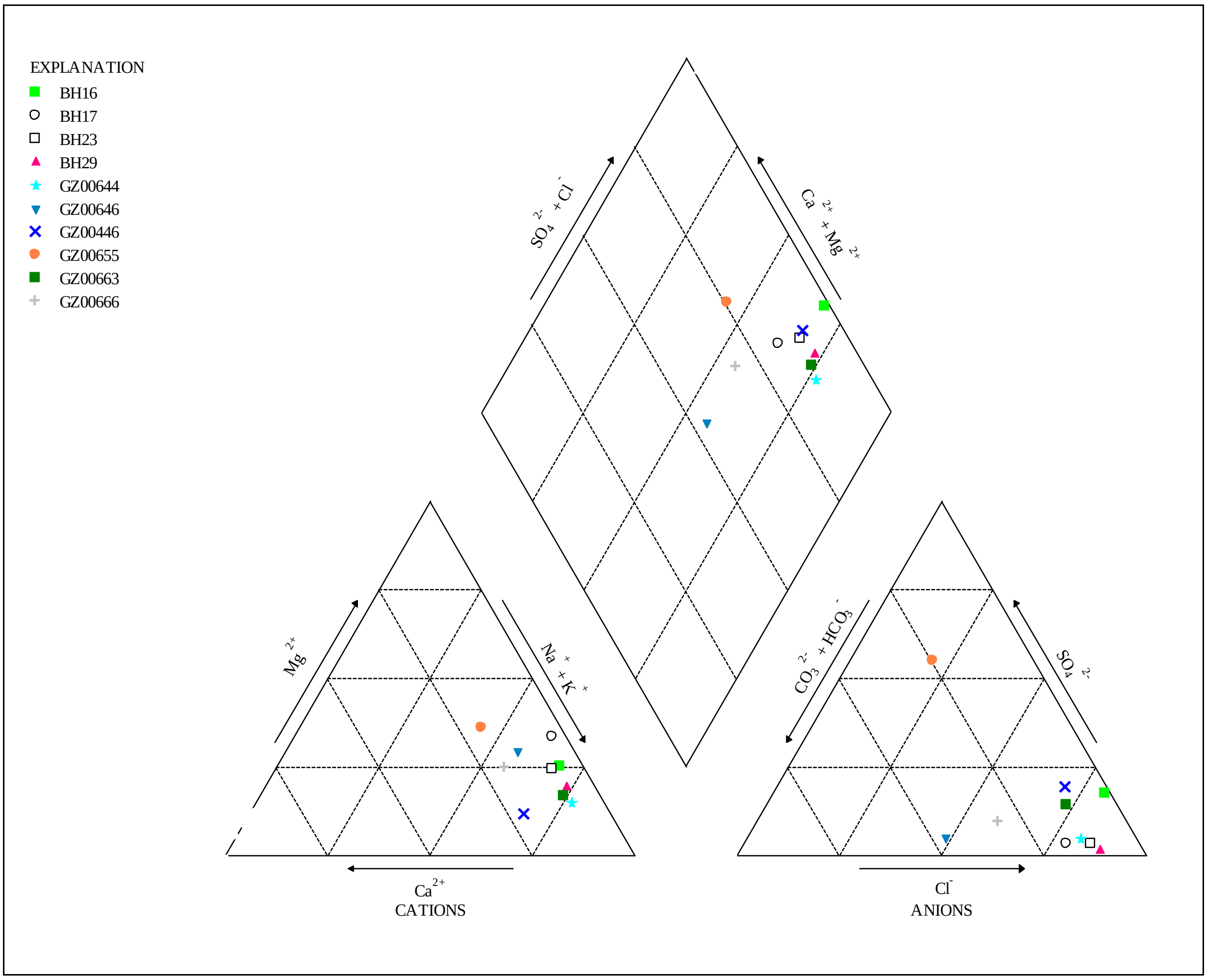


Figure 2.21 Piper trilinear diagram showing water qualities from the Gouritz hydrocensus

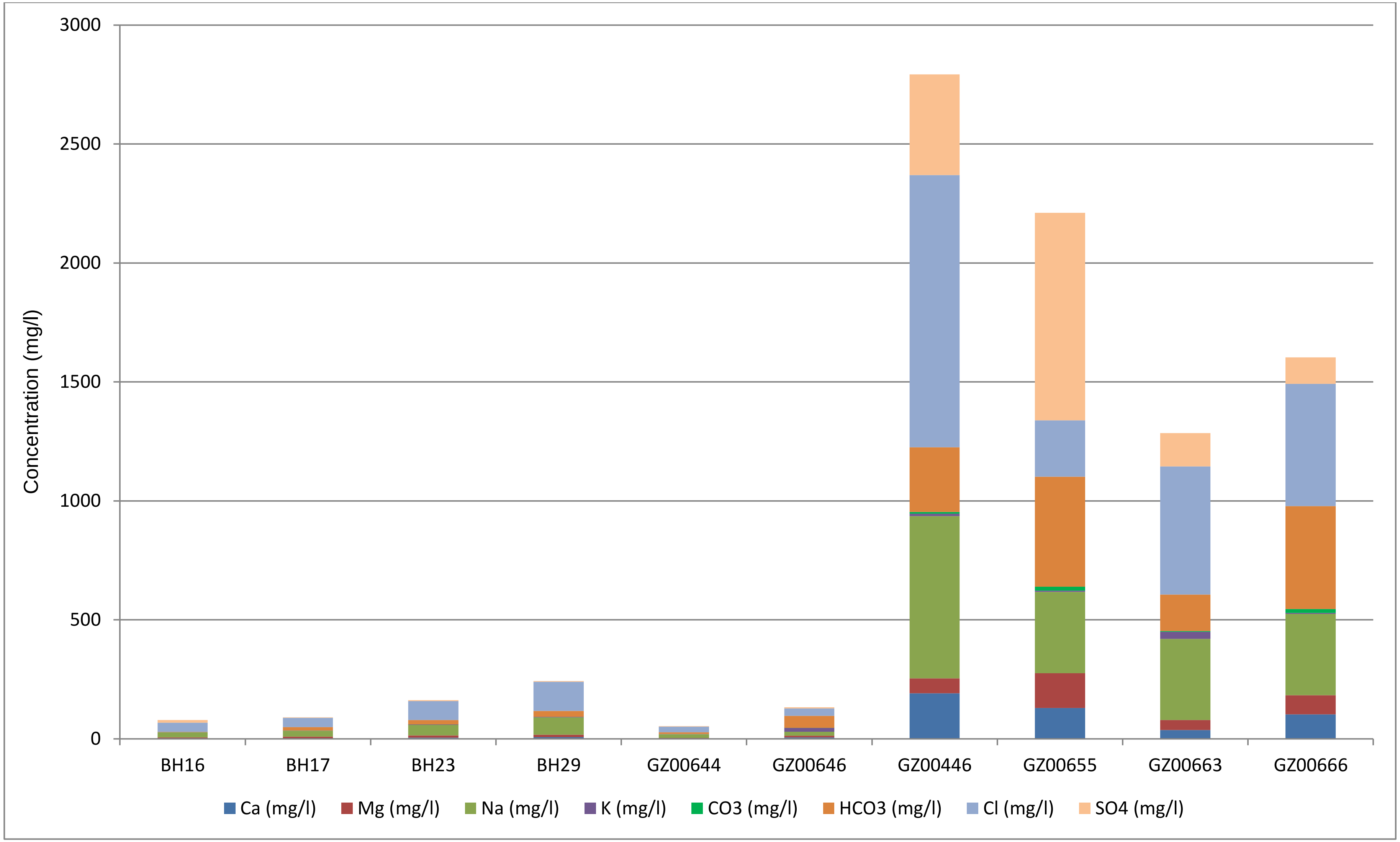


Figure 2.22 Hydrocensus water qualities of the 10 water samples selected

2.4.3 Groundwater levels

A total of 86 groundwater levels were measured during the Gouritz hydrocensus, depending on where they could be accessed. These include spring head levels that are typically at surface level or above it as well as water levels deeper than 100 mbgl. Groundwater levels deeper than 100 m could however not be accurately measured due to the water level measuring instrument (dip meter) only being able to measure up to 100 mbgl. For the dataset, the shallowest (minimum) groundwater level was 0.21 magl (flows out from borehole casing), the deepest water level was 100 mbgl (actual >100 m) and mean groundwater level was calculated to be at 16.32 mbgl. The mean water level calculated for these areas is thus regarded as a slightly shallower groundwater level than in reality due to two boreholes with groundwater levels deeper than 100 mbgl. The two boreholes with groundwater levels deeper than 100 m were included as water levels of 100 mbgl in the statistics. There was also one dry borehole surveyed during the hydrocensus, but not included in the mean groundwater level calculation. Its borehole depth was shallow at 14.35 mbgl.

The area covered by the Gouritz hydrocensus is geohydrologically heterogeneous and can be sub-divided into four different hydrocensus sub-areas. These areas are:

- Waboomskraal catchment and Peninsula Formation direct recharge area.
- Southern Kammanassieberg.
- Western Kammanassieberg.
- Middle- to upper-Olifants River.

For other regions in the study area the DWS monitoring borehole water levels are available or existing studies have covered groundwater levels and groundwater quality. A desktop study was then performed to obtain data on these areas.

2.5 GROUNDWATER QUALITY

Groundwater quality is in most cases dominated by the mineralogical composition of the lithology it flows through and the residence time within each of the lithologically distinct units respectively. Given this groundwater-geology relationship the groundwater quality will be discussed according to the GRUs delineated for the Gouritz WMA in **Table 2.6**.

2.5.1 Alluvial aquifers (GRU 2b) and Bredasdorp Group (GRU 2a)

While alluvial aquifers may have the highest hydraulic conductivity (K) and specific yield (S_Y), their water quality in inland deposits can often be mineralised due to excessive evapotranspiration in a shallow groundwater environment and near drainages where shallow groundwater occurs. Coastal sand deposits can have similar high salinity problems due to the on-shore winds blowing in NaCl loaded mist from the ocean onto the dunes or due to sea water intrusion from excessive abstraction close to the ocean. The opposite can however also occur when dew precipitation during night time driven by seaward winds infiltrates easily into the dune sands and helps to flush out the NaCl precipitated from sea mist. Coastal sands often form good aquifers along the coastal belt and are being used as the primary aquifers in the Sedgefield area. For the H90E Intermediate Reserve GRU catchment, 15 samples were available from the groundwater monitoring investigation by GEOSS

(2013a). The general groundwater type of the coastal aquifers in this is area is a Na-Cl type as well as a Na-HCO_3 type found in a borehole slightly more inland of Stilbaai. The background water quality from a representative monitoring borehole in Stilbaai from the GEOSS (2013a) investigation is provided in **Table 2.12**.

Table 2.12 Groundwater quality for Stilbaai monitoring borehole in H90E quaternary catchment (after GEOSS, 2013a)

Geosite ID	Overall Water Quality Class	pH	EC mS/m	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	CO_3 mg/l	HCO_3 mg/l	Cl mg/l	SO_4 mg/l	Fe mg/l	N mg/l
GZ00167	Class 2	7.8	119.2	723.0	94.9	27.9	135.3	3.8	18.0	317.8	299.6	42.4	0.01	5.5
MA02	Class 1	7.9	90.4	544.0	83.7	19.7	95.7	2.3	21.0	328.5	185.1	27.1	0.00	4.7

The Bredasdorp Group strata consisting of shelly limestone appears to have a groundwater type that weighs more to the Na-HCO_3 side than the Na-Cl side, even close to the coast. This is expected to be due to the more abundant CO_3 present in the rocks as the cementing material.

According to the 1:1 000 000 metallogenic regional geology map large deposits of alluvium are also found in the Oudtshoorn basin.

2.5.2 Grahamstown Formation (GRU 12)

Within selected Intermediate Reserve quaternary catchments, no silcrete and Grahamstown Formation is found in the coastal regions or H90E. There is however scattered smaller accumulations of silcrete found in all inland Intermediate Reserve quaternary catchments, excluding the Great Karoo basin catchments, J21A, J22K, J23A and J24B. The silcrete overlying deep weathering profiles varies in composition. Compositions range from sand grains to pebbles cemented in a hard secondary siliceous matrix to cemented scree deposits (Partridge *et al.*, 2006). Thicknesses vary from centimetres to 2 m and more, but these thicknesses are not enough to justify a good aquifer thickness even if the formation itself would have had better hydraulic conductivity and storage values. The Grahamstown Formation is classified as a poor aquifer in the explanation of the hydrogeological map of Port Elizabeth and understandably so given the rock matrix and lack of fissures. It can rather be classified as an aquitard. No samples could be discerned from investigations for this formation, but they would have little significance as viable resources.

2.5.3 Uitenhage Group, Enon Formation (GRU 8)

The Enon Formation is described as a poor aquifer in terms of hydraulic conductivity, due to its fine grained ground mass in between the larger clasts and pebbles. The Uitenhage Group is confirmed to consist of beds of low permeability rocks by the explanation to the 1:500 000 Hydrogeological Map of Port Elizabeth (Meyer, 1998).

The Enon Formation water quality was however sampled as part of the Gouritz hydrocensus and analysed with the results already presented in **Table 2.11**. Results from the most representative borehole GZ00663 located in the middle of an Enon Formation deposit indicate a dominant Na-Cl groundwater quality type with abundant chloride. The drinking water quality class is Class 2 due to elevated EC, TDS, Na and Cl concentrations.

2.5.4 Karoo Dolerite (GRU 4)

Karoo dolerite is separated from the rest of the Karoo Supergroup formations present in the WMA due to the significantly higher groundwater yields that can be expected from it at contact aureoles that tap the country rock. Karoo dolerite is well studied and for a complete review the reader is referred to Woodford and Chevallier (2002). A problem that in some cases arises from targeting and intersecting large dolerite intrusions at depth is elevated Fluoride (F) in the groundwater, which is expensive to treat except when blending is used. The selected Intermediate Reserve determination quaternary catchment J21A, where Beaufort West is located, is a good example where dolerite is an important aquifer. For the study area no water qualities were available for boreholes drilled directly into dolerite intrusions or contact aureoles, but groundwater qualities from the Beaufort West groundwater Resource development and water use licensing investigations performed by GEOSS (2012a) are from boreholes that have dolerite in close proximity. The water qualities are summarised in **Table 2.13**.

2.5.5 Cape Granite Suite (GRU 6)

Except for the shallow weathered zone, the Cape Granite Suite presents little groundwater potential, due to its dense and unfractured nature at depth. This is mainly because it has intruded in the WMA as massive plutonic rock. No samples or water qualities were available from the Cape Granite Suite. Groundwater qualities in the Cape Granite Suite were however described as having an EC value ranging between 30 and 350 mS/m in the explanation to the 1:500 000 hydrogeological map of Cape Town (Meyer, 2000).

2.5.6 Beaufort & Ecca Groups (GRU 7a)

The area in the Gouritz WMA north of the Swartberge known as the Great Karoo, is almost exclusively underlain by sedimentary rocks of the Beaufort Group of the Karoo Supergroup of rocks. The only exception to the Beaufort Group is the hypabassal dolerite intrusions found in this area. The water quality for the Beaufort Group and and Ecca Group within the Gouritz MWA can be summarised by results from three investigations performed by GEOSS, namely water use licence application and hydrogeological assessment for Laingsburg and Matjiesfontein (GEOSS, 2012b), groundwater sampling at Merweville (GEOSS, 2011) and geohydrological assessments performed at Beaufort West (GEOSS, 2012a). The water quality results are summarised in **Table 2.13**. Results for Laingsburg pertain only to the Ecca Group formations while results for Merweville and Beaufort West pertain only to the Beaufort Group formations.

2.5.7 Dwyka Group (GRU 11)

The Dwyka Group consists predominantly of diamictites formed in a glacial depositional environment. The Dwyka Group strata in most cases show ductile deformation under tectonic stress, thus limiting fracturing and have also in many investigations been shown to have poor groundwater quantity prospects. Due to the fine grained argillaceous groundmass or rock matrix in which the randomly distributed drop stones are set, a poor water quality is also normally asscociated with the Dwyka Group. No water qualities were available within the study area for GRU 11.

2.5.8 Witteberg Group (GRU 9)

The Weltevrede- and Lake Mentz-Subgroups of the Witteberg Group occur within the Gouritz WMA study area. The shale units within the Witteberg Group are associated with poor water quality and targeting the sandstone units with higher groundwater potential also poses the risk of drawing groundwater of poor quality from the shale units (Meyer, 1998).

2.5.9 Bokkeveld Group (GRU 10, GRU 10a and GRU 10b)

The Bokkeveld Group consists of two subgroups within the study area, namely the Ceres Subgroup and the Bidouw/Traka Subgroup. The Bidouw/Traka Subgroup is differentiated as the Bidouw Subgroup west of 21° longitude and the Traka Subgroup east of 21° longitude (Thamm & Johnson, 2006). The Bokkeveld Group has been subdivided into Bokkeveld undifferentiated GRU 10, the Bidouw/Traka Sugroup as GRU 10a and the Ceres Subgroup as GRU 10b, based on available spatial characterisation and due to their different hydrogeological character. The Ceres Subgroup groundwater potential varies widely as does its groundwater quality, while boreholes in the Bidouw/Traka Subgroup seldom yield more than 1 ℓ/s (Meyer, 1998). No direct groundwater qualities could be obtained for GRU 10 during this study.

2.5.10 Table Mountain Group (GRU 1a and GRU 1b)

The TMG within the study area consists of the Peninsula, Pakhuis and Cedarberg Formations as well as the overlying Nardouw Subgroup. The Nardouw Subgroup consists of the Goudini Formation aquitard, Skurweberg Formation aquifer and Baviaanskloof Formation aquitard. Water qualities available for the TMG are summarised in **Table 2.13**. The most prominent groundwater developments in the Gouritz WMA are associated with the TMG formations and GRUs, more notably the quartzitic sandstone of the Peninsula Formation. These developments include the KKRWSS, the DAGEOS and Calitzdorp groundwater supply. Two main types of aquifers are associated with the TMG GRUs:

- An unconfined aquifer associated with the Nardouw Subgroup's shallow weathered and 0 - 300 mbgl fractured rocks as well as the Peninsula Formation where it outcrops. Water quality results from Zoar, Calitzdorp and the KKRWSS represent the unconfined TMG GRU.
- A confined aquifer associated with the Peninsula Formation and the DAGEOS groundwater exploration and development.

Sources of the data:

- Zoar and Calitzdorp from - GEOSS (2013b; 2014a).
- KKRWSS from Smith (2006), data received from DWS (2014) and GEOSS (2014b).
- DAGEOS confined aquifer – Data received from Umvoto Africa (2014).

2.5.11 Cango Caves Group (GRU 3)

The Cango Caves Group is exposed to the north of the Oudtshoorn quaternary sediments basin. The Cango Caves rocks that outcrop are the direct result of the Cango fault and a throw of more than 7000 m is estimated (Smith, 2006). Sixty-four percent of boreholes drilled into this Group of formations yield < 2 ℓ/s and 16% yield > 5 ℓ/s (Meyer, 1998). The groundwater is generally of a Na-Cl type and groundwater qualities fall within the EC range of 100 - 300 mS/m (Meyer, 1998).

2.5.12 Kaaimans Group (GRU 5)

The Kaaimans Group only outcrops in the southern part of the Gouritz WMA along the west-east orientation of the Outeniqua mountain range and directly to the south of it (**Figure 2.15**). The west-east extent of the outcrop is approximately from Mossel Bay to Knysna. The Kaaimans Group shows evidence of a complex tectonic and metamorphic history and consists of sedimentary rocks of various metamorphic grades as well as multi-phase granitic intrusions (Gresse *et al.*, 2006). Due to the largely argilleaceous nature of the Kaaimans Group as well as the metamorphism and associated phillites, groundwater yield and groundwater quality associated these metamorphosed shales is limited. The Kaaimans Group on the southern side of the Outeniqua mountains create a boundary-embankment effect on its contact with the TMG, due to lower hydraulic conductivity. At the Kaaimans-TMG contact a number of cold springs are formed and issue from the Peninsula Formation, once again proof of the lower groundwater potential of the Kaaimans Group compared to the Peninsula Formation. No groundwater qualities were found for the Kaaimans Group during this phase of the study.

There were no groundwater qualities available from the NGA dataset. Only pH, EC and TDS field measurements were available from the DWA actively monitored boreholes. The Gouritz hydrocensus water quality results were thus the most representative water qualities on which to base interpretations as well as existing studies where available.

Table 2.13 Groundwater quality data obtained from existing studies for various GRUs in the Gouritz WMA

Quaternary catchment	Location	Geosite ID	Overall Water quality Class	pH	EC (mS/m)	TDS (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	CO_3 (mg/l)	HCO_3 (mg/l)	Cl (mg/l)	SO_4 (mg/l)	Fe (mg/l)
Stilbaai	H90E	GZ00167	Class 2	7.8	119.2	723.0	94.9	27.9	135.3	3.8	18.0	317.8	299.6	42.4	0.01
Stilbaai	H90E	MA02	Class 1	7.9	90.4	544.0	83.7	19.7	95.7	2.3	21.0	328.5	185.1	27.1	0.00
Laingsburg	J11E	LB_BH3	Class 2	7.4	200.0	0.0	112.9	62.3	385.8	16.4	0.0	708.9	409.7	346.0	0.00
Laingsburg	J11E	LB_BH4	Class 2	7.3	244.0	0.0	101.0	60.2	371.1	2.7	0.0	799.2	445.0	330.0	0.00
Merweville	J24B	ME2	Class 1	7.2	76.3	644.0	100.7	15.6	87.4	3.7	12.1	364.4	100.7	65.8	0.01
Merweville	J24B	ME3	Class 1	7.2	77.5	579.0	82.6	14.9	84.7	3.2	9.0	372.6	74.2	52.0	0.02
Beaufort West	J21A	Flagship BH	Class 2	7.6	170.0	1088.0	118.0	39.0	198.0	0.0	0.0	316.0	195.0	195.0	0.01
Beaufort West	J21A	HR15	Class 3	7.2	305.0	1952.0	320.0	79.0	203.0	9.5	0.0	277.0	605.0	399.0	0.00
Beaufort West	J21A	HR16	Class 3	7.2	302.0	1933.0	321.0	79.0	204.0	6.3	0.0	272.0	619.0	409.0	0.00
Beaufort West	J21A	SR9	Class 2	8.0	284.0	2130.0	148.4	59.3	345.3	2.8	18.1	425.7	370.1	368.4	0.03
Zoar	J25B	ZBH4	Class 2	5.7	5.0	32.0	4.8	2.5	3.4	1.0	0.0	18.3	13.6	6.0	3.23
Calitzdorp	J25D	GCS well	Class 2	6.3	38.0	243.0	11.0	8.0	38.0	9.0	0.0	31.0	68.0	31.0	4.30
KKRWSS west	J25E	KG1	Class 4	5.9	31.8	0.0	15.6	9.0	36.3	10.7	0.0	31.0	85.7	38.8	18.40
KKRWSS west	J25E	DL15	Class 2	7.2	44.5	0.0	12.0	10.0	37.0	14.2	0.0	89.9	90.0	20.0	3.41
KKRWSS east	J33E	J3N0014	Class 0	5.1	9.0	54.0	1.3	1.6	10.0	0.6	0.0	3.0	19.0	2.8	0.10
KKRWSS east	J33E	VR6	Class 0	5.1	8.0	52.0	1.7	1.5	13.0	0.4	0.0	4.3	22.0	2.2	0.10
DAGEOS	J35B etc.	C1b1 (Skwbg)	Class 2	8.0	23.0	0.0	19.5	1.3	16.8	7.2	0.0	0.0	14.3	7.0	1.62
DAGEOS	J35B	C1b3 (Ope)	Class 0	8.2	22.8	0.0	20.1	3.8	9.2	12.8	0.0	0.0	11.2	16.0	0.21
DWA drinking WQ guidelines 1998															
Class 0: Ideal water quality				*5.0<pH<9.5*	*70*	*450*	*80*	*70*	*100*	*25*	*N/A*	*N/A*	*100*	*200*	*0.5*
Class 1: Good water quality				*5.0>pH>9.5*	*150*	*1000*	*150*	*100*	*200*	*50*			*200*	*400*	*1*
Class 2: Marginal water quality				*4.5>pH>10.0*	*370*	*2400*	*300*	*200*	*400*	*100*			*600*	*600*	*5*
Class 3: Poor water quality				*4.0>pH>10.5*	*520*	*3400*	*300+*	*400*	*1000*	*500*			*1200*	*1000*	*10*
Class 4: Unacceptable water quality				*3.0>pH>11.0*	*520+*	*3400+*		*400+*	*1000+*	*500+*			*1200+*	*1000+*	*10+*

2.6 GROUNDWATER-SURFACE WATER INTERACTION

2.6.1 Springs

Numerous springs are located within the Gouritz WMA and are in most cases associated with the TMG rocks, their contacts with other geology units as well as fault structures. Two major types of spring systems are recognised in the study area, namely cold springs associated with shallow surface aquifers and hot (thermal) spring systems associated with deep circulating groundwater (see **Sections 2.2.6** and **2.2.7**).

2.6.2 Groundwater baseflow to rivers

Springs and the groundwater component of baseflow are not unrelated in a number of the rivers in the Gouritz WMA. Many of the cold spring systems on the Outeniqua Mountains form the sources of perennial rivers flowing south from the mountains.

The groundwater contribution to baseflow was evaluated in the Gouritz WMA preliminary Intermediate Reserve determination using a combination of stochastic modelling and time series rainfall modelling. The baseflow evaluation was updated once the EWR study determined baseflow values during the preliminary Reserve determination (**Sections 2.7.16** to **2.7.17**).

2.7 INTERMEDIATE RESERVE DETERMINATION RESULTS

The Desktop-Rapid level groundwater Reserve iteration indicated that 28 of the 130 quaternary catchments are potentially stressed. In the Intermediate level Reserve, these 28 catchments are modelled in more detail to take account of storage and transient variability in rainfall.

2.7.1 Groundwater recharge and rainfall

The percentage of recharge to groundwater from rainfall is one of the most important parameters in the calculation of a groundwater balance. Given the total volumes of water that fall annually within a quaternary catchment, this parameter is highly sensitive in the groundwater balance and it is important to calculate and define it as best possible.

For this study no groundwater qualities were available from the NGA database, where normally at least a few boreholes with water qualities are available to apply the Chloride Mass Balance (CMB) method in areas of interest. Numerous previous studies and research reports (Jia, 2007; Xu *et al.*, 2009; DWAF, 2006) are however available and these recharge values were collected for geology GRUs within the study area and applied in the GYMR. Conservative assumptions of recharge based on lithology were made where recharge was unavailable for a specific formation. Recharge was applied in the GYMR model by:

- First determining a recharge percentage of rainfall for each type of geology within the study area (see **Table 2.14**; **Table 2.15** provides values for specific yield and storativity used later in calculations of groundwater in storage estimates).
- Calculating the area of each geology type per selected quaternary catchment.

- Deciding on a recharge figure per GRU group of geology formations. Allowance was made for up to 10 different sub-hydrogeology zones in each quaternary catchment; and
- Applying recharge per GRU area and then calculating the cumulative recharge volumes of all GRUs per quaternary catchment.

Rainfall data was obtained from the WR2005 dataset (Middleton and Bailey, 2008; 2011) and were statistically analysed to calculate the 98% assurance of supply rainfall. This was done in order to account for drought cycles in scenarios in the GYMR. Based on the 98% assurance level, rainfall (mm) ranging between 38 mm/a, to 635 mm/a was calculated for selected Intermediate Reserve GRUs. Some of the catchments in the inland Great Karoo basin, notably J23A, will have no groundwater recharge during a drought cycle. For the same rainfall data and GRUs, the MAP level of assurance (P_{50}) for the rainfall ranges between 127 and 882 mm/a. **Figure 2.23** and **Figure 2.24** show examples of monthly rainfall and statistics for one of the driest catchments in the Gouritz WMA and one of the wettest catchments in the Gouritz WMA for comparison.

Table 2.14 Table of recharge values according to geology and GRU grouping used in GYMR Reserve calculations

Main Unit	Aquifer type	Unit in map	Recharge % of rainfall	Lithology	GRU	Comments
Alluvium	Major	Alluvium	5.0%	Coastal sands, quaternary sediments	GRU2b	The updated regional scale geology map show s larger areas of porous/ intergranular aquifers, but thickness is unknow n and critical to sustainability
Bredasdorp Group	Major	Bredasdorp	5.0%	Conglomerate, shelly limestones, calcarenites and calcrete	GRU2a	Essentially regarded as coastal aquifers
Grahamstow n Fm	Poor	Silcrete	2.0%	Silcrete-sand grains to pebbles cemented in a hard secondary siliceous matrix	GRU11	Poor aquifer
Uitenhage Group	Poor	Enon Fm/ Kirkw ood Fm	2.0%	Conglomerate, sandstone and siltstone	GRU8	Poor aquifer
Karoo dolerite	Major/ Sole source	Karoo dolerite (Jd)	3.3%	Hypabyssal dolerite, igneous rock	GRU4	Dolerite and contact zones major groundw ater targets in the Karoo
Cape Granite suite	Poor	Cape Granite Suite	3.0%	Plutonic igneous rock	GRU6	
Beaufort Group	Minor/ Sole source	Beaufort undifferentiated	2.5%	Siltstone, mudstone and sandstone	GRU7a	Karoo Sedimentary rocks w ith approximately similar groundw ater characteristics
Ecca Group	Minor/ Sole source	Ecca Group	3.0%	Shale, mudstone and minor sandstone		
	Poor	Tierberg Fm	3.0%	Predominantly argillaceous w ell-laminated dark grey to black shale		
	Minor/ Sole source	Waterford (previously Koedoesberg Fm)	3.0%	Arenaceous very fine-grained lithofeldspathic sandstone and mudrock		
	Minor	Fort Brow n Fm	3.0%	Rythmite and mudrock, minor sandstone intercalations		
	Minor/ Sole source	Koedoesberg Fm	3.0%	Fine- to medium-grained sandstone, siltstone, shale, rhytmite		
Dw yka Group	Poor	Dw yka Group	2.0%	Diamictite	GRU11	Poor groundw ater prospects; aquitard; ductile deformation
Witteberg Group	Poor	Lake Mentz Subgroup	3.0%	Quartzites, mudrock and siltstone	GRU9	According to explanation abstract of 1:500 000 Port Elizabeth geohydrological map, poor aquifers in terms of quality
	Minor	Witpoort	3.0%	Sandstone		
	Poor	Weltevrede Subgroup	3.0%	Siltstone, shale and sandstone		
Bokkeveld Group	Poor	Bokkeveld undifferentiated	2.5%	Feldspathic sandstone, shale and siltstone	GRU10	Generally poor aquifers due to abundant fine grained rock matrix
	Poor	Bidouw /Traka Subgroup	2.5%	Shale, siltstone and sandstone	GRU10a	
	Minor	Ceres Subgroup	3.5%	Feldspathic sandstone, mudrock and siltstone	GRU10b	Borehole yields vary w idely
Table Mountain Group	Minor	Nardouw Subgoup	2.5%	Feldspathic sandstone and siltstone, fractured quartzite, sandstone, siltstone and shale, tillite	GRU1b	Containing 1 aquifer unit, i.e Skurw eberg Fm (400m) and tw o aquitards; the Baviaanskloof Fm (200m) and thicker Goudini Fm (300m)
	Major	Skurw eberg Formation	3.5%	Thick bedded sandstone	GRU1c	Skurw eberg Fm (400m) aquifer
	Major	Peninsula Formation	5.0%	Fractured quartzite	GRU1a	The major aquifer unit in the WMA
Schoemanspoort Fm	Minor	Schoemanspoort Fm	4.0%	Conglomerate	GRU3	Conglomerate and sandstone
Cango Caves Group	Minor	Cango Caves	4.0%	Metasediments		Low - to medium-grade metamorphosed sedimentary rocks
Kansa Group	Minor	Kansa	4.0%	Coarse-grained clastic succession		Coarse clastic succession
Kaaimans Group	Poor	Kaaimans	2.0%	Low grade metasediments	GRU5	Metamorphosed sedimentary rock

Table 2.15 Table of specific yield and storativity values according to geology as used in GYMR Reserve calculations

Main Unit	Aquifer type	Unit in map	Specific Yield (S_Y) Weathered Zone GRA II *	Storativity (S) Fractured Zone GRA II *	Lithology	GRU	Comments
Alluvium	Major	Alluvium	5.0E-02	8.0E-03	Coastal sands, quaternary sediments	GRU2b	The updated regional scale geology map shows larger areas of porous/ intergranular aquifers, but thickness is unknown and critical to sustainability
Bredasdorp Group	Major	Bredasdorp	5.0E-02	8.0E-03	Conglomerate, shelly limestones, calcarenites and calcrete	GRU2a	Essentially regarded as coastal aquifers
Grahamstown Fm	Poor	Silcrete	5.0E-03	1.0E-03	Silcrete	GRU11	Poor aquifer
Uitenhage Group	Poor	Enon Fm/ Kirkwood Fm	5.0E-03	1.0E-03	Conglomerate, sandstone and siltstone	GRU8	Poor aquifer
Karoo dolerite	Major/ Sole source	Karoo dolerite (Jd)	1.0E-03	1.0E-04	Hypabyssal dolerite, igneous rock	GRU4	Dolerite and contact zones major groundwater targets in the Karoo
Cape Granite suite	Poor	Cape Granite Suite	7.0E-05	7.0E-06	Plutonic igneous rock	GRU6	
Beaufort Group	Minor/ Sole source	Beaufort undifferentiated	5.0E-03	2.0E-03	Siltstone, mudstone and sandstone	GRU7a	Karoo Sedimentary rocks with approximately similar groundwater characteristics
Ecca Group	Minor/ Sole source	Ecca Group	1.0E-03	1.0E-03	Shale, mudstone and minor sandstone		
	Poor	Tierberg Fm	1.0E-03	1.0E-03	Predominantly argillaceous well-laminated dark grey to black shale		
	Minor/ Sole source	Waterford (previously Koedoesberg Fm)	1.0E-03	1.0E-03	Arenaceous very fine-grained lithofeldspathic sandstone and mudrock		
	Minor	Fort Brown Fm	1.0E-03	1.0E-04	Rythmite and mudrock, minor sandstone intercalations		
	Minor/ Sole source	Koedoesberg Fm	1.0E-03	1.0E-03	Fine- to medium-grained sandstone, siltstone, shale, rhytmite		
Dwyka Group	Poor	Dwyka Group	1.0E-04	1.0E-04	Diamictite	GRU11	Poor groundwater prospects; aquitard; ductile deformation
Witteberg Group	Poor	Lake Mentz Subgroup	1.0E-03	1.0E-04	Quartzites, mudrock and siltstone	GRU9	According to explanation abstract of 1:500 000 Port Elizabeth geohydrological map, poor aquifers in terms of quality
	Minor	Witpoort Formation	1.0E-03	1.0E-04			
	Poor	Weltevrede Subgroup	1.0E-03	1.0E-04	Siltstone, shale and sandstone		
Bokkeveld Group	Poor	Bokkeveld undifferentiated	3.5E-04	7.0E-05	Feldspathic sandstone, shale and siltstone	GRU10	Generally poor aquifers due to abundant fine grained rock matrix
	Poor	Bidouw/Traka Subgroup	7.0E-05	7.0E-06	Shale, siltstone and sandstone	GRU10a	
	Minor	Ceres Subgroup	3.5E-04	7.0E-05	Feldspathic sandstone, mudrock and siltstone	GRU10b	Borehole yields vary widely
Table Mountain Group	Minor	Nardouw Subgoup	3.5E-04	7.0E-05	Feldspathic sandstone and siltstone, fractured quartzite, sandstone, siltstone and shale, tillite	GRU1b	Containing 1 aquifer unit, i.e Skurweberg Fm (400m) and two aquitards; the Baviaanskloof Fm (200m) and thicker Goudini Fm (300m)
	Major	Skurweberg Formation	5.0E-04	1.0E-04	Feldspathic sandstone	GRU1c	Skurweberg Fm (400m) aquifer
	Major	Peninsula Formation	5.0E-04	1.0E-04	Fractured quartzite	GRU1a	The major aquifer unit in the WMA
Schoemanspoort Fm	Minor	Schoemanspoort Fm	5.0E-03	1.0E-03	Conglomerate	GRU3	Conglomerate and sandstone
Cango Caves Group	Minor	Kango	1.0E-02	5.0E-03	Metasediments		Low- to medium-grade metamorphosed sedimentary rocks
Kansa Group	Minor	Kansa	1.0E-02	5.0E-03	Coarse-grained clastic succession		Coarse clastic succession
Kaaimans Group	Poor	Kaaimans	1.0E-03	1.0E-03	Low grade metasediments	GRU5	Metamorphosed sedimentary rock

* Specific yield and storativity were applied to Weathered Zone and Fractured Zone respectively from GRA II (DWAF, 2006) to calculate static groundwater volume in storage

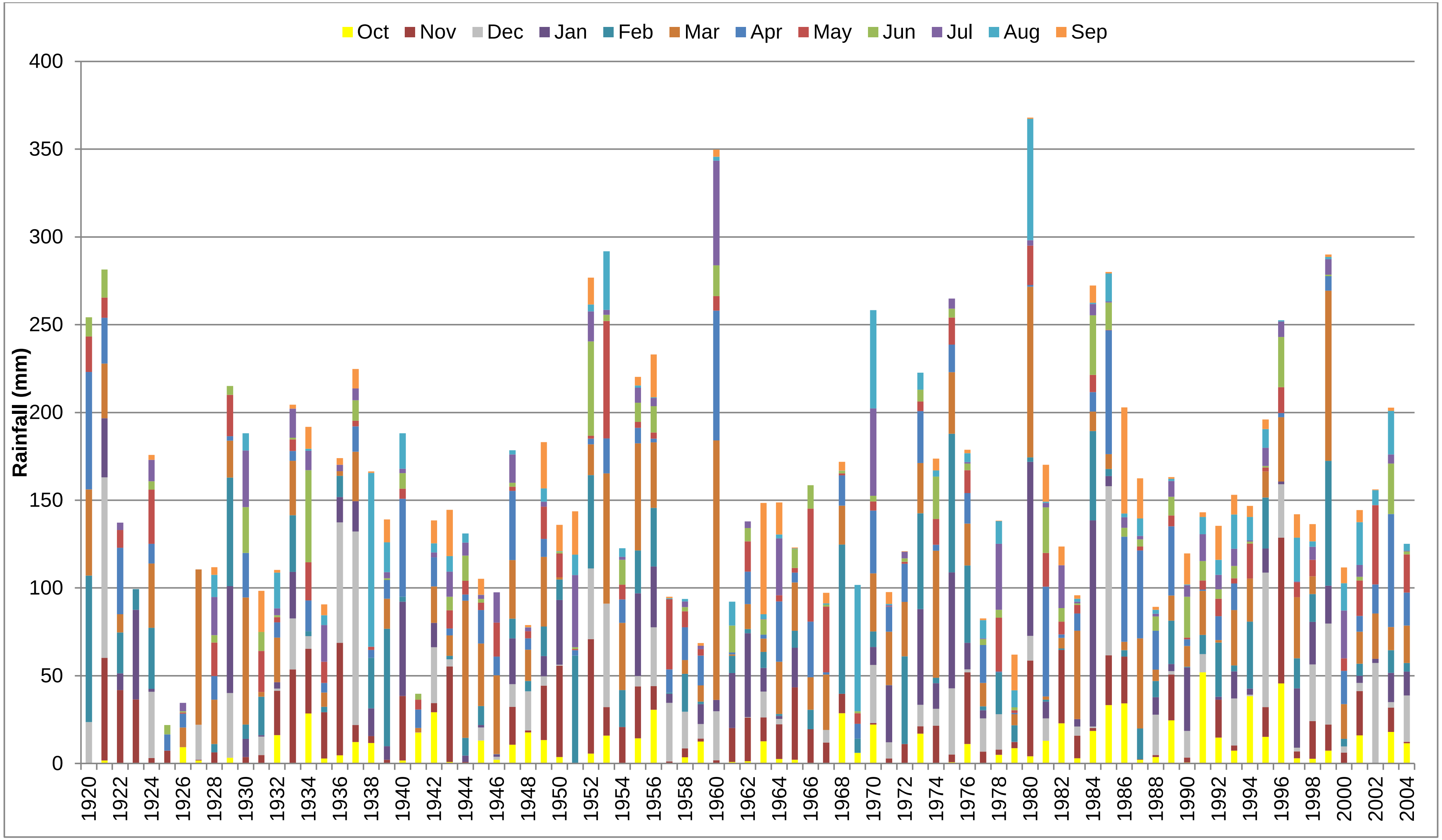


Figure 2.23 Monthly rainfall for the J24B (MAP 160mm/a), one of the lowest rainfall selected Intermediate Reserve catchments

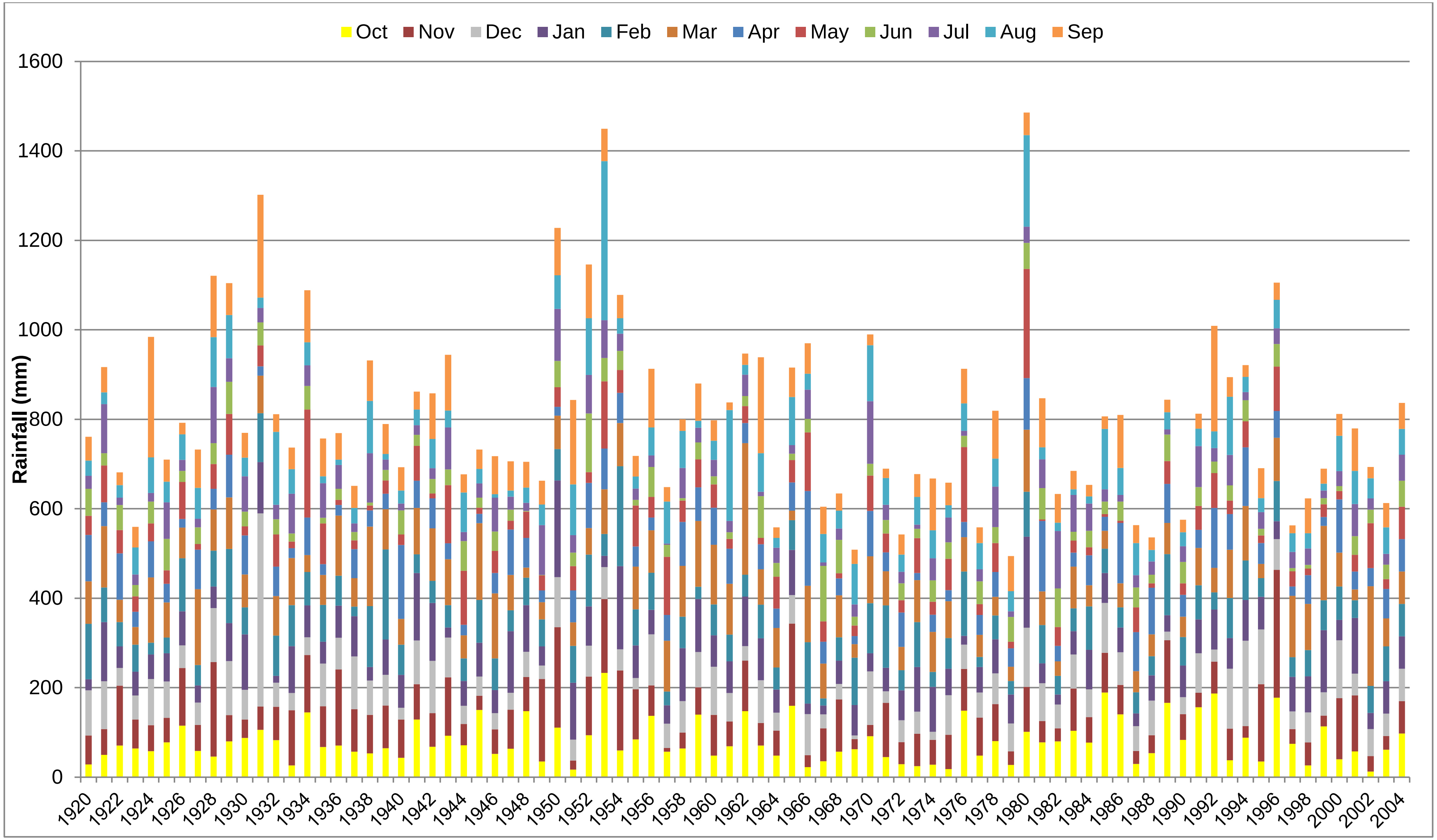


Figure 2.24 Monthly rainfall for the K30C (MAP 805mm/a), one of the highest rainfall selected Intermediate Reserve catchments

2.7.1.1 Assurance levels

The rainfall values in the section above show the deviation between the lower 98th percentile (lower P_{98} or 2nd percentile) and the MAP for the selected GRU Intermediate Reserve quaternary catchments. The MAP (P_{50}) does not account for dry periods and is markedly higher than the P_{98} assured rainfall. The lower P_{98} would correspond to 1:50 year drought conditions.

The more constant the rainfall, the closer the lower P_{98} is to the MAP. A negligible difference (small difference between MAP and lower P_{98}) would have been an ideal rainfall-recharge scenario in terms of aquifer sustainability. The lower P_{98} for all selected GRUs for instance is 283 mm/a, which is 39% less than the average MAP of 463 mm/a, where the lower P_{95} in Karoo regions of the country can be in the order of 50% lower than the MAP.

2.7.2 Borehole yields and groundwater levels

2.7.2.1 Existing borehole information

There are a large number of NGA boreholes identified for the Gouritz WMA (6510), but in the databases some boreholes date back to for example 1965. There are questions on the accuracy of these coordinates due to Cape/WGS84 coordinate conversions and it is noted that some of these coordinates were estimated from the 1:50 000 topo map. None the less these boreholes were clipped for the selected quaternary catchments / GRUs as well as the DAGEOS RUs. Different datasets show different data availabilities, for example the number of NGA boreholes with hydraulic heads (n = 1580) is different from the number of boreholes indicating the type of equipment installed (n = 857). Very good hydraulic head information is available from the DWS actively monitored boreholes (n = 64) in the Gouritz WMA, and a good spatial distribution is available (see **Figure 2.20**).

2.7.2.2 Hydraulic heads (groundwater levels)

Groundwater levels were compared between the NGA dataset, DWS actively monitored boreholes dataset, Gouritz hydrocensus dataset and GRA II raster dataset. The NGA water levels were seen to compare well with the other datasets and since there are many more observed water levels in the NGA dataset per GRU, it was used in the GYMR. According to the NGA water levels the shallowest groundwater level is encountered in J21A catchment at 9.7 mbgl, the deepest groundwater level in K60G at 68.1 mbgl and the mean water level for the selected GRUs is 23.9 mbgl. The mean water levels were further used to calculate groundwater volumes in storage per quaternary catchment (see **Table 2.16**).

2.7.3 Dam seepage

As a contributing source of groundwater in the Gouritz WMA, dam seepage from earthen farm dams was brought into consideration by calculating the area of farm dams per quaternary catchment and calculating from that a seepage volume per annum. The WR2005 dataset was used to obtain farm dam area information (Middleton and Bailey, 2008; 2011). The leakage coefficient was calculated on hydraulic conductivity value of fine silt 0.001 metres per day (m/d).

2.7.4 General Authorisations

General authorisations (GAs) have been declared for each quaternary catchment in South Africa and are provided as a volume/hectare per annum. The volumes that would result from GA allocations per quaternary catchment for the 28 quaternary catchments in the Gouritz WMA were calculated. Scenarios where the GAs are taken into account were however not shown since it will be demonstrated that a groundwater balance deficit results for most of the 28 Intermediate Reserve GRUs/quaternary catchments evaluated when the EWRs and losses are taken into account. It is evident that the GA's in these catchments should perhaps be reviewed and reduced from a groundwater perspective.

2.7.5 WARMS registered groundwater volumes

Water Authorisation and Management System (WARMS) registered groundwater abstraction volumes were obtained from the DWA Western Cape office for incorporation in the GYMR. All WARMS volumes were incorporated for their applicable quaternary catchments. A total of 83 registered springs and 413 registered borehole volumes were incorporated. **Table 2.17** provides the groundwater discharge data from WARMS per Intermediate Reserve quaternary catchment.

2.7.6 Existing borehole abstraction

Existing borehole abstraction was incorporated by using the NGA database and assigning yields to boreholes based on pump equipment types. An algorithm that assigns these values for large datasets was written in Excel VBA. Furthermore NGA abstraction boreholes that were located close to WARMS registered boreholes or springs were omitted from the calculation since this could probably be the same source. A recommendation is made that NGA / GZ borehole numbers be determined and assigned for WARMS registered boreholes and springs.

It is very difficult to estimate abstraction rates as these are not readily available or measured. The approach that was followed, was to obtain all the WARMS and NGA (NGDB) data and assign rates for existing borehole based on installed equipment and typical farming schedules. It is expected that the volume of 140 million m^3/a, is a maximum as other comparable volumes from DWS (2013) and GRA II is in the order of 64 million m^3/a. In line with the conservative approach on Desktop-Rapid level, the maximum was assumed.

2.7.7 Deep Groundwater Blossoms wellfield

As a separate scenario for strategic future developments, the Blossoms wellfield and estimated yield was taken into consideration for the DAGEOS unconfined and confined GRUs. The GRU boundaries were digitized from DAGEOS wellfield Reserve determination approach. Apart from the pristine scenario, an abstraction rate of 120 ℓ/s was used to evaluate the sustainability of the resource (Hartnady *et al.*, 2014).

Table 2.16 Table with groundwater levels and calculated groundwater volume in storage

No	Quaternary catchment	Total Surface Area (km^2)	Depth to water level NGA (mbgl)	Min depth to water level NGA (mbgl)	Aquifer thickness Weathered Zone GRAII (m)	Aquifer thickness Fractured Zone GRAII (m)	Base of Fractured Zone (mbgl)	Water level management constraint Weathered Zone (mbgl)	Water level management constraint Fractured Zone (mbgl)	Usable groundwater volume in storage Weathered Zone (million m^3)	Usable groundwater volume in storage Fractured Zone (million m^3)	Max usable groundwater volume in storage WZ+FZ (million m^3)
1	H90E	498.4	-45.6	-0.2	7.6	144.9	-198.1	-47.5	-81.8	46.2	1.3	47.4
2	J11E	811.6	-11.9	-2.4	44.9	108.6	-165.3	-23.1	-39.1	31.0	11.0	42.0
3	J11F	344.1	-12.2	-3.0	47.6	146.4	-206.1	-24.0	-48.7	14.3	1.3	15.6
4	J11J	449.5	-15.4	-1.1	57.6	199.9	-272.9	-29.8	-65.3	32.0	1.6	33.6
5	J11K	515.5	-15.4	-3.7	59.2	198.3	-272.9	-30.2	-65.0	17.9	1.3	19.2
6	J21A	854.2	-9.7	-0.3	43.3	99.4	-152.4	-20.5	-34.5	150.4	21.2	171.7
7	J22K	478.8	-10.4	-0.9	45.5	97.0	-152.9	-21.8	-34.7	60.6	11.6	72.2
8	J23A	761.6	-15.2	-2.4	42.5	100.0	-157.7	-25.8	-40.2	62.3	19.0	81.4
9	J24B	767.2	-15.4	-4.1	40.6	101.9	-157.9	-25.5	-40.8	46.3	19.5	65.9
10	J25B	396.6	-12.6	0.0	56.3	190.3	-259.2	-26.7	-60.2	20.9	1.9	22.8
11	J31A	447.0	-16.7	0.0	53.0	203.5	-273.2	-29.9	-67.5	20.7	1.8	22.5
12	J33E	328.7	-25.2	-0.1	49.2	167.3	-241.7	-37.5	-67.0	40.0	6.9	46.9
13	J33F	365.6	-34.6	-0.3	45.8	130.8	-211.2	-46.0	-67.3	107.0	6.0	112.9
14	J34D	354.2	-25.6	-4.3	51.8	205.7	-283.1	-38.6	-77.1	17.0	1.3	18.3
15	J34E	258.0	-31.5	-10.4	52.6	204.9	-289.0	-44.6	-82.7	2.7	0.9	3.7
16	J34F	320.0	-14.0	-1.5	51.0	178.4	-243.3	-26.7	-58.6	29.8	1.0	30.8
17	J35B	651.1	-15.1	-0.7	53.6	189.3	-258.0	-28.5	-62.4	81.8	2.2	84.0
18	J35C	264.5	-10.3	-2.0	52.2	198.0	-260.6	-23.4	-59.8	10.7	0.9	11.6
19	J35E	215.2	-13.2	-1.6	47.4	127.5	-188.2	-25.1	-45.1	34.8	0.5	35.3
20	K10E	132.5	-44.0	-18.0	40.1	180.7	-264.9	-54.0	-89.2	0.9	1.2	2.1
21	K20A	168.9	-19.4	-6.1	32.7	148.1	-200.2	-27.6	-56.4	3.6	3.1	6.7
22	K30A	196.6	-34.2	-12.3	30.8	138.2	-203.2	-41.9	-68.8	0.9	0.1	1.0
23	K30B	139.6	-36.7	-7.6	31.4	137.4	-205.5	-44.6	-71.1	0.5	0.0	0.5
24	K30C	190.7	-28.7	-2.7	34.9	151.4	-215.0	-37.4	-66.6	1.0	0.7	1.7
25	K30D	178.8	-19.6	-19.6	38.1	157.3	-215.0	-29.1	-58.9	14.4	0.7	15.1
26	K40D	131.2	-46.7	-0.2	29.4	123.1	-199.2	-54.0	-77.5	36.6	0.4	37.1
27	K50B	204.0	-23.3	-10.7	38.7	218.8	-280.8	-33.0	-78.1	39.1	1.1	40.2
28	K60G	168.9	-68.1	-5.0	27.7	229.8	-325.6	-75.0	-125.5	28.2	1.0	29.2
	Total									**952**	**119**	**1 071**

2.7.8 Mining

There were no operating mines identified in the Gouritz WMA and consequently no mining groundwater volumes were assigned in the Gouritz GYMR. There may be some quarries that are not known but which is assumed to have small impacts on the water quantity.

2.7.9 Basic Human Needs (BHN) Reserve

The BHNR forms an important component of the groundwater Reserve. The BHNR was calculated by using population figures in each of the 28 Intermediate Reserve quaternary catchments. The population figures were obtained by using a combination of GRDM 2012 database population figures and comparing them to the DWS All Towns Reconciliation Strategies figures, given large towns in quaternary catchments make up the bulk of the population figures. Most of the large towns receive its water supply from surface water resources. There are however some that are reliant on groundwater e.g., Beaufort West.

2.7.10 Irrigation water use

Irrigation water use is from the GYMR results seen as one of the greatest groundwater uses in the Gouritz WMA. WR2005 data (Middleton and Bailey, 2008; 2011) was used to obtain areas under irrigation in the Gouritz WMA. Given the large volumes that result from irrigation water use, it was assumed that 10 - 15% of all irrigation water is obtained from groundwater.

2.7.11 Forestry water use

Forestry groundwater use was taken into consideration by reviewing figures from Le Maitre *et al.* (2000) as well as Mallory *et al.* (2011) and using a mm/a figure applied to forestry surface area. A groundwater use figure of 20 mm/a was used. The effect of forestry is twofold in that it can increase evapotranspiration in the riparian zone and it reduces recharge in the catchment area.

2.7.12 Alien vegetation

Alien vegetation coverage for the Gouritz WMA was obtained from the WR2005 (Middleton and Bailey, 2008; 2011) dataset and used to calculate groundwater use given alien vegetation area per quaternary catchment. Alien vegetation is seen as the biggest groundwater user in the WMA and it is recommended that further studies be done to better quantify actual alien vegetation water use in catchments where this is necessary. Alien vegetation is a potentially very large user of groundwater in the riparian zone and it can have a significant effect on reducing recharge (see **Table 2.18** for alien vegetation volumes per catchment).

Table 2.17 Groundwater discharge components within the Gouritz WMA as calculated for the GYMR table 1 of 2

No	Quaternary catchment	Total Surface Area (km2)	Registered Springs	Registered Boreholes	WARMS Registered Volumes (m3/a)	Number of abstraction boreholes (Other)	Total borehole abstraction (m3/a)	Future water supply schemes	Future water supply schemes (m3/a)	Population GRDM 2012 & All Towns study	Basic Human Needs (BHN) Reserve (m3/a)	Farm irrigation area (km2) WR2005	Farm irrigation water use (m3/a)
1	H90E	498	23	23	-3 592 736	20	-378 432	0	0	6 337	-138 780	0.00	0
2	J11E	812	1	33	-2 249 441	35	-1 103 760	0	0	4 773	-104 529	0.70	-105 000
3	J11F	344	3	18	-613 720	8	-252 288	0	0	734	-16 075	0.84	-126 000
4	J11J	449	8	7	-1 662 097	2	-63 072	0	0	1 333	-29 193	20.70	-2 070 000
5	J11K	515	13	26	-1 490 279	9	-283 824	0	0	11 732	-256 931	6.50	-975 000
6	J21A	854	3	54	-2 489 814	54	-1 671 408	0	0	34 661	-759 076	1.80	-270 000
7	J22K	479	0	1	-61 800	78	-2 459 808	0	0	100	-2 190	0.80	-120 000
8	J23A	762	0	29	-2 289 890	141	-4 446 576	0	0	2 080	-45 552	0.00	0
9	J24B	767	1	11	-280 300	32	-1 009 152	0	0	1 521	-33 310	0.00	0
10	J25B	397	10	5	-1 185 405	100	-378 432	0	0	4 135	-90 557	10.60	-1 060 000
11	J31A	447	1	4	-225 500	36	-946 080	0	0	75	-1 643	0.68	-102 000
12	J33E	329	0	22	-1 864 288	60	-1 829 088	0	0	13 522	-296 132	32.10	-3 210 000
13	J33F	366	0	3	-47 838	70	-2 175 984	0	0	34 154	-747 973	56.20	-5 620 000
14	J34D	354	0	3	-47 477	18	-567 648	0	0	1 915	-41 939	8.50	-1 275 000
15	J34E	258	0	11	-518 059	5	-157 680	0	0	1 321	-28 930	3.30	-495 000
16	J34F	320	0	17	-454 595	25	-788 400	0	0	2 928	-64 123	24.00	-2 400 000
17	J35B	651	0	51	-1 526 500	116	-3 626 640	0	0	5 831	-127 699	15.80	-1 580 000
18	J35C	264	2	9	-249 100	31	-977 616	0	0	3 633	-79 563	6.70	-1 005 000
19	J35E	215	10	0	-1 232 400	15	-473 040	0	0	1 224	-26 806	11.40	-1 140 000
20	K10E	132	0	2	-40 440	2	-63 072	0	0	4 122	-90 272	0.40	-60 000
21	K20A	169	2	1	-41 388	4	-126 144	0	0	9 650	-211 335	3.80	-570 000
22	K30A	197	0	11	-241 054	8	-252 288	0	0	6 994	-153 169	16.82	-1 682 000
23	K30B	140	4	14	-889 331	1	-94 608	0	0	6 334	-138 715	5.12	-768 000
24	K30C	191	2	4	-466 490	4	-126 144	0	0	146 970	-3 218 643	0.04	-6 000
25	K30D	179	0	5	-200 111	2	-189 216	0	0	9 839	-215 474	8.56	-1 284 000
26	K40D	131	0	16	-710 092	2	-63 072	0	0	20 130	-440 847	3.64	-546 000
27	K50B	204	0	23	-1 009 746	0	0	0	0	14 745	-322 916	0.00	0
28	K60G	169	0	10	-797 711	7	-220 752	0	0	23 053	-504 861	0.38	-57 000
0	Total	10593	**83**	**413**	**-26 477 602**	**885**	**-24 724 224**	**0**	**-3 784 320**	**373 846**	**-8 187 227**	**201**	**-26 526 000**

Table 2.18 Groundwater discharge components within the Gouritz WMA as calculated for the GYMR table 2 of 2

No	Quaternary catchment	Total Surface Area (km2)	Average Forestry area WR2005 (km2)	Average Forestry water use (m3/a)	Alien vegetation WR2005 (km2)	Alien vegetation water use (m3/a)	Wetlands NFEPA (km2)	Wetland water use (m3/a)	No of springs not already accounted for in WARMS	Spring flow (m3/a)	Total outflow before losses (sinks) m3/a	Total outflow before losses (sinks) million m3/a
1	H90E	498	0.00	0	149.2	-18 799 200	10.15	-2 539	1	-31 536	-22 943 223	-22.9
2	J11E	812	0.00	0	0.0	0	0.88	-221	0	0	-3 562 951	-3.6
3	J11F	344	0.00	0	0.2	-20 160	3.89	-973	0	0	-1 029 215	-1.0
4	J11J	449	0.00	0	0.1	-15 120	1.64	-411	0	0	-3 839 893	-3.8
5	J11K	515	0.00	0	1.2	-147 420	1.17	-294	0	0	-3 153 748	-3.2
6	J21A	854	0.00	0	12.8	-1 615 320	10.30	-2 576	0	0	-6 808 194	-6.8
7	J22K	479	0.00	0	0.0	0	4.38	-1 096	0	0	-2 644 894	-2.6
8	J23A	762	0.00	0	3.2	-403 200	0.49	-122	0	0	-7 185 340	-7.2
9	J24B	767	0.00	0	0.0	0	0.25	-63	0	0	-1 322 825	-1.3
10	J25B	397	0.00	0	1.1	-137 340	1.61	-402	0	0	-2 852 135	-2.9
11	J31A	447	0.00	0	0.7	-89 460	0.25	-63	1	-31 536	-1 396 281	-1.4
12	J33E	329	0.00	0	2.9	-362 880	1.21	-301	0	0	-7 562 689	-7.6
13	J33F	366	0.00	0	15.7	-1 974 420	1.74	-436	0	0	-10 566 650	-10.6
14	J34D	354	0.00	0	25.1	-3 163 860	1.96	-490	0	0	-5 096 414	-5.1
15	J34E	258	0.00	0	2.6	-325 080	6.11	-1 527	0	0	-1 526 276	-1.5
16	J34F	320	2.20	-44 000	1.4	-176 400	2.64	-661	0	0	-3 928 179	-3.9
17	J35B	651	0.02	-406	16.4	-2 067 660	4.06	-1 014	0	0	-8 929 919	-8.9
18	J35C	264	0.00	0	4.6	-580 860	0.51	-127	0	0	-2 892 265	-2.9
19	J35E	215	0.00	0	0.0	0	0.78	-196	0	0	-2 872 442	-2.9
20	K10E	132	24.60	-492 000	11.8	-1 486 800	17.49	-4 373	0	0	-2 236 957	-2.2
21	K20A	169	44.10	-882 000	0.6	-75 600	22.76	-5 689	0	0	-1 912 156	-1.9
22	K30A	197	40.00	-800 000	0.0	0	9.35	-2 337	0	0	-3 130 848	-3.1
23	K30B	140	19.20	-384 000	0.8	-100 800	3.89	-974	0	0	-2 376 427	-2.4
24	K30C	191	50.90	-1 018 000	14.5	-1 827 000	1.97	-493	0	0	-6 662 770	-6.7
25	K30D	179	1.80	-36 000	12.6	-1 587 600	13.45	-3 363	0	0	-3 515 765	-3.5
26	K40D	131	12.60	-252 000	13.9	-1 751 400	25.59	-6 398	0	0	-3 769 809	-3.8
27	K50B	204	4.60	-92 000	15.9	-2 003 400	25.16	-6 290	0	0	-3 434 352	-3.4
28	K60G	169	8.80	-176 000	2.8	-352 800	6.77	-1 692	0	0	-2 110 815	-2.1
	Total	10593	**209**	**-4 176 406**	**310**	**-39 063 780**	**180**	**-45 120**	**2**	**-63 072**	**-129 263 432**	**-129.3**

2.7.13 Wetlands

Wetlands within the Gouritz WMA were clipped per quaternary catchment. Wetlands spatial coverage was obtained from the NFEPA wetlands dataset. A wetlands water use (0.25 mm/a per km^2) was used to calculate final volumes per annum per quaternary catchment in the GYMR. An assumption was made that all wetlands are groundwater fed. This is a comparably small volume in the groundwater balance.

2.7.14 Riparian vegetation

Riparian vegetation occurs along drainage lines and is associated with the wetter soils on the banks of the rivers and streams as well as the water of the streams themselves. Evapotranspiration loss and associated water loss from riparian vegetation is however already accounted for in the evapotranspiration losses component in the GYMR and the riparian vegetation water use component was consequently not included as a separate component in the GYMR.

2.7.15 Evapotranspiration

The lengths of all secondary drainages in the quaternary catchments selected for Intermediate Reserve Determination were accumulated to a total length of 1 588.3 km. A width of 5 m on each side or bank of the drainage was then used to calculate, with the cumulative drainage length, the total evapotranspiration for coastal and most inland Klein Karool quaternary catchments. A riparian zone width of 2.5 m was used for drier Klein Karoo catchments and a width of 2 m was used for the Groot Karoo quaternary catchments and drier (northern) Klein Karoo catchments.

2.7.16 Groundwater contribution to baseflow

The groundwater contribution to baseflow is the final outflow out of a groundwater system as well as the GYMR groundwater flow balance. Should the river system be leaking into the groundwater system, baseflow can become negative meaning that it is taken out of the surface water system.

Desktop estimates of the groundwater contribution to baseflow and baseflow estimates are available through the GRA II (DWA, 2006) study and the GRDM 2.3.2.0 software database. These values were evaluated for comparison with the GYMR groundwater contribution to baseflow results obtained. The Herold baseflow separation method was used to obtain a desktop estimate from the modelled runoff streamflow sequences available per quaternary catchment from the WR2005 dataset. This was done to verify the available desktop estimates from Hughes, Pitman, Shultz and Van Tonder in the GRA II (DWA, 2006) dataset. An example of the Herold baseflow separation method performed for the H90E GRU is shown in **Figure 2.25**. The Herold method in its own right is however still subjective, as almost all analytical baseflow separation methods are, since there are one or two parameters that are manually adjusted (based on the subjective interpretation of the analyst) to obtain the desired groundwater contribution fit of the hydrograph. Cognisance also has to be taken of the fact that the modelled naturalised streamflow sequences from WR2005 (Middleton and Bailey, 2008; 2011) per quaternary catchment are not always similar to or representative of observed streamflow sequences.

The actual drought low flows calculated from observed and patched streamflow records by Van Niekerk and Sparks for the ORDS (DWA, 2010) are very low compared to the desktop estimates of baseflow and groundwater contribution to baseflow (based on naturalised streamflow per quaternary catchment). The comparison is shown in **Table 2.19** below. When the groundwater contribution to baseflow estimates are compared to the calculated low flows from observed streamflow records, the mean ratio of observed:estimated (lowest estimate) is 0.42:1 (42%). Calculated drought low flows from observed, patched and extrapolated streamflow records were however not available for all Intermediate Reserve GRUs / catchments evaluated. A decision was made to use the lowest baseflow or groundwater contribution to baseflow estimate from the Herold calculated and existing baseflow and groundwater contribution to baseflow estimates.

It is recommended that the chemical tracer method be used to more accurately determine the groundwater contribution to baseflow volumes in the eight GRUs / catchments that were found to be groundwater stressed.

Table 2.19 Comparison of groundwater contribution to baseflow estimates

No	Quaternary catchment	GYMR GW contribution to baseflow (m3/a)	Baseflow Hughes (m3/a)	Baseflow Pitman (m3/a)	Baseflow Schultze (m3/a)	Baseflow Van Tonder (m3/a)	Baseflow (GRDM Default) m3/a	GW contribution to Baseflow GRAII (m3/a)	BKS ORDS GW Reserve drought low flow calculated	Calculated GW contribution to Baseflow (GRDM software Herold)	Desktop estimates GW contribution to baseflow from MAR (m3/a)
1	H90E	-11 152 691	6 340 000	1 110 000	2 330 000	2 390 000	1 110 000	5 255 280		1 857 000	1 110 000
2	J11E	-38 680	0	0	0	0	0	0		357 000	0
3	J11F	647 014	0	0	0	0	0	0		203 000	0
4	J11J	745 205	430 000	30 000	0	0	30 000	0		267 000	0
5	J11K	-18 195	80 000	0	0	0	0	0		98 000	0
6	J21A	-1 241 224	1 700 000	30 000	0	0	30 000	0		2 919 000	0
7	J22K	-1 248 023	0	0	0	0	0	0		158 000	0
8	J23A	-5 859 215	0	0	0	0	0	0		43 000	0
9	J24B	718 672	60 000	0	0	0	0	0		34 000	0
10	J25B	1 785 629	4 110 000	630 000	1 590 000	1 530 000	630 000	1 340 340		1 858 000	630 000
11	J31A	4 003 398	3 090 000	390 000	1 120 000	1 080 000	390 000	1 419 540		852 000	390 000
12	J33E	-2 637 056	7 580 000	1 020 000	2 830 000	2 710 000	1 020 000	2 448 620		4 048 000	1 020 000
13	J33F	-6 539 172	3 990 000	780 000	1 650 000	1 600 000	780 000	2 229 120		1 881 000	780 000
14	J34D	-313 015	2 740 000	450 000	990 000	1 010 000	450 000	1 774 540		728 000	450 000
15	J34E	1 606 714	1 540 000	300 000	590 000	610 000	300 000	1 162 830		407 000	300 000
16	J34F	-448 248	1 730 000	300 000	700 000	680 000	300 000	1 278 320		435 000	300 000
17	J35B	-782 266	3 450 000	630 000	1 370 000	1 340 000	630 000	2 656 350		926 000	630 000
18	J35C	-333 241	1 050 000	210 000	450 000	430 000	210 000	879 192		283 000	210 000
19	J35E	-1 638 135	1 260 000	210 000	520 000	490 000	210 000	878 853		1 042 000	210 000
20	K10E	793 344	15 040 000	5 620 000	6 500 000	7 480 000	5 620 000	4 262 960	247 000	2 561 000	2 561 000
21	K20A	2 082 848	20 860 000	9 930 000	9 050 000	11 460 000	9 930 000	6 082 820	399 000	8 059 000	6 082 820
22	K30A	1 665 889	27 620 000	13 190 000	11 210 000	14 940 000	13 190 000	7 226 070	477 000	6 708 000	6 708 000
23	K30B	685 960	22 160 000	10 760 000	8 470 000	11 900 000	10 760 000	5 066 390	433 000	8 560 000	5 066 390
24	K30C	-2 061 066	28 110 000	13 440 000	12 050 000	15 420 000	13 440 000	8 024 160	690 000	14 570 000	8 024 160
25	K30D	654 641	19 410 000	8 990 000	9 590 000	10 930 000	8 990 000	7 519 710	382 000	5 254 000	5 254 000
26	K40D	326 679	18 460 000	10 810 000	7 480 000	10 970 000	10 810 000	3 682 880	429 000	10 091 000	3 682 880
27	K50B	2 765 304	26 380 000	12 890 000	14 810 000	15 780 000	12 890 000	8 766 390	831 000	13 265 000	8 766 390
28	K60G	3 966 877	11 160 000	5 420 000	5 580 000	6 430 000	5 420 000	6 907 480	587 000	4 758 000	4 758 000

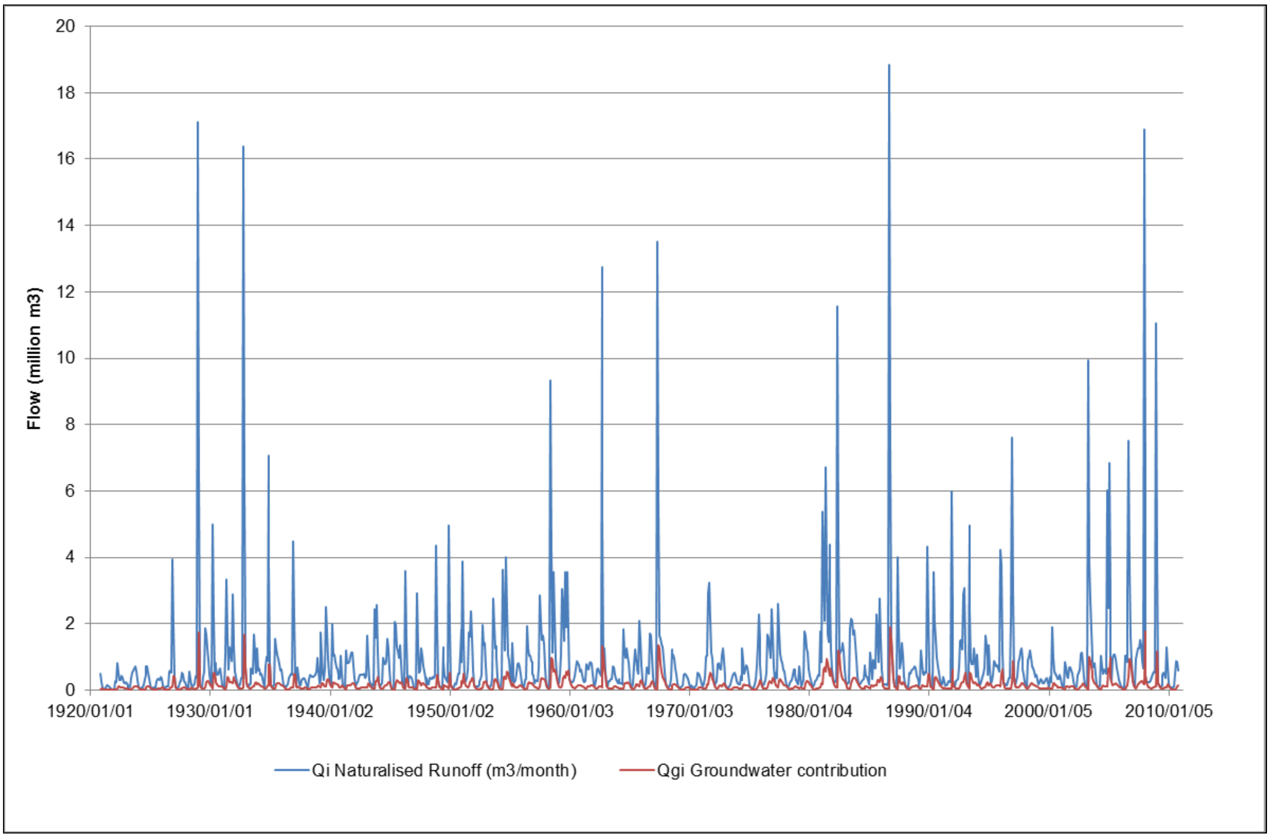


Figure 2.25 Example of Herolds baseflow separation to estimate groundwater contribution to baseflow for H90E

2.7.17 The ecological Reserve and Ecological Water Requirements (EWR)

In Groundwater Dependent Ecosystems (GDEs) some part of the flow making up the ecological Reserve or EWR comes from groundwater. GDEs include riparian zones along drainages (where hydraulic head is in close proximity to channel surface depth as well as channel banks), groundwater driven wetlands and permanent seeps along hillsides.

These flows were initially assumed to use 40% of groundwater baseflow. These figures were revised based on EWRs from existing studies and an assumption was made (where data were not available) that where baseflow is zero and there are no riparian GDEs present in an ephemeral drainage (e.g. in the Great Karoo), then groundwater contribution to EWR can also be assumed to be zero. EWR figures are typically determined by ecologists and surface water specialists and were not available in all selected quaternary catchments/GRUs for the Intermediate groundwater Reserve determination.

Estimates which typically make up the largest proportion of groundwater contribution to EWR, are shown in **Table 2.20**. Note that the term “IFR EWR” used on **Table 2.20** is referring to the instream flow requirement, or flow component of the EWR.

Note on EWR volumes: It must be recognised that the total EWR volume consists of surface water runoff, periodic flow releases from dams, maintenance low flow and drought low flow. It is thought that only the drought low flow EWR volume is actually applicable to the groundwater contribution to EWR. The differentiation of flows is however often not available and this creates a skewed picture of how much groundwater is actually needed to supply the surface water EWR.

A number of EWR volumes per quaternary catchment were obtained from the DAGEOS Reserve determination report (Riemann and Blake, 2010). These volumes in turn were obtained from the Resource Directed Measures (RDM) database. It is assumed that many of these EWR volumes were SPATSIM software desktop model estimates and were also not split up into different flow components. They include maintenance low flow components which are supplied from periodic surface water releases from dams, hence not groundwater only.

There is currently no groundwater EWR available for the J31A catchment. It is recommended that an EWR assessment be performed for this catchment to determine the different components of the EWR and thus the component applicable to groundwater as well.

Table 2.20 Calculated and estimated EWRs from various sources and comparison

Quaternary catchment	GYMR GW contribution to baseflow (m3/a)	Desktop estimates GW contribution to baseflow from MAR (m3/a)	IFR EWR 40% assumption (m3/a)	DWS RDM table listed in Umvoto DAGEOS Reserve Determination	ORDS/ Gouritz EWR Maintanance Low flow % MAR	ORDS/ Gouritz EWR Drought Low flow % MAR	ORDS/ Gouritz EWR Drought Low flow Volume m3/a	IFR Ecological Water Requirement (EWR) UPDATED (m3/a)	Reference	Desktop Estimates: GW contribution to IFR EWR UPDATED (%)	GYMR GW contribution to IFR EWR UPDATED (%)	GYMR GW contribution to IFR EWR UPDATED (m3/a)	Allocable GW from GW contribution to Baseflow (m3/a)	GRDM INDEX
H90E	-11 152 691	1 110 000	-4 461 615		21.00%	13.10%	-1 461 960	-1 461 960	Goukou. Current Gouritz Estuary study slides.	100%	0%	0	0	190%
J11E	-38 680	0	-562 946					0	Matjiesfontein. 0 Baseflow	0%	0%	0	0	80%
J11F	647 014	0	-79 982					0	Laingsburg. 0 Baseflow	0%	0%	0	647 014	48%
J11J	745 205	0	-12 431					0	Ladismith Adjacent. Mon BHs on River. Swartberg River	0%	0%	0	745 205	76%
J11K	-18 195	0	-274 505					0	Ladismith catchment.	0%	0%	0	0	85%
J21A	-1 241 224	0	-1 179 020					-1 480 000	Beaufort West. EWR already determined. GEOSS report. No BF recorded. Spatsim used for IFR	100%	0%	0	0	102%
J22K	-1 248 023	0	-921 989					0	Leeu River. No towns. Active Mon BHs on River. Hydrograph little flow	0%	0%	0	0	126%
J23A	-5 859 215	0	-3 107 913					0	Leeu Gamka. Mon BHs. Gamka River. Perennial.	0%	0%	0	0	276%
J24B	718 672	0	-375 331					0	Merweville. Dwyka River.	0%	0%	0	718 672	42%
J25B	1 785 629	630 000	-731 567	15.6%				-1 458 590	Zoar. Huis/Kobus River.	100%	82%	-1 458 590	327 039	53%
J31A	4 003 398	390 000	-1 352 367					No EWR available	Wanhoop Farm. Upper reaches of Olifants River. No EWR. Get SPATSIM desktop estimate	0%	0%	0	4 003 398	20%
J33E	-2 637 056	1 020 000	-1 259 162	10.4%				-1 174 160	De Rust. Olifants River. Includes Vermaaks Riv BHs. See Mike report	100%	0%	0	0	125%
J33F	-6 539 172	780 000	-2 662 503	15.3%				-1 224 729	Dysselsdorp. Olifants River. Mon BH on River	100%	0%	0	0	209%
J34D	-313 015	450 000	-177 307	15.4%				-691 712	SW Kammanassie. DWS mon BHs. Kammanassie River. Perennial.	100%	0%	0	0	89%
J34E	1 606 714	300 000	-585 062	15.6%				-761 950	Brak/Eseljag River. Upper catchment.	100%	47%	-761 950	844 764	41%
J34F	-448 248	300 000	-181 434	15.6%				-1 589 640	Herold town. Doring River. Upper catchment.	100%	0%	0	0	90%
J35B	-782 266	630 000	-464 572	15.1%				-470 808	DAGEOS C1b3.	75%	0%	0	0	90%
J35C	-333 241	210 000	-137 318	15.8%				-989 080	Moeras River.	100%	0%	0	0	94%
J35E	-1 638 135	210 000	-658 340	11.6%				-1 783 320	Clearly Olifants River baseflow. Alluvial channel. Middle catchment	100%	0%	0	0	169%
K10E	793 344	247 000	-12 569		17.60%	5.10%	-785 400	-785 400	Moordkuil River. South draining. ORDS GYMR PD + EWR. EWR site in K10F. p.47. Review of Rapid III	31%	99%	-785 400	7 944	63%
K20A	2 082 848	399 000	-552 323		11.50%	7.00%	-1 976 100	-1 976 100	Groot-Brak entire River catchment. ORDS GYMR PD + EWR. Intermediate level study.	32%	95%	-1 976 100	106 748	43%
K30A	1 665 889	477 000	-433 644		9.60%	5.64%	-2 271 228	-2 271 228	Entire Maalgate Riv catchment. ORDS GYMR PD + EWR	34%	100%	-1 665 889	0	61%
K30B	685 960	433 000	-112 080		9.60%	5.60%	-2 400 160	-2 400 160	Gwaing & tributaries. ORDS GYMR PD + EWR	47%	100%	-685 960	0	65%
K30C	-2 061 066	690 000	-1 126 265		25.70%	13.00%	-6 633 900	-6 633 900	Kaaimans Riv, Swart tributary. George catch. ORDS GYMR PD + EWR	83%	0%	0	0	127%
K30D	654 641	382 000	-494		28.20%	2.60%	-820 300	-820 300	Wilderness. Touws River & tributaries. Current Gouritz WMA Study Reserve	16%	100%	-654 641	0	68%
K40D	326 679	429 000	-127 170		21.70%	3.23%	-1 026 817	-1 026 817	Sedgefield. Sedgefield Riv & no of tributaries. ORDS GYMR PD + EWR. Diep River Reserve (K40A) used.	28%	100%	-326 679	0	84%
K50B	2 765 304	831 000	-977 821		33.70%	6.62%	-3 073 991	-3 073 991	Knysna. Knysna River. ORDS GYMR PD + EWR. Mean of Knysna and Gouna Reserves	35%	100%	-2 765 304	0	51%
K60G	3 966 877	587 000	-1 277 973		28.20%	13.00%	-2 392 000	-2 392 000	Plett. Piesang, Noetsie, Keurbooms, Bitou. ORDS GYMR PD + EWR. Noetsie River EWR used	50%	60%	-2 392 000	1 574 877	32%
Total	-11 862 054	10 505 000	-23 805 702					-34 465 845					8 975 661	

BKS ORDS calculated drought low flow volumes from observed and patched streamlfow records

2.7.18 Groundwater Reserve Scenarios

The GYMR groundwater balance was set up in steady-state to assess potential groundwater balances on an annual basis per quaternary catchment. Recommendations on management options based on the outcome of the assessments are made, for the DWS and RDM office's decision-making purposes.

Two scenarios were simulated for the 28 selected GRUs as well as a third scenario for the DAGEOS semi-confined aquifer, which uses a different set of calculations. The scenarios were as follows:

- **Scenario1:** MAP or P_{50} applied to groundwater recharge based on geological units identified as GRUs within each selected quaternary catchment. The following conditions apply: GAs are excluded; GYMR modelled in steady state – groundwater volumes available based on annual recharge to aquifers excluding groundwater storage effects in aquifers were simulated with best but conservative estimates of recharge. This scenario does not account for drought cycles, but groundwater losses and the groundwater baseflow component was included. The EWR (based on best available EWR volumes and Desktop estimates where EWRs are not available) was also taken into account.
- **Scenario 2:** Groundwater recharge percentage applied to 98% assured rainfall based on geological units identified as GRUs within each selected quaternary catchment. The following conditions apply: GAs are excluded; GYMR modelled in steady state – groundwater volumes available based on annual recharge to aquifers excluding groundwater storage effects in aquifers were simulated with best conservative estimates of recharge. This scenario accounts for drought cycles, groundwater losses and the groundwater baseflow component (based on best available EWR volumes and desktop estimates where EWRs are not available).
- **Scenario 3:** DAGEOS semi-confined and confined TMG aquifer Intermediate Reserve numerical simulation. Since this is a strategic groundwater resource in the WMA it must be included in the Intermediate Reserve. Scenarios of both MAP and 98% assured rainfall applied with best estimates of groundwater recharge to unconfined DAGEOS RU 1 were performed. The semi-confined shallow RU 1 is assumed to be the only source of groundwater to the deep confined RU 2 (**Section 2.2.8**). This means that e.g. inflow from leakage of surface water from the surface streams and the Skurweberg Aquifer via inferred faults were not considered or included. Conceptual numerical groundwater modelling of the DAGEOS GRUs (GRUs are the same as RUs in this investigation) was performed and details of the process and results are provided in **Appendix D** (Exigo, 2015).

From the GYMR scenario modelling (**Table 2.21** to **2.24** and **Figure 2.26** to **2.29**) summarise the Intermediate Reserve results for the selected GRUs within the Gouritz WMA.

Table 2.21 Groundwater sources within Scenario 1: Present day MAP Intermediate Reserve

No	Quaternary catchment	Total surface area (km^2)	MAP (mm/a) WR2005 data	Rainfall 98% assured (mm/a)	Recharge MAP (m^3/a)	Recharge 98% assured (m^3/a)	Farm dam seepage area WR2005 (km^2)	Total dam seepage (m^3/a)	Total inflow MAP (m^3/a)	Total inflow MAP (million m^3/a)
1	H90E	498	490	308	12 064 567	7 574 425	0.06	6 000	12 070 567	12.1
2	J11E	812	188	89	4 389 727	2 081 064	0.47	47 000	4 436 727	4.4
3	J11F	344	209	99	2 113 287	1 001 859	0.10	10 000	2 123 287	2.1
4	J11J	449	304	170	4 944 739	2 761 756	1.22	122 000	5 066 739	5.1
5	J11K	515	221	123	3 622 517	2 023 263	0.88	88 000	3 710 517	3.7
6	J21A	854	230	101	6 434 520	2 812 760	2.70	270 000	6 704 520	6.7
7	J22K	479	151	66	2 053 502	897 454	0.48	48 000	2 101 502	2.1
8	J23A	762	127	48	2 563 837	978 206	0.36	36 000	2 599 837	2.6
9	J24B	767	160	38	3 133 164	745 881	0.13	13 000	3 146 164	3.1
10	J25B	397	326	180	5 312 840	2 940 338	1.11	111 000	5 423 840	5.4
11	J31A	447	441	213	6 968 411	3 357 966	0.24	24 000	6 992 411	7.0
12	J33E	329	446	236	6 014 189	3 181 241	0.60	60 000	6 074 189	6.1
13	J33F	366	343	192	4 940 155	2 765 637	1.26	126 000	5 066 155	5.1
14	J34D	354	471	285	5 674 009	3 436 566	0.60	60 000	5 734 009	5.7
15	J34E	258	427	259	3 566 167	2 159 913	1.84	184 000	3 750 167	3.8
16	J34F	320	415	251	4 223 455	2 558 011	1.36	136 000	4 359 455	4.4
17	J35B	651	411	249	9 708 363	5 880 045	2.20	220 000	9 928 363	9.9
18	J35C	264	373	226	3 030 638	1 835 560	0.31	31 000	3 061 638	3.1
19	J35E	215	270	139	1 644 811	847 236	0.54	54 000	1 698 811	1.7
20	K10E	132	679	401	3 562 699	2 102 220	0.05	5 000	3 567 699	3.6
21	K20A	169	722	473	4 256 303	2 787 827	1.55	155 000	4 411 303	4.4
22	K30A	197	753	493	5 035 053	3 297 899	1.16	116 000	5 151 053	5.2
23	K30B	140	787	515	3 631 735	2 378 743	0.48	48 000	3 679 735	3.7
24	K30C	191	805	527	5 131 371	3 360 987	1.08	108 000	5 239 371	5.2
25	K30D	179	724	474	5 093 199	3 335 984	0.41	41 000	5 134 199	5.1
26	K40D	131	757	508	4 473 504	3 001 882	0.20	20 000	4 493 504	4.5
27	K50B	204	882	635	6 766 346	4 873 962	0.08	8 000	6 774 346	6.8
28	K60G	169	860	619	6 493 881	4 677 699	0.47	47 000	6 540 881	6.5
	Total	**10 593**	**12 972**	**0**	**136 846 990**	**79 656 385**	**21.94**	**2 194 000**	**139 040 990**	**139.0**

Table 2.22 Summary table of GYMR results for Scenario 1: Present Day with MAP rainfall

No	Quaternary catchment	Total surface area (km^2)	BHNR (million m^3/a)	Total inflow MAP (million m^3/a)	Total outflow before losses (million m^3/a)	Evapotranspiration streamflow loss (million m^3/a)	GYMR GW[1] contribution to baseflow (million m^3/a)	EWR (million m^3/a)	GYMR GW contribution to EWR (m^3/a)	GW allocation (million m^3/a)	GRDM Index	GRDM Present Status Category
1	H90E	498.43	-0.14	12.07	-22.94	-0.28	-11.15	-1.46	0.00	0.00	190%	III
2	J11E	811.58	-0.10	4.44	-3.56	-0.91	-0.04	0.00	0.00	0.00	80%	III
3	J11F	344.14	-0.02	2.12	-1.03	-0.45	0.65	0.00	0.00	0.65	48%	III
4	J11J	449.48	-0.03	5.07	-3.84	-0.48	0.75	0.00	0.00	0.75	76%	III
5	J11K	515.49	-0.26	3.71	-3.15	-0.57	-0.02	0.00	0.00	0.00	85%	III
6	J21A	854.17	-0.76	6.70	-6.81	-1.14	-1.24	-1.48	0.00	0.00	102%	III
7	J22K	478.81	0.00	2.10	-2.64	-0.70	-1.25	0.00	0.00	0.00	126%	III
8	J23A	761.62	-0.05	2.60	-7.19	-1.27	-5.86	0.00	0.00	0.00	276%	III
9	J24B	767.16	-0.03	3.15	-1.32	-1.10	0.72	0.00	0.00	0.72	42%	III
10	J25B	396.57	-0.09	5.42	-2.85	-0.79	1.79	-1.46	-1.46	0.33	53%	III
11	J31A	447.04	0.00	6.99	-1.40	-1.59	4.00	0.00	0.00	4.00	20%	I
12	J33E	328.67	-0.30	6.07	-7.56	-1.15	-2.64	-1.17	0.00	0.00	125%	III
13	J33F	365.63	-0.75	5.07	-10.57	-1.04	-6.54	-1.22	0.00	0.00	209%	III
14	J34D	354.20	-0.04	5.73	-5.10	-0.95	-0.31	-0.69	0.00	0.00	89%	III
15	J34E	257.99	-0.03	3.75	-1.53	-0.62	1.61	-0.76	-0.76	0.84	41%	III
16	J34F	319.97	-0.06	4.36	-3.93	-0.88	-0.45	-1.59	0.00	0.00	90%	III
17	J35B	651.14	-0.13	9.93	-8.93	-1.78	-0.78	-0.47	0.00	0.00	90%	III
18	J35C	264.48	-0.08	3.06	-2.89	-0.50	-0.33	-0.99	0.00	0.00	94%	III
19	J35E	215.16	-0.03	1.70	-2.87	-0.46	-1.64	-1.78	0.00	0.00	169%	III
20	K10E	132.50	-0.09	3.57	-2.24	-0.54	0.79	-0.79	-0.79	0.01	63%	III
21	K20A	168.94	-0.21	4.41	-1.91	-0.42	2.08	-1.98	-1.98	0.11	43%	III
22	K30A	196.60	-0.15	5.15	-3.13	-0.35	1.67	-2.27	-1.67	0.00	61%	III
23	K30B	139.65	-0.14	3.68	-2.38	-0.62	0.69	-2.40	-0.69	0.00	65%	III
24	K30C	190.68	-3.22	5.24	-6.66	-0.64	-2.06	-6.63	0.00	0.00	127%	III
25	K30D	178.79	-0.22	5.13	-3.52	-0.96	0.65	-0.82	-0.65	0.00	68%	III
26	K40D	131.21	-0.44	4.49	-3.77	-0.40	0.33	-1.03	-0.33	0.00	84%	III
27	K50B	203.97	-0.32	6.77	-3.43	-0.57	2.77	-3.07	-2.77	0.00	51%	III
28	K60G	168.89	-0.50	6.54	-2.11	-0.46	3.97	-2.39	-2.39	1.57	32%	II
	Total	**10 593**	**-8.19**	**139.04**	**-129.26**	**-21.64**	**-11.86**	**-34.47**	**-13.47**	**8.98**	**93%**	

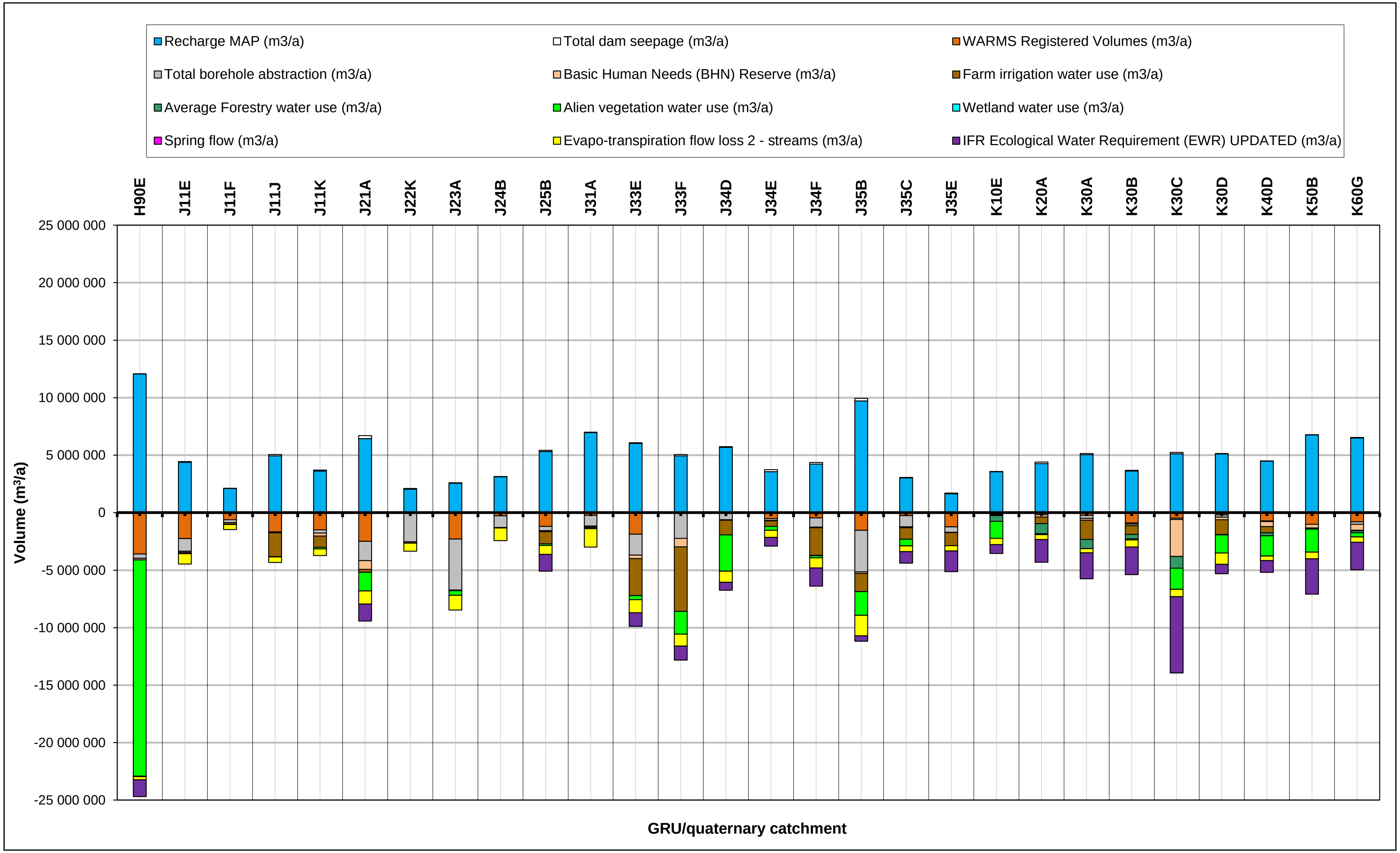


Figure 2.26 Graph of comparative contribution of sources and sinks in the GYMR Present Day MAP scenario 1

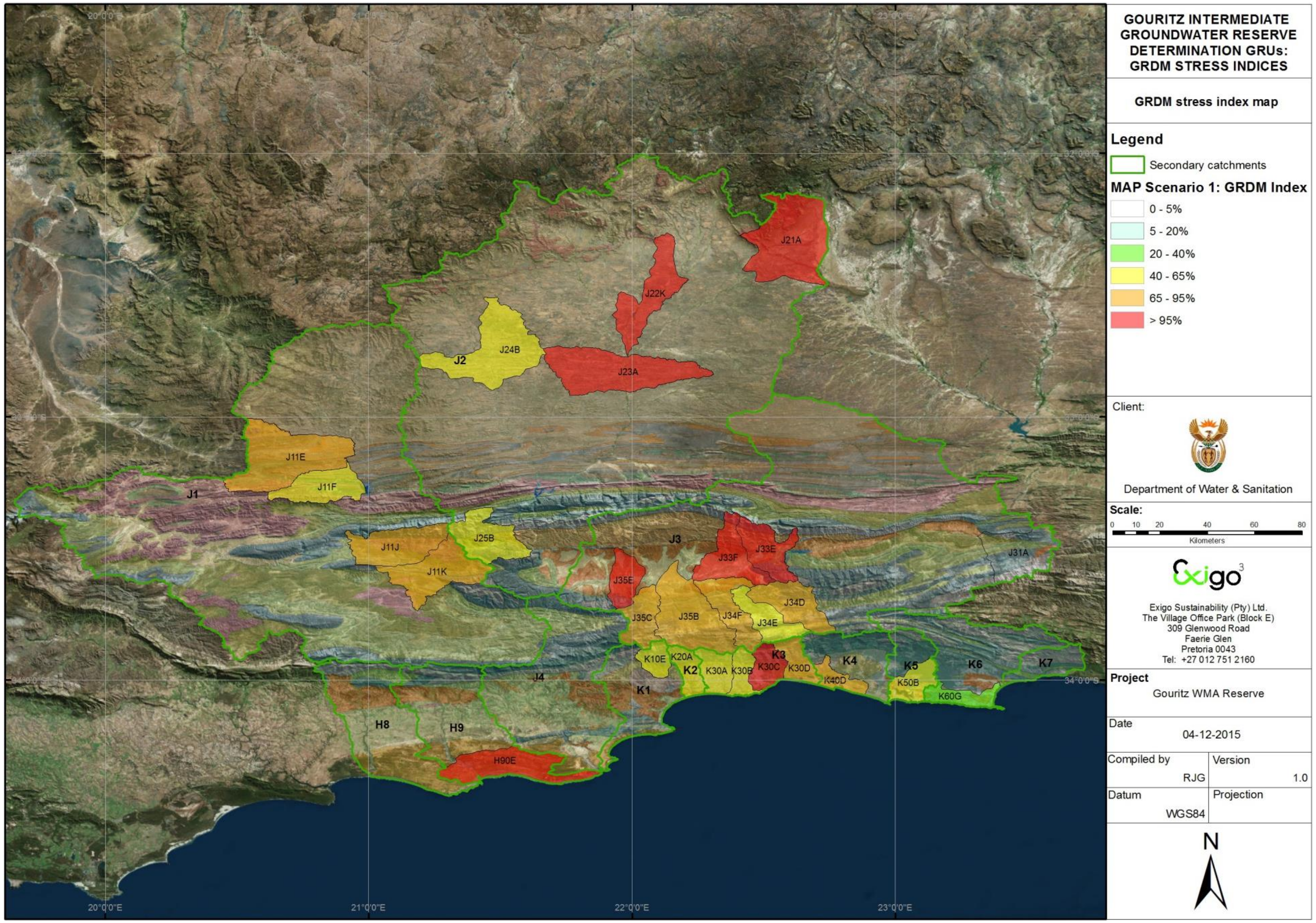


Figure 2.27 Map showing GRDM index per Intermediate Reserve selected catchment in the Gouritz WMA

Table 2.23 Groundwater sources within Scenario 2: Present Day 98% assurance Intermediate Reserve

No	Quaternary catchment	Total surface area (km^2)	MAP (mm/a) WR2005 Data	Rainfall 98% assured (mm/a)	Recharge MAP (m^3/a)	Recharge 98% assured (m^3/a)	Farm dam seepage area WR2005 (km^2)	Total dam seepage (m^3/a)	Total inflow 98% assured (m^3/a)	Total inflow 98% assured (million m^3/a)
1	H90E	498	490	308	12 064 567	7 574 425	0.06	0	7 574 425	7.6
2	J11E	812	188	89	4 389 727	2 081 064	0.47	0	2 081 064	2.1
3	J11F	344	209	99	2 113 287	1 001 859	0.10	0	1 001 859	1.0
4	J11J	449	304	170	4 944 739	2 761 756	1.22	0	2 761 756	2.8
5	J11K	515	221	123	3 622 517	2 023 263	0.88	0	2 023 263	2.0
6	J21A	854	230	101	6 434 520	2 812 760	2.70	0	2 812 760	2.8
7	J22K	479	151	66	2 053 502	897 454	0.48	0	897 454	0.9
8	J23A	762	127	48	2 563 837	978 206	0.36	0	978 206	1.0
9	J24B	767	160	38	3 133 164	745 881	0.13	0	745 881	0.7
10	J25B	397	326	180	5 312 840	2 940 338	1.11	0	2 940 338	2.9
11	J31A	447	441	213	6 968 411	3 357 966	0.24	0	3 357 966	3.4
12	J33E	329	446	236	6 014 189	3 181 241	0.60	0	3 181 241	3.2
13	J33F	366	343	192	4 940 155	2 765 637	1.26	0	2 765 637	2.8
14	J34D	354	471	285	5 674 009	3 436 566	0.60	0	3 436 566	3.4
15	J34E	258	427	259	3 566 167	2 159 913	1.84	0	2 159 913	2.2
16	J34F	320	415	251	4 223 455	2 558 011	1.36	0	2 558 011	2.6
17	J35B	651	411	249	9 708 363	5 880 045	2.20	0	5 880 045	5.9
18	J35C	264	373	226	3 030 638	1 835 560	0.31	0	1 835 560	1.8
19	J35E	215	270	139	1 644 811	847 236	0.54	0	847 236	0.8
20	K10E	132	679	401	3 562 699	2 102 220	0.05	0	2 102 220	2.1
21	K20A	169	722	473	4 256 303	2 787 827	1.55	0	2 787 827	2.8
22	K30A	197	753	493	5 035 053	3 297 899	1.16	0	3 297 899	3.3
23	K30B	140	787	515	3 631 735	2 378 743	0.48	0	2 378 743	2.4
24	K30C	191	805	527	5 131 371	3 360 987	1.08	0	3 360 987	3.4
25	K30D	179	724	474	5 093 199	3 335 984	0.41	0	3 335 984	3.3
26	K40D	131	757	508	4 473 504	3 001 882	0.20	0	3 001 882	3.0
27	K50B	204	882	635	6 766 346	4 873 962	0.08	0	4 873 962	4.9
28	K60G	169	860	619	6 493 881	4 677 699	0.47	0	4 677 699	4.7
	Total	**10 593**	**12 972**	**7 919**	**136 846 990**	**79 656 385**	**21.94**	**0**	**79 656 385**	**79.7**

Table 2.24 Summary table of GYMR results for Scenario 2: Present Day with 98% assured rainfall for drought cycles

No	Quaternary catchment	Total surface area (km^2)	BHNR (million m^3/a)	Total inflow 98% assured (million m^3/a)	Total outflow before losses (million m^3/a)	Evapotranspiration streamflow loss (million m^3/a)	Net baseflow before EWR (million m^3/a)	EWR (million m^3/a)	GYMR GW contribution to EWR (m^3/a)	GW Allocation (million m^3/a)	GRDM Index	GRDM Present Status Category
1	H90E	498.43	-0.14	7.57	-22.94	-0.28	-15.65	-1.46	0.00	0.00	303%	III
2	J11E	811.58	-0.10	2.08	-3.56	-0.91	-2.39	0.00	0.00	0.00	171%	III
3	J11F	344.14	-0.02	1.00	-1.03	-0.36	-0.39	0.00	0.00	0.00	103%	III
4	J11J	449.48	-0.03	2.76	-3.84	-0.48	-1.56	0.00	0.00	0.00	139%	III
5	J11K	515.49	-0.26	2.02	-3.15	-0.57	-1.71	0.00	0.00	0.00	156%	III
6	J21A	854.17	-0.76	2.81	-6.81	-1.14	-5.13	-1.48	0.00	0.00	242%	III
7	J22K	478.81	0.00	0.90	-2.64	-0.70	-2.45	0.00	0.00	0.00	295%	III
8	J23A	761.62	-0.05	0.98	-7.19	-1.27	-7.48	0.00	0.00	0.00	735%	III
9	J24B	767.16	-0.03	0.75	-1.32	-1.10	-1.68	0.00	0.00	0.00	177%	III
10	J25B	396.57	-0.09	2.94	-2.85	-0.79	-0.70	-1.46	0.00	0.00	97%	III
11	J31A	447.04	0.00	3.36	-1.40	-1.59	0.37	0.00	0.00	0.37	42%	III
12	J33E	328.67	-0.30	3.18	-7.56	-1.15	-5.53	-1.17	0.00	0.00	238%	III
13	J33F	365.63	-0.75	2.77	-10.57	-1.04	-8.84	-1.22	0.00	0.00	382%	III
14	J34D	354.20	-0.04	3.44	-5.10	-0.95	-2.61	-0.69	0.00	0.00	148%	III
15	J34E	257.99	-0.03	2.16	-1.53	-0.62	0.02	-0.76	-0.02	0.00	71%	III
16	J34F	319.97	-0.06	2.56	-3.93	-0.88	-2.25	-1.59	0.00	0.00	154%	III
17	J35B	651.14	-0.13	5.88	-8.93	-1.78	-4.83	-0.47	0.00	0.00	152%	III
18	J35C	264.48	-0.08	1.84	-2.89	-0.50	-1.56	-0.99	0.00	0.00	158%	III
19	J35E	215.16	-0.03	0.85	-2.87	-0.46	-2.49	-1.78	0.00	0.00	339%	III
20	K10E	132.50	-0.09	2.10	-2.24	-0.54	-0.67	-0.79	0.00	0.00	106%	III
21	K20A	168.94	-0.21	2.79	-1.91	-0.42	0.46	-1.98	-0.46	0.00	69%	III
22	K30A	196.60	-0.15	3.30	-3.13	-0.35	-0.19	-2.27	0.00	0.00	95%	III
23	K30B	139.65	-0.14	2.38	-2.38	-0.62	-0.62	-2.40	0.00	0.00	100%	III
24	K30C	190.68	-3.22	3.36	-6.66	-0.64	-3.94	-6.63	0.00	0.00	198%	III
25	K30D	178.79	-0.22	3.34	-3.52	-0.96	-1.14	-0.82	0.00	0.00	105%	III
26	K40D	131.21	-0.44	3.00	-3.77	-0.40	-1.16	-1.03	0.00	0.00	126%	III
27	K50B	203.97	-0.32	4.87	-3.43	-0.57	0.86	-3.07	-0.86	0.00	70%	III
28	K60G	168.89	-0.50	4.68	-2.11	-0.46	2.10	-2.39	-2.10	0.00	45%	III
	Total	**10 593**	**-8.19**	**79.66**	**-129.26**	**-21.55**	**-71.16**	**-34.47**	**-3.44**	**0.37**		

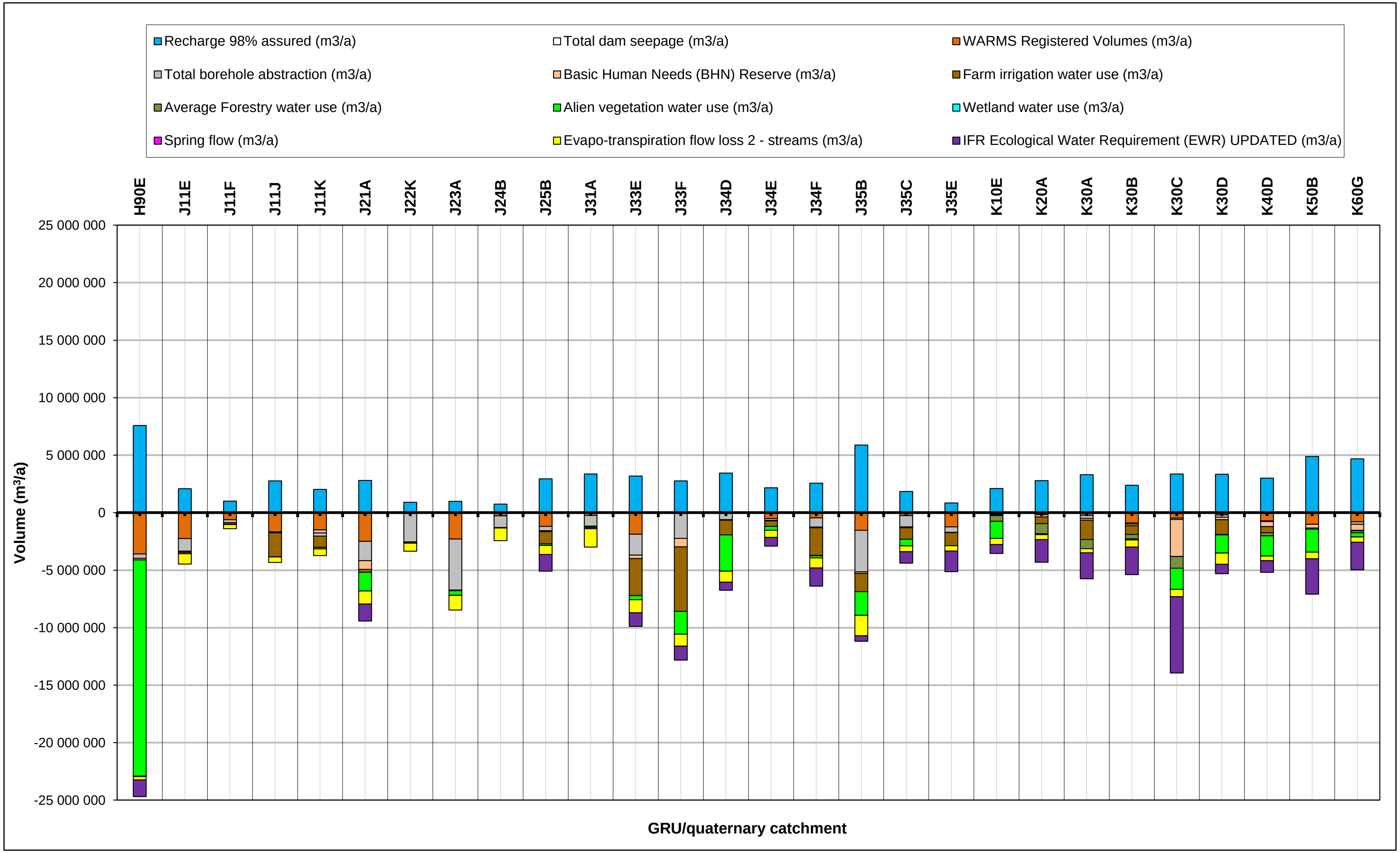


Figure 2.28 Graph of comparative contribution of sources and sinks in the GYMR Present day drought conditions scenario 2

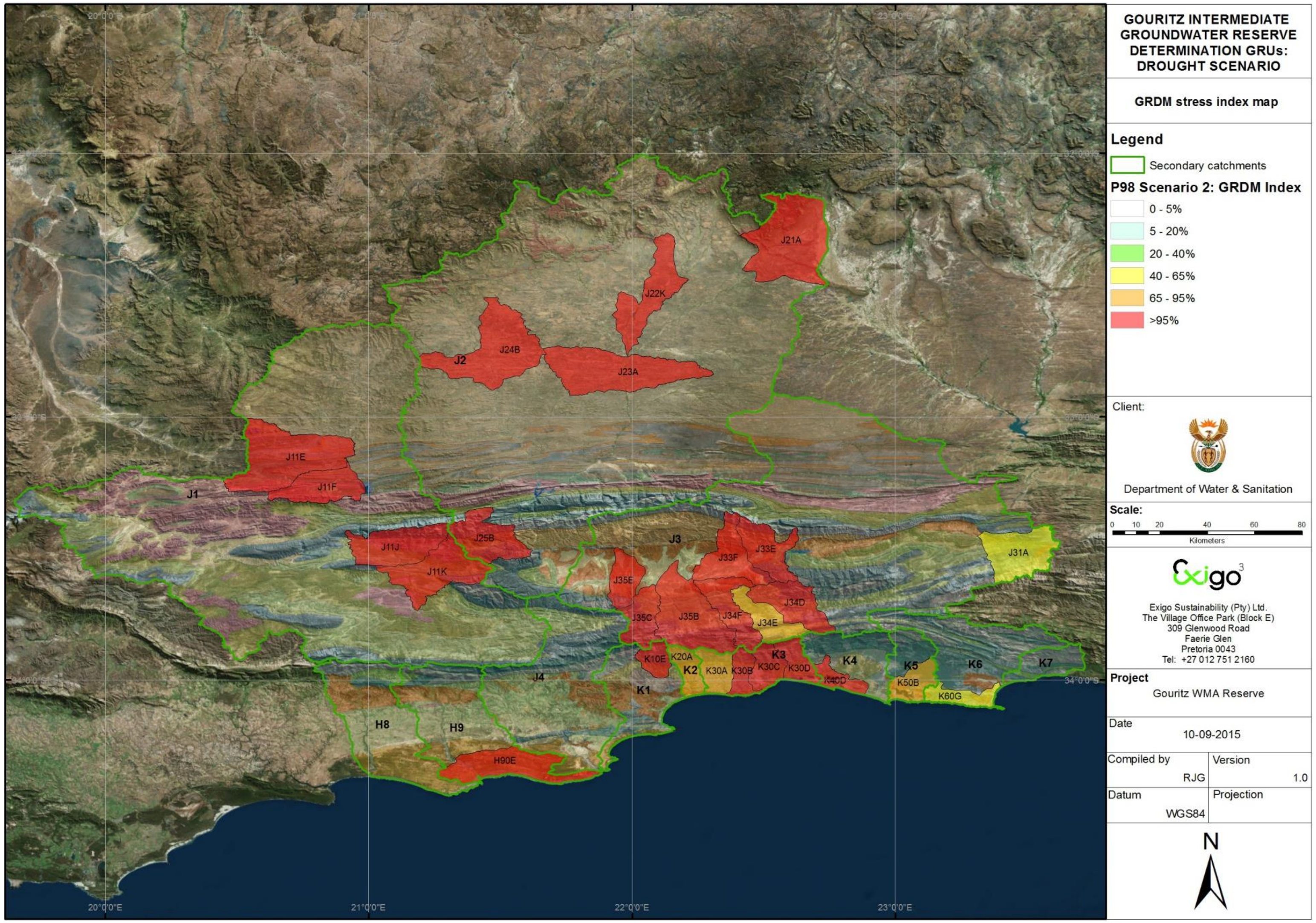


Figure 2.29 Map showing GRDM index per Intermediate Reserve catchment: Scenario 2: 98% assured rainfall (drought conditions)

2.8 DISCUSSION OF GYMR INTERMEDIATE RESERVE RESULTS

The steady-state groundwater balance for the 28 selected quaternary catchments (GRUs) and the DAGEOS deep confined aquifer was simulated using the GYMR model and the following points summarise the minimum groundwater balance results:

- Invasive alien vegetation is the largest potential groundwater discharge component in the Gouritz WMA and accounts for potentially 39 million m^3/a (10% of recharge) of groundwater removed from the system, based on land use data and literature estimates of alien vegetation water use. It is assumed that all alien vegetation use or reduce groundwater recharge.
- There is a good correlation between catchments indicated as stressed and deeper groundwater levels. This provides a check that catchments indicated as stressed are in fact experiencing groundwater stress.
- The Gouritz WMA is experiencing groundwater stress in a number of areas, more specifically in the Great Karoo basin as well as the Klein Karoo area and H90E. In the coastal areas further east, like K50B and K60G less groundwater stress is experienced due to the availability of surface water.
- In the present day (status quo) scenario, using MAP, eight catchments (29%) of the 28 selected catchments show a groundwater deficit.
- Total groundwater recharge for the selected quaternary catchments amount to 131 million m^3/a based on based MAP rainfall.
- Total groundwater outflows for the selected quaternary catchments before natural losses such as evapotranspiration and baseflow amount to 128.5 million m^3/a. These outflows include all spring outflows as well. The future groundwater development of the DAGEOS deep confined aquifer is excluded from this calculation for the shallow aquifers.
- In 1 in 50 year drought conditions (Scenario 2), with rainfall at a 98% level of assurance, 22 of the 28 selected quaternary catchments show a groundwater deficit. This shows that the methodology de-flagged six catchments that were analysed too conservatively in the Desktop-Rapid level Reserve iteration.
- Apart from alien vegetation there are also other large groundwater users in the Gouritz WMA:
    - Riparian zone water use and evapotranspiration along drainages (especially coastal belt) is estimated at ±31 million m^3/a.
    - WARMS registered groundwater uses total 26.5 million m^3/a.
    - Other existing borehole abstraction especially in the Great Karoo and Klein Karoo areas and the western coastal areas estimated at ±24 million m^3/a.
    - Irrigation from groundwater is estimated at 21.6 million m^3/a.
- There is a good record of registered groundwater uses as well as registered spring use as evidenced by the comparably large volume for the WARMS groundwater use component. These registered volumes are also reflected in the DWS All Towns Reconciliation Strategy documents for towns in the Gouritz WMA.
- The volumes of other existing borehole abstraction, irrigation and springs need to be further refined during the next phase of the Gouritz Reserve determination for selected water resources.
- EWR need to be further refined for the selected quaternary catchments / GRUs using satellite imagery to delineate significant aquatic ecosystems and calculate their water use away from riverine systems and risk based on interpolated groundwater levels. Currently the NFEPA

wetland spatial coverage was used and a wetland water use estimate calculated with sufficient allocations made to the wetlands in terms of the ecological requirements.

- The deep confined Peninsula Aquifer (RU 2) is recharged by inflow from RU 1 (Conceptual Models 2-1 to 2-3).
  - A FEFLOW conceptual numerical model was developed for the shallow and deep aquifers (RU 1 and RU 2) to determine the regional groundwater flow balance (Exigo, 2015). The potential flow from the shallower semi-confined surface aquifer (RU 1) to RU 2, under conditions of abstraction would in time reduce the baseflow contribution of RU 1.
  - From the groundwater modelling, it is expected that it would take 15 - 20 years for the planned abstraction of Phase 1 at 3.8 million m^3/a (120 ℓ/s) to affect the northern reaches of the shallow semi-confined aquifer along the Doring River. Increased leakage from surface streams due to abstraction may negate the depletion in storage, which would result in partial dewatering of the deep confined aquifer, but with an impact on the surface streams linked to RU 1.
  - Based on this assessment, the combined yield of RUs 1 and 2 is 8.2 million m^3/a, for average conditions (P_{50}) and the assured yield (P_{98}) at 5.2 million m^3/a. It is estimated that a yield of 1.5 million m^3/a, during average conditions and 1.0 million m^3/a during drought conditions, may be applicable for RU 2, the deep confined aquifer. This will however need to be proven with more detailed follow up monitoring and modelling. This figure is much lower than the current calculated yield of 14.8 million m^3/a (Riemann and Blake, 2010). The approved water use licence volume from RU1 and RU2 combined is however a minimum of 3.68 million m^3/a subject to an adaptive management approach. There is a Regional Bulk Infrastructure Grant (RBIG) study for Oudtshoorn deep groundwater development and aquifer modelling currently underway that should take the above flags that were raised into consideration, and provide updated estimates on aquifer parameters and DAGEOS scheme(s) available volumes.
  - It is important that secondary impacts on other high lying aquifers in the same system such as the Waboomskraal aquifer as well as on environmental components such as wetlands be taken into account when the long-term sustainable yield of the TMG regional aquifers (RU 1 and RU 2) is verified.
  - An option for long-term sustainable use of the deep confined aquifer is to utilise storage which can be replenished via surface water artificial recharge during flood peaks. If this is a management option, it will have to be evaluated in more detail through a detailed feasibility study.
- The EWR needs to be updated once the Preliminary Reserve EWR study component is completed.

2.9 COMPARISON AND BENCHMARKING OF GYMR RESULTS TO GRA II RESULTS

The allocable groundwater volumes available from baseflow from the GYMR groundwater balance were compared to the Average Groundwater Exploitation Potential (AGEP) and Utilisable Groundwater Exploitation Potential (UGEP) of the GRA II project (DWA, 2006). One of the biggest factors limiting the abstraction of groundwater volumes that are for instance given in the GYMR, is the inability to construct a network of suitably spaced production boreholes to abstract all the groundwater recharged to an aquifer system or regional scale catchment (AGES, 2005). The inability to construct such borehole networks are due to factors such as the low permeability or transmissivity of some aquifer units, aquifer heterogeneity, inaccessibility of some terrain to drilling rigs as well as unknown aquifer boundary conditions (AGES, 2005).

To this end the AGEP takes into consideration the hydrogeological character of the different formations in South Africa as well as practical problems such as inaccessibility of some terrain to drilling rigs.

It is also recognized that there are often legislative, anthropogenic and ecological considerations that also need to be taken into account during groundwater resource development. The UGEP was also developed during the GRA II project and takes the above mentioned aspects such as the basic human needs Reserve into consideration. Water quality was also taken into consideration in the UGEP.

Table 2.25 shows how the allocable groundwater from baseflow from the Intermediate Reserve compares to the AGEP and the UGEP from GRA II for present day MAP conditions. It is noted that groundwater volumes obtained during the Gouritz Intermediate level groundwater Reserve are conservative as a minimum groundwater balance approach was followed. The allocable groundwater available per quaternary catchment can be thought of as within the range created between the GYMR results and the UGEP results. This is due to the large amount of uncertainty associated with the recharge and various sinks in the groundwater system, e.g. WARMS volumes and existing borehole abstraction possible overlap or unsurveyed boreholes in use, irrigation from surface water or groundwater as well as alien vegetation losses (surface vs. groundwater). The figures reported in the Intermediate Reserve results tables (**Table 2.22**, **Table 2.24**) however remain the official Intermediate Reserve figures from this study. More allocable groundwater can be made available as figures are refined in future studies. It is recommended that groundwater recharge and discharge components (sinks) such as alien vegetation, irrigation and WARMS registered use vs. existing NGA boreholes abstraction be further constrained during the brief review of the classification phase.

Table 2.26 shows how the allocable groundwater from baseflow from the Intermediate Reserve compares to the AGEP and the UGEP from GRA II for present day under drought conditions.

Catchment J31A in the GYMR results is highlighted because there was no EWR estimate available for this catchment during this study. Its allocable groundwater volume available should thus be lower than the volume reported in the Intermediate Reserve GYMR results.

The GYMR Intermediate Reserve volumes in **Table 2.22** and **Table 2.24** contain the EWR volume estimates that need to be supported by groundwater contribution to baseflow and **Table 2.22** contains the volumes of groundwater contribution to EWR.

Table 2.25 Comparison of GYMR volumes and AGEP and UGEP GRA II volumes, present Day MAP conditions

No	Quaternary catchment	Total surface area (km^2)	AGEP MAP (m^3/a)	UGEP MAP (m^3/a)	Allocable GW from GW contribution to baseflow (m^3/a)
1	H90E	498.4	3 118 790	2 344 770	0
2	J11E	811.6	6 506 830	2 588 670	0
3	J11F	344.1	1 522 280	-707 637	647 014
4	J11J	449.5	3 886 940	3 209 680	745 205
5	J11K	515.5	3 891 550	2 114 150	0
6	J21A	854.2	6 764 960	893 734	0
7	J22K	478.8	1 442 880	-1 261 270	0
8	J23A	761.6	2 111 780	-2 631 030	0
9	J24B	767.2	2 397 650	1 078 010	718 672
10	J25B	396.6	1 942 740	1 579 150	327 039
11	J31A	447.0	4 087 220	3 234 040	4 003 398
12	J33E	328.7	4 052 560	1 061 250	0
13	J33F	365.6	2 443 500	1 249 430	0
14	J34D	354.2	2 487 870	1 689 840	0
15	J34E	258.0	2 204 130	1 501 440	844 764
16	J34F	320.0	2 573 670	1 294 970	0
17	J35B	651.1	6 244 420	4 124 860	0
18	J35C	264.5	1 186 370	788 380	0
19	J35E	215.2	710 452	103 633	0
20	K10E	132.5	5 589 990	5 328 130	7 944
21	K20A	168.9	6 698 280	6 507 810	106 748
22	K30A	196.6	8 667 300	8 401 750	0
23	K30B	139.6	7 007 550	6 774 780	0
24	K30C	190.7	9 355 310	9 206 790	0
25	K30D	178.8	5 817 000	5 388 350	0
26	K40D	131.2	5 662 950	5 758 740	0
27	K50B	204.0	7 683 120	7 543 680	0
28	K60G	168.9	2 200 110	1 495 400	1 574 877
	Total	**10 593**	**118 258 202**	**80 661 500**	**8 975 661**

Table 2.26 Comparison of GYMR volumes and AGEP and UGEP GRA II volumes, Present Day under drought conditions

No	Quaternary catchment	Total surface area (km²)	AGEP MAP (m³/a)	UGEP MAP (m³/a)	Allocable GW from GW contribution to baseflow (m³/a)
1	H90E	498.4	1 161 770	383 457	0
2	J11E	811.6	6 217 250	2 298 660	0
3	J11F	344.1	1 422 930	-807 236	0
4	J11J	449.5	2 833 880	2 144 120	0
5	J11K	515.5	3 343 410	1 575 370	0
6	J21A	854.2	5 987 570	122 325	0
7	J22K	478.8	1 375 530	-1 326 670	0
8	J23A	761.6	2 045 580	-2 697 180	0
9	J24B	767.2	2 301 230	980 722	0
10	J25B	396.6	1 207 190	841 501	0
11	J31A	447.0	2 798 370	1 961 280	368 953
12	J33E	328.7	2 775 160	-234 707	0
13	J33F	365.6	1 758 330	597 642	0
14	J34D	354.2	1 649 340	858 766	0
15	J34E	258.0	1 520 390	832 895	0
16	J34F	320.0	1 879 870	624 025	0
17	J35B	651.1	4 356 070	2 243 250	0
18	J35C	264.5	756 634	349 367	0
19	J35E	215.2	521 558	-70 477	0
20	K10E	132.5	3 650 170	3 418 640	0
21	K20A	168.9	4 411 340	4 198 100	0
22	K30A	196.6	6 068 610	5 783 870	0
23	K30B	139.6	4 896 560	4 664 940	0
24	K30C	190.7	6 277 160	6 090 610	0
25	K30D	178.8	3 432 610	3 073 430	0
26	K40D	131.2	3 909 930	3 918 410	0
27	K50B	204.0	4 813 510	4 652 940	0
28	K60G	168.9	1 032 870	361 888	0
	Total	**10 593**	**84 404 822**	**46 839 938**	**368 953**

2.10 GROUNDWATER DEVELOPMENT POTENTIAL

Much of the focus of this study so far was on the identification of potential stressed areas and to identify management and mitigation measures for these catchments. In the biggest part (78%) of the study area groundwater development is possible and the recommended option.

Groundwater potential is linked to the type of geological formation occurring within a catchment (**Table 2.6**) and a catchment showing little groundwater use vs. recharge does not necessarily mean it has high groundwater potential as it could be located on low yielding areas or an aquitard. Similarly it could be that a town is flagged as a hotspot, but that does not necessarily mean the whole quaternary catchment is off limits for another groundwater development further away from the town hotspot.

2.10.1 Alluvial and coastal aquifers

There are a number of coastal alluvial aquifers that can be utilised more effectively, provided that diligent groundwater monitoring is performed. The monitoring ensures that the hydraulic head in the coastal aquifer remains at a higher level than the ocean so as to not create sea water intrusion.

Another reason for the groundwater potential of coastal aquifers is their ability to recharge from rainfall and artificial recharge techniques should be implemented with potable/excess rainfall runoff water and through rainfall harvesting techniques.

In coastal aquifer cases such as H90E where significant alien vegetation areas are present, specialist studies should be done to quantify water use of the alien vegetation areas. If alien vegetation clearing is proven financially viable and justified given the volumes of water that would become available, these areas should be cleared first before development of the coastal aquifers is performed.

2.10.2 TMG aquifers: Peninsula Formation and Skurweberg Formation

The Peninsula Formation has in many studies (Umvoto, 2005; Jia, 2007; Xu *et al.*, 2009) been shown to have good aquifer characteristics except for a slightly low storage coefficient (10^{-5} to 10^{-3}). Since there are many springs (perennial and non-perennial) flowing from the TMG formations (Xu *et al.*, 2009), in tapping and utilising this aquifer, care should be taken to keep abstraction rates well within the range of water the Peninsula Aquifer can yield, to not incur excess mixing of oxidising waters with reducing waters as this would liberate more iron from the system. Intermittent abstraction with high abstraction rates has also shown to accelerate the mixing of the oxidising and reducing waters. The mixing has been shown to create iron bacteria clogging problems in well screens and borehole pumps. The dissolved iron is actually thought to be derived from the more argillaceous formations adjacent to the Peninsula and Skurweberg Formations, where the thickness (± 2000 m) and transmissivity of the Peninsula Formation limits the amount of iron drawn from adjacent formations compared to the Skurweberg Formation (±400 m thickness). New water treatment technologies are however available that can be used to remove iron cost effectively from drinking water supplies.

2.10.3 Karoo dolerite intrusions and Karoo Super Group Formations

The contact zones of dolerite intrusions in the form of dykes and sills remain good groundwater targets in the Great Karoo in northern part of the WMA, at locations where excessive borehole development and groundwater abstraction is not yet taking place. A wellfield aimed at effectively utilising Karoo aquifers require a number of successful boreholes to be located at an adequate distance (considering radius of influence and outer boundaries) from each other and these boreholes should then feed into one reticulation system. Too often it is seen that a number of boreholes are located close to the town and in very close proximity to each other targeting an aquifer usually consisting of a combination of limited thickness alluvium overlying a weathered zone of Beaufort Group or dolerite dyke. The local aquifer may have favourable aquifer parameters, but the concentrated abstraction is problematic, with the borehole radii of influence reaching each other and creating a compounding drawdown effect, while limiting the overall yield and well field efficiency.

2.10.4 Groundwater development volumes

The Desktop-Rapid Reserve was focused on flagging the potentially stressed catchments for the purposes of the Intermediate groundwater Reserve. The minimum allocable groundwater volumes determined at a minimum for average rainfall conditions (P_{50}) is 60 million m^3/a (1.1 mm/a), for average conditions (see **Figure 2.30**, **Appendix A**) and 31 million m^3/a (0.4 mm/a) for drought conditions (lower P_{98}) (**Figure 2.31**, **Appendix A**). To put this figure in perspective, 60 million m^3/a represents 23% of the surface water yield of 263 million m^3/a. It is the equivalent of 6 000 ha of irrigation and means that there is still high groundwater development potential. Additional groundwater development potential is available for 102 quaternary catchments which is more than 78% of the WMA. It must be noted that this volume is very conservative as it was assumed that groundwater losses are a given. Once groundwater is used, losses would decrease. If only 10% of the losses are used, then another 25 million m^3/a, could be freed. More detailed studies will have to be done to substantiate the origin of the losses. Should it be due to riparian vegetation, then less volume would be available than e.g. if it is alien vegetation.

The volumes of allocable groundwater produced during the Reserve determinations are also not an indication of how many boreholes would be or could be required to abstract this volume. It is unlikely that more than 50% of the recharge would be abstracted successfully in most of the low transmissivity aquifers.

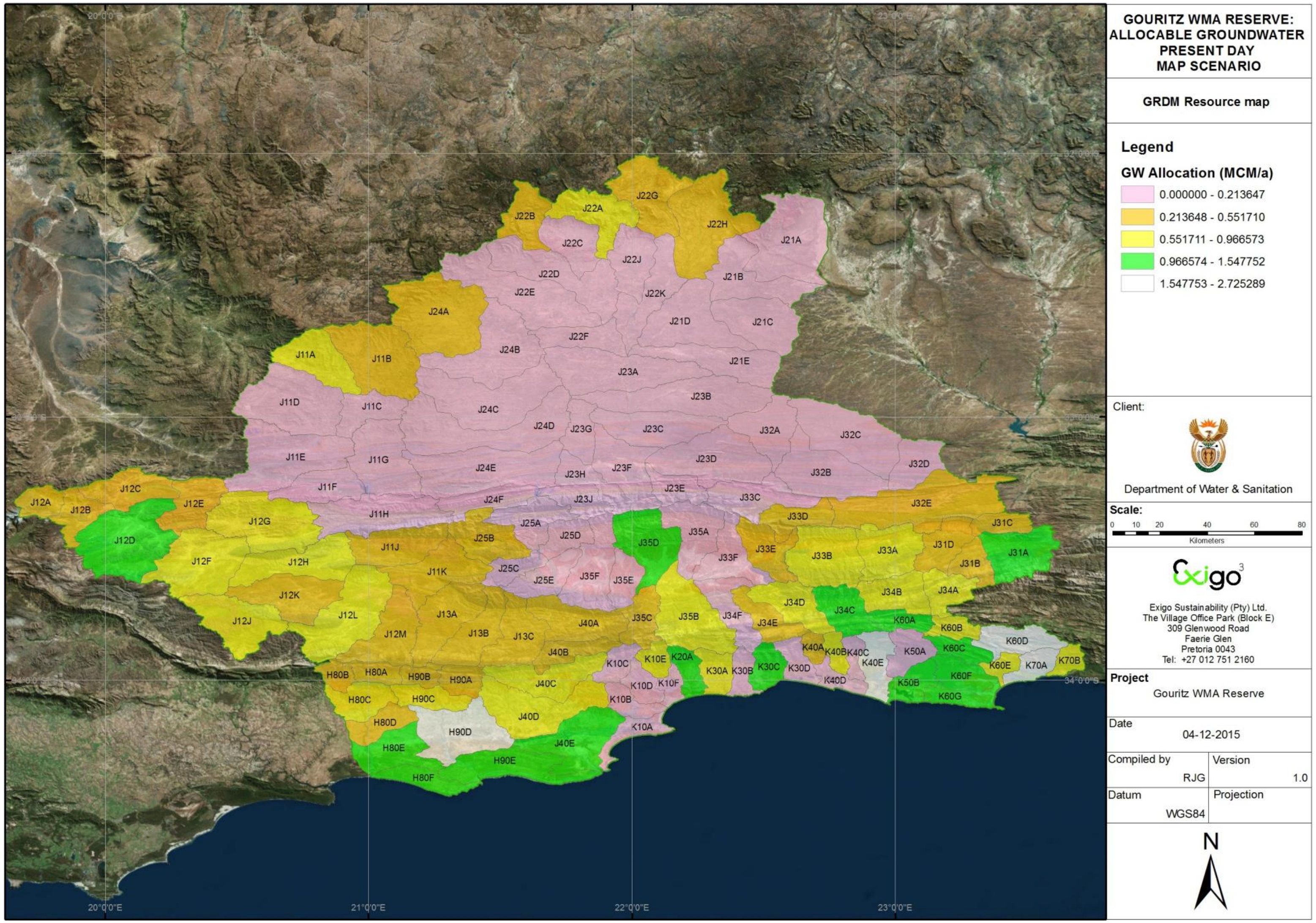


Figure 2.30 Groundwater development potential map – average conditions (P_{50})

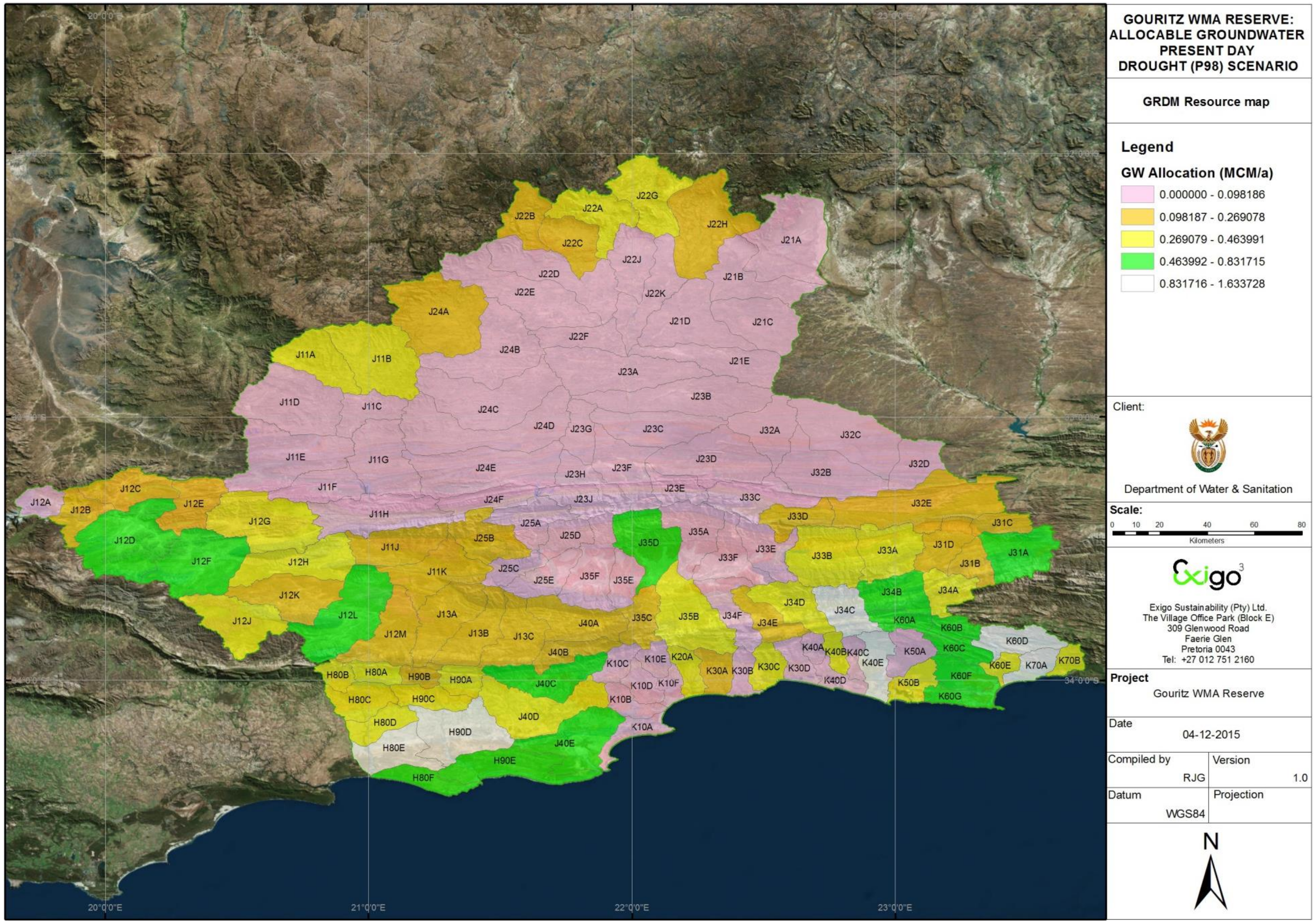


Figure 2.31 Groundwater development potential map – assured conditions (lower P_{98})

2.10.5 Benchmarking of groundwater results for the Reserve

From the various report reviews received, several aspects were highlighted. The main aspects that were flagged are listed below:

1. The GRDM should not include or be linked to a resource quantification component.
2. To make use of surface water quaternary catchments for groundwater may not or is not a valid approach.
3. The groundwater approach that was followed was very conservative and may lead to groundwater development constraints.
4. The groundwater contribution to base flow values that were used, were much too high and should be reviewed.
5. The groundwater contribution to EWR values that were used are too high and unsubstantiated.

The first two aspects are dealt with in **Appendix C** (**Section C7.5** and **C 7.7**). The rest of the aspects will be discussed at the end of this section. For the purposes of the benchmarking, overall parameters and outputs are compared for the whole catchment. There may be deviations on a smaller scale, which is not considered in this section.

The approach that was followed where data was limited and uncertain, and how the effects of scale was incorporated in the study, is described in **Appendix C**.

To be able to put the above into perspective, benchmarking was done on surface water quantities. The reality is that groundwater volumes or flows cannot be visually confirmed and only be measured at boreholes and these measurements are not available for most of the data that are available for groundwater use. Groundwater is seldom developed in quantities of more than 10 million m^3/a, per e.g. wellfield development. The highest groundwater abstraction in South Africa is from dewatering of mines that is 13 million m^3/a. To deal with groundwater quantities in the order of 100 million m^3/annum or more becomes a complex task as there are no field verifications for this order of magnitude of yields or flows. This section compares the groundwater volume from this study (GYMR) with the GRA II and surface water flows. It may not be absolutely correct in especially the drier regions of the study area where recharge could be more than runoff, but it is the only references available and would be the best available data set for comparison purposes.

The comparison between these studies indicates the following (**Table 2.27**):

- The surface water yield of 263 million m^3/a represents 16% of the Mean Annual Runoff (MAR) of 1680 million m^3/a.
- The *minimum* groundwater recharge from the GRDS (GYMR) is 450 million m^3/a for average conditions (P_{50}) and 268 million m^3/a for drought (P_{98}) conditions. The GRA II study indicates a recharge value of 714 million m^3/a, for average conditions (P_{50}) and 595 million m^3/a for dry conditions. The discrepancy is that the minimum recharge estimated for average conditions in the GYMR is 1.8 % of MAP and in the GRA II, it is 4%. The difference is that the GYMR makes allowance for reduced recharge with upscaling where GRA II uses wellfield type recharge which provides a higher "average" as wellfields are developed on pre-determined high potential groundwater zones – the so called "wellfield bias" and is considered by this study as too high

and unsubstantiated. The approach followed during this study is that if there is uncertainty, a minimum (or in some cases a maximum) value is used as to err on the safe side.

- GYMR makes provision for groundwater flow losses (i.e. evapotranspiration) in the order of 244 million m^3/a where the GRA II did not allow for any groundwater flow losses. A natural groundwater system is subjected to flow losses where shallow groundwater zones occur. Not taking groundwater flow losses into account is an important omission which can have a significant impact on the groundwater availability as a resource and for the Reserve.
- The GYMR also makes provision for allocation to non-riparian environmental components such as wetlands, reduced recharge in forestry areas and alien vegetation on groundwater availability.
- The GYMR's minimum groundwater contribution to base flow is 54 million m^3/a for average conditions whereas the GRA II estimates a value of 267 million m^3/a, which is 5 times higher. The higher value from GRA II is ascribed to a much higher average recharge and the fact that allowance is not made for groundwater flow losses.
- The total groundwater yield (existing + allocable) from the GYMR is 200 million m^3/a for average conditions (P_{50}) and 120 million m^3/a for dry conditions (P_{98}). The GRA II values are almost 40% higher at 327 million m^3/a for average conditions.
- The GRA II estimations do not make provision for the EWR component.

To determine values for groundwater parameters such as recharge, groundwater contribution to base flow and groundwater storage is very difficult. These parameters can only be estimated, calculated or modelled as it is very difficult and costly to determine using field tests and it is spatially and temporally variable. The GYMR's conservative approach in determining minimum volumes for groundwater recharge, allocable groundwater and the groundwater contribution to base flow is the best for decision-making and management purposes. Based on the minimax principle (**Appendix C**), more groundwater can only be credited when the resource is proven using more detailed field studies. It is much better to follow a bottom up approach than to have to reduce the resource yield as more data becomes available. It is more important to build trust into groundwater flow volumes or yield figures than to supply yield volumes that cannot be substantiated.

To get back to the review questions listed in 3 - 5 above, the following is concluded from this benchmarking section:

3. The conservatism that was used in the GYMR is not considered overly conservative as the minimum allocable groundwater component is still 60 million m^3/a, which represents 23% of the total surface water yield or 6000 ha of irrigation, which is a substantial volume of water. There is currently not sufficient evidence to defend a volume of additional groundwater in the order of 100 million m^3/a or more. This does not mean that the higher volumes of groundwater are not possible, what it does mean is that it has not been proven yet. Based on the decision-making process followed in the GYMR process, if it has not been proven yet, credit cannot be taken for it and instead a minimum is used. A counter argument could be that any very low value would suffice in the minimum groundwater flow balance approach. To evaluate this, the process and the outcomes need to be considered. In terms of the process, the groundwater flow value that was derived was based on sound spatial data and allowances were made for environmental components such as wetlands etc. In terms of the outcomes, only 28 (21%) of the 131

quaternary catchments flagged as potentially stressed. This is not reflective of an overly conservative approach.

4. In terms of the groundwater contribution to baseflow. Like recharge, it is a very difficult parameter to determine. The groundwater contribution to baseflow determined from this study is in the order of 54 million m^3/a for average conditions (P_{50}) and 33 million m^3/a for drought (P_{98}) conditions. In comparison, the GRA II values is 267 million m^3/a for average (P_{50}) conditions. The baseflow values used in this study is therefore *not* too high.
5. The EWR values were reviewed in this updated version as actual values were not available previously and a conservative estimate was used in the absence of actual values.

Most of the review comments that deal with the groundwater resource and availability for the Reserve are based on opinions and are not on actual data. It is important that actual and relevant data be used that opinions can be based on.

Table 2.27 Comparison between the GYMR, GRA II and surface water results

No	Component	GYMR (million m^3/a)	DWA 2004 (million m^3/a)	GRA II (million m^3/a)	Comment
1	MAR	1 680			
2	Surface water yield - P_{98}	263			16% of MAR
3	Irrigation from surface water	254			Equals 24500 ha of irrigation area
4	Base flow	114	114		
5	EWR		325		20% of MAR
6	EWR - groundwater contribution	32			10% of total EWR
7	Groundwater contribution to base flow - average (P_{50})	54		267	
8	Groundwater contribution to base flow - dry (P_{98})	33			
9	Groundwater recharge wet			833	
10	Groundwater recharge average (P_{50})	450		714	GRA II value calculated
11	Groundwater recharge dry (P_{98})	268		595	
12	Existing groundwater use	140	64	64	
13	Groundwater flow losses (ET)	244			
14	Allocable groundwater wet			301	
15	Allocable groundwater average	60		263	
16	Allocable groundwater dry	31		225	GRA II value calculated
17	Total groundwater yield average conditions	200		327	

3 CONCLUSIONS

- The Gouritz WMA covers a large area of 52 570 km^2 in the Southern and Western Cape Provinces. It contains 130 quaternary catchments and is the second largest water management area in the country and supports mainly agricultural and urban land use areas.
- The WMA can be divided into three regions. The southern coastal plain area between the Outeniqua Mountains and the ocean has a high rainfall and depends mostly on surface water. The Klein Karoo area, bounded by the Outeniqua Mountains in the south and Swartberg Mountains in the north, is underlain by the CFB formations. This area is in general very dry and relies partially on groundwater for water supply. The Great Karoo is located north of the Swartberg Mountains. This area is very dry and depends mostly on groundwater as a sole source of water supply.
- Groundwater forms an important part of the water resources in the Gouritz WMA. In the semi-arid areas north of the Outeniqua Mountains, the Klein Karoo and north of the Swartberg Mountains, groundwater is the only water resource during the winter months and during dry cycles. Groundwater supports water supply to local communities, towns and farms.
- The rainfall ranges from high at 882 mm/a in the coastal/orographic catchment K50B to a low of 127 mm/a in the Great Karoo in Catchment J23A. The average rainfall across the WMA is 463 mm/a. The Mean Annual Evaporation (MAE) is in the order of 1700 mm/a, which is more than double the MAP.
- The WMA is underlain by geology of the CFB and the Karoo Formations. The most important aquifers are formed by the TMG quartzitic sandstone, Karoo fractured aquifers associated with dolerite intrusions and the coastal shallow alluvial aquifers and Bredasdorp Group deposits. Of these, the Peninsula Formation and the Skurweberg Formation form the most important aquifers in the TMG and fractured Karoo formations. The presence of large scale faults in the TMG and dolerite dykes and faults in the Karoo formations are important areas where groundwater is developed.
- Deep groundwater is being developed at the Blossoms wellfield near Oudtshoorn as a source of water supply. The conceptual models that were developed and the groundwater Reserve that was determined indicates that the deep groundwater is a feasible option for water supply but the resource quantification and impacts on the Reserve must be determined adequately prior to large scale development. The current Blossoms wellfield is monitored, the data of which should be used to develop a regional three-dimensional numerical groundwater flow model which should be used to simulate the potential impacts on the Reserve components and to determine the sustainable yield of the aquifer system.
- The purpose of the Desktop-Rapid Reserve was to quantify the regional groundwater resources for the purpose of the Reserve and to focus the Intermediate Reserve on the relevant catchments. The Desktop-Rapid Reserve indicated that:
  - The minimum recharge in the WMA is estimated at 447 million m^3/a (8.5 mm/a), for average rainfall and 268 million m^3/a (5.1 mm/a) for assured rainfall or drought conditions. The average recharge across the regional WMA is minimum 1.8% of rainfall.
  - The groundwater contribution to baseflow is in the order of 54 million m^3/a (1 mm/a), for average conditions and 33 million m^3/a (0.6 mm/a), for dry cycles.
  - Current groundwater use is in the order of 140 million m^3/a (2.7 mm/a), and the BHN Reserve is in the order of 10 million m^3/a (0.2 mm/a).

- The allocable groundwater that is still available is 60 million m^3/a (1.1 mm/a), for average conditions and 31 million m^3/a (0.6 mm/a) for dry conditions. This means that additional groundwater development potential is available for 102 quaternary catchments which are more than 70% of the Gouritz WMA. Once groundwater is used, losses would decrease. If only 10% of the losses are used, then another 25 million m^3/a, could be freed. More detailed studies will have to be done to substantiate the origin of the losses. Should it be due to riparian vegetation, then less volume would be available than, e.g. if it is alien vegetation.
- A total of 28 of the 130 quaternary catchments classified with a high GRDM index under average conditions (P_{50}) which may be stressed. These catchments represent 20% of the total WMA that can be considered as potentially under stress. When assured recharge is considered at the lower P_{98}, then a total of 44 (34%) catchments flag as stressed. This means that even under 1:50 year drought conditions, 60% of the groundwater would still be available. Given that storage was not taken into account, it is expected that the droughts would be partially buffered and the 28 catchments that did flag as stressed under average conditions, could be less. These catchments were assessed in more detail in the Intermediate Reserve.

- While the groundwater yield for drought conditions (lower P_{98}) is 40% lower, the practical experience is that groundwater is used more during drought conditions when surface water is not available. This aspect will have to be dealt with in reconciliation strategies.
- If the groundwater Reserve determination provides a positive result on a catchment basis, it does not mean that there couldn't be over-abstraction on a localised or wellfield scale. Several areas and towns that could be regarded as groundwater hotspots and those with a high risk of over-abstraction were identified in this study. In most cases, the problem can be overcome by regional development of additional aquifers to alleviate the pressure on the local abstraction. This may mean that additional land or water rights have to be acquired.
- Hydrocensus results:
  - A total of 97 boreholes were surveyed during the optimised Gouritz hydrocensus.
  - The areas that were focused on were the Waboomskraal area (recharge area for the Peninsula Formation and DAGEOS aquifer), the middle- and upper-Olifants River as well as around the Kammanassie Mountain.
  - From groundwater level measurements taken the groundwater has a shallowest level of 0.21 magl (i.e. artesian), a deepest level of 100 mbgl (limited by dip meter) and a mean groundwater level of 16.32 mbgl.
- The groundwater quality of the regional area is generally good, but influenced by the local geology. The TMG aquifers have in general a high iron content that is exacerbated during abstraction when oxygen enters the system. The Bokkeveld- and Witteberg-Groups and the Dwyka Group in the Karoo have in general salinity problems. Most of the groundwater quality problems can be overcome with the latest water treatment technologies.
- The Intermediate Reserve was completed for the 28 catchments that were flagged (had a high GRDM index) in the Desktop-Rapid Reserve. The Intermediate Reserve results indicate that:
  - Alien vegetation has the potential to reduce the groundwater recharge and hence groundwater potential significantly.
  - Irrigation also has one of the biggest influences on the groundwater balance. When the irrigation land use and typical irrigation water use is considered, the volumes are so large

that it was concluded that there must be large surface water dams, river abstraction or irrigation canals present to justify these volumes. An assumption was made that 10 - 15% of all irrigation comes from groundwater. It is recommended that groundwater irrigation volumes be refined during the brief review in the classification phase of this Reserve study or that future studies focus on delineating groundwater only irrigation in the WMA.

- Deep confined Peninsula Aquifer (DAGEOS):
  - Based on the current information, the average yield (P_{50}) of the deep confined Peninsula Aquifer (RU2) is 1.5 million m^3/a, and the assured yield (98% assured) at 1.0 million m^3/a. The yield takes account of the interaction with the semi-confined surface aquifer and existing discharges as deep-seated springs and baseflow. This deep aquifer system is entirely reliant on recharge from the semi-confined surface aquifers (RU1) for its long-term sustainability. These yield estimates will however need to be verified with more detailed follow up monitoring and modelling.
  - The current management strategy is to utilise mainly storage that would result in partial dewatering of the aquifer over a period of time. This strategy is not recommended as the secondary impacts on the EWRs are not known.
  - However, should this be the preferred option, then the time to depletion, impacts on other Reserve components and the alternative or fall back water supply option once the resource has been depleted, must be determined.
  - The usable (i.e. drainable) volume in storage was calculated during this study at 130 million m^3 based on a 10% groundwater in storage use constraint. From Conceptual Models 2-2 and 2-3, if it is assumed that a maximum of 20 - 30% of this volume in storage could be accessible via boreholes at the current recommended abstraction of 3.8 million m^3/a (120 L/s), then it would take, depending on the actual recharge, between 6 - 20 years to deplete the volume in storage before adverse impacts are expected. This was shown by initial evaluations using numerical modelling, indicating that the zone of influence from abstraction at the Blossoms wellfield could reach the semi-confined surface aquifer within 10 - 20 years.
  - From Conceptual Model 2-4, the aquifer may not deplete as increased leakage from surface streams would be expected, which would impact on the Reserve. These conclusions will have to be refined and verified using detailed numerical groundwater flow modelling.
  - The deep confined Peninsula Aquifer (RU 2) is dependent on inflow from RU 1, has a high transmissivity and relatively low storativity. The absence of internal groundwater flow boundaries means that flow can take place across a large area which renders it a sensitive aquifer. Spatial impacts on environmental groundwater components such as surface water streams, riparian vegetation and wetlands are important.
  - There is a RBIG study for Oudtshoorn deep groundwater development and aquifer modelling currently underway that should take the above flags that were raised into consideration, and provide updated estimates on aquifer parameters and DAGEOS scheme(s) available volumes.
  - It is important that secondary impacts on other high lying aquifers in the same system such as the Waboomskraal as well as on environmental components such as wetlands be taken into account when the long-term sustainable yield of the TMG regional aquifers (RU1 and RU2) is verified.

- An option for long-term sustainable use of the deep confined aquifer is to utilise storage which can be replenished via surface water artificial recharge during flood peaks. If this is a management option, it will have to be evaluated in more detail through a detailed feasibility study.

- Based on this assessment, the combined yield of RU1 and RU2 is 8.2 million m^3/a, for average conditions (P_{50}) and the assured yield (lower P_{98}) at 5.2 million m^3/a.
- The Intermediate Reserve is useful as it focuses and prioritises future, detailed groundwater work within the WMA. Of particular importance are the catchments that are selected for alien vegetation eradication.
- The exploration and exploitation of deep shale gas in the Karoo Formations is an important future potential development in the Gouritz WMA. This should be done with due diligence as there is limited information available on the deep groundwater flow dynamics in the Karoo. Groundwater in the Karoo is the only resource of water supply for approximately one third of the study area. Two main risks were identified with regard to potential shale gas exploration and exploitation. The first is the toxicity of the fracking fluids and the second is the inferred artesian nature of the Karoo Basin.
- Groundwater development potential is possible in 70% of the catchments. The allocable groundwater potential is between a minimum of 31 million m^3/a to 60 million m^3/a if advantage can be taken from reducing losses.
- Conjunctive use between surface water and groundwater and artificial recharge are two future water use strategies that would be important to explore. Artificial recharge during times of flood or surplus flow conditions into deep aquifers could be a useful future strategy to store water for drought conditions.

4 RECOMMENDATIONS

1. Alien vegetation must be monitored and eradicated as far as possible in the WMA. The catchments that classified as the highest GRDM index should be targeted first. Alien vegetation should preferably be removed first in riparian-, spring- and wetland-areas. The water gained from Working for Water alien vegetation eradication programmes as well as the financial input for such programmes need to be justified, hence estimates of alien vegetation water use must be accurate (Mallory *et al.*, 2011).
2. More research is required to determine under which conditions more groundwater may be available if losses can be reduced.
3. Groundwater monitoring should be done across the WMA but with preference in the hotspot areas and catchments that classified with high GRDM stress indices.
4. Detailed groundwater investigations and numerical flow management models using models such as MIKE SHE and FEFLOW, should be developed to characterise catchments H90E, J33E and J33F to verify the role that groundwater storage can play in the buffering of dry cycles. It will be important to verify the water use quantities. The deep confined Peninsula Aquifer will require a detailed three-dimensional numerical groundwater flow model to refine and verify the yield.
5. The general authorizations in the 28 potentially stressed catchments must be reviewed and reduced to sustainable levels and in some cases it may be zero.
6. The yield of the semi-confined shallow aquifer (RU 1) and the deep confined Peninsula Aquifer (RU 2) must be quantified using detailed 3D numerical groundwater flow models based on the latest data sets. The potential constraints of protected areas and surface water features, e.g. streams and dams must be evaluated and environmental impacts qualified.
7. Detailed field investigations and models should be used to determine a buffer zone to mitigate saline water intrusion. This aspect should be further investigated at K40D, K50B, K40E and K10A.
8. The groundwater contribution to baseflow should be verified in the catchments that flagged with a high GRDM index rating. This must be done with sampling of the water quality changes and parameter tracing based on hydro-chemical mixing models.
9. Additional groundwater development in the hotspot and stressed areas should be prevented if the stressed status is verified. Options to regionally distribute groundwater abstraction to alleviate local concentrated abstraction should be investigated.
10. Groundwater contribution to surface water EWR volumes should be reviewed as part of Classification if possible.
11. Conjunctive use strategies between surface water and groundwater should be investigated and a guideline document be compiled that would account for the constraints in each catchment.
12. Artificial recharge should be considered as a future water management option. For aquifer types suitable for artificial recharge as well as artificial recharge methods that can be applied the reader is referred to the National Artificial Recharge strategy DWAF (2007b). Also see report by Murray *et al.* for DWA (2010b) of case studies in which artificial recharge has been successfully applied. Notably artificial recharge case studies include Prince Albert and Plettenberg Bay that fall within the Gouritz WMA study area.

13. The water management strategy for the deep confined TMG aquifers should be reviewed and a guideline document be compiled to ensure sustainable development and utilisation of the deep groundwater systems.
14. Shale gas exploration (fracking) in the Karoo formations should be done with due diligence and care should be taken not to adversely affect the groundwater quality and supplies. The level of information on the hydrogeology of the deep Karoo Aquifers is currently too limited to make informed decisions on this aspect. Progress has been made in improving knowledge on the processes of deep groundwater circulation in Karoo aquifers and their flow mechanisms, notably the study performed by the KGEG (Steyl *et al.*, 2012b) and more recently a study performed by Murray *et al*. (2015). Detailed groundwater investigations and baseline monitoring data must be collected before exploratory work is done.
15. Spillages from hydrocarbon fuel depots should be prevented or minimised with strict design, management and monitoring measures.

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APPENDIX A: GROUNDWATER RAPID RESERVE AND DEVELOPMENT POTENTIAL

A.1 RAPID RESERVE BASED ON AVERAGE RECHARGE (P_{50})

No	Catchment	Area (km^2)	MAP (mm/a)	P_{50} Recharge (MCM/a)	GW Base flow (MCM/a)	GW Use (MCM/a)	BHNR (MCM/a)	GW losses (MCM/a)	EWR (MCM/a)	Total Reserve (MCM/a)	Stress Index (%)	GW Allocation (MCM/a)	GRAII GW BF (MCM/a)
1	J32D	301.7	160	0.50	0.00	0.00	0.00	0.50	0.00	0.00	0%	0.10	0.00
2	J11A	437.6	295	2.84	0.00	0.01	0.00	2.84	0.00	0.00	0%	0.57	0.00
3	J12B	251.0	268	1.31	0.00	0.00	0.17	1.14	0.00	0.17	0%	0.23	0.00
4	J22A	436.1	233	3.14	0.00	0.01	0.00	3.13	0.00	0.00	0%	0.63	0.00
5	J32E	971.0	234	1.90	0.00	0.01	0.02	1.87	0.00	0.02	0%	0.37	0.00
6	J22B	321.6	205	1.19	0.00	0.01	0.00	1.18	0.00	0.00	1%	0.24	0.00
7	J22G	566.8	221	2.33	0.00	0.02	0.00	2.32	0.00	0.00	1%	0.46	0.00
8	J25E	286.5	245	0.69	0.00	0.01	0.01	0.67	0.00	0.01	1%	0.13	0.04
9	J12G	760.9	277	3.36	0.02	0.01	0.01	3.32	0.01	0.02	1%	0.67	0.00
10	J24A	926.0	203	2.25	0.00	0.03	0.00	2.23	0.00	0.00	1%	0.45	0.00
11	J11B	737.8	252	2.79	0.00	0.03	0.00	2.76	0.00	0.00	1%	0.55	0.00
12	J23G	240.6	98	0.50	0.00	0.01	0.00	0.49	0.00	0.00	1%	0.10	0.00
13	J22C	364.3	197	1.07	0.00	0.02	0.01	1.05	0.00	0.01	2%	0.21	0.00
14	J12E	355.7	307	1.96	0.03	0.01	0.01	1.91	0.01	0.03	2%	0.39	0.00
15	J23D	707.7	178	0.74	0.00	0.02	0.00	0.73	0.00	0.00	2%	0.15	0.00
16	J32C	734.5	136	0.50	0.00	0.02	0.00	0.48	0.00	0.00	3%	0.10	0.00
17	J22H	807.3	230	1.64	0.01	0.05	0.02	1.55	0.01	0.03	4%	0.31	0.00
18	J13C	435.1	351	2.14	0.05	0.03	0.00	2.05	0.02	0.03	4%	0.42	0.00
19	J24E	862.2	134	0.45	0.00	0.02	0.00	0.43	0.00	0.00	4%	0.09	0.00
20	J24D	926.1	128	0.50	0.00	0.02	0.01	0.47	0.00	0.01	4%	0.09	0.00
21	J23C	514.4	124	0.25	0.00	0.01	0.00	0.24	0.00	0.00	5%	0.05	0.00
22	J31C	167.9	369	1.99	0.08	0.02	0.00	1.89	0.03	0.05	5%	0.39	0.38
23	J11C	292.2	204	0.18	0.00	0.01	0.00	0.17	0.00	0.00	5%	0.03	0.00
24	J12K	516.6	193	2.10	0.00	0.12	0.00	1.98	0.00	0.00	6%	0.40	0.00
25	J12F	709.9	245	5.17	0.00	0.33	0.01	4.83	0.00	0.01	6%	0.97	0.00
26	J33A	449.4	393	3.35	0.20	0.01	0.00	3.14	0.08	0.13	6%	0.65	1.45
27	J12M	483.0	290	2.35	0.03	0.13	0.00	2.19	0.01	0.02	7%	0.44	0.00
28	J12H	549.4	260	3.10	0.00	0.22	0.00	2.88	0.00	0.00	7%	0.58	0.00
29	H80E	373.4	431	7.99	0.57	0.01	0.01	7.40	0.23	0.35	7%	1.55	2.12
30	J12L	757.6	314	4.93	0.08	0.28	0.01	4.55	0.03	0.06	7%	0.92	0.00
31	J31B	200.5	359	1.46	0.11	0.00	0.00	1.35	0.04	0.06	7%	0.28	0.48
32	J34A	252.1	477	3.15	0.23	0.02	0.16	2.74	0.09	0.30	8%	0.58	1.50
33	J12C	366.0	287	1.29	0.00	0.10	0.00	1.18	0.00	0.00	8%	0.24	0.00
34	J34B	341.5	569	4.99	0.43	0.01	0.04	4.51	0.17	0.30	9%	0.95	2.86
35	J12J	548.9	250	4.38	0.00	0.40	0.00	3.98	0.00	0.00	9%	0.80	0.00
36	J34C	318.9	674	7.95	0.72	0.00	0.01	7.21	0.29	0.45	9%	1.53	3.46
37	J31A	446.8	441	7.36	0.36	0.32	0.00	6.68	0.14	0.21	9%	1.38	1.42
38	H90D	602.1	425	10.10	0.92	0.02	0.04	9.13	0.37	0.59	9%	1.94	3.31

No	Catchment	Area (km^2)	MAP (mm/a)	P_{50} Recharge (MCM/a)	GW Base flow (MCM/a)	GW Use (MCM/a)	BHNR (MCM/a)	GW losses (MCM/a)	EWR (MCM/a)	Total Reserve (MCM/a)	Stress Index (%)	GW Allocation (MCM/a)	GRAII GW BF (MCM/a)
39	H80F	203.6	533	5.49	0.55	0.01	0.01	4.92	0.22	0.34	10%	1.05	2.82
40	J24B	767.7	160	0.49	0.00	0.05	0.03	0.41	0.00	0.03	10%	0.08	0.00
41	J31D	303.6	300	2.04	0.11	0.10	0.01	1.82	0.04	0.07	10%	0.38	0.47
42	J34D	354.3	471	3.34	0.38	0.01	0.04	2.92	0.15	0.27	11%	0.63	1.77
43	J32B	642.8	160	0.10	0.00	0.01	0.02	0.07	0.00	0.02	12%	0.01	0.00
44	J24C	861.3	146	0.13	0.00	0.02	0.00	0.11	0.00	0.00	13%	0.02	0.00
45	H80D	230.7	413	2.67	0.33	0.01	0.00	2.33	0.13	0.20	13%	0.51	1.23
46	J12D	830.9	289	6.41	0.00	0.81	0.01	5.59	0.00	0.01	13%	1.12	0.00
47	J34E	258.1	427	2.31	0.30	0.00	0.03	1.98	0.12	0.21	13%	0.43	1.16
48	J35C	264.6	373	1.40	0.19	0.00	0.08	1.13	0.07	0.19	14%	0.25	0.88
49	J13B	401.8	306	2.07	0.02	0.28	0.01	1.76	0.01	0.03	15%	0.35	0.00
50	J32A	415.2	154	0.06	0.00	0.01	0.00	0.05	0.00	0.00	15%	0.01	0.00
51	J25C	180.6	288	0.76	0.00	0.12	0.03	0.62	0.00	0.03	15%	0.12	0.05
52	J11G	604.3	166	0.10	0.00	0.02	0.00	0.08	0.00	0.00	16%	0.02	0.00
53	H90C	217.6	467	3.55	0.57	0.01	0.41	2.57	0.23	0.75	16%	0.58	1.88
54	J25A	353.6	289	0.69	0.11	0.01	0.00	0.57	0.04	0.07	16%	0.13	1.02
55	J40E	554.2	440	6.48	1.09	0.05	0.04	5.30	0.44	0.70	18%	1.19	3.48
56	J11K	515.9	221	2.12	0.00	0.40	0.26	1.47	0.00	0.26	19%	0.29	0.00
57	H80C	284.8	479	4.20	0.77	0.03	0.22	3.18	0.31	0.69	19%	0.73	2.92
58	K70B	106.4	997	3.40	0.68	0.00	0.02	2.70	0.27	2.27	20%	0.62	4.58
59	K60D	292.5	815	14.83	2.97	0.00	0.01	11.85	1.19	6.99	20%	2.73	12.35
60	K60F	242.1	807	7.94	1.59	0.00	0.22	6.13	0.64	2.58	20%	1.42	9.39
61	K60C	160.8	744	6.34	1.27	0.00	0.04	5.04	0.51	3.09	20%	1.16	6.64
62	K60A	161.4	664	5.57	1.11	0.00	0.00	4.45	0.45	1.50	20%	1.02	4.15
63	K60B	143.2	754	4.64	0.93	0.00	0.00	3.71	0.37	2.61	20%	0.85	5.78
64	H80B	123.0	792	2.52	0.50	0.00	0.00	2.01	0.20	2.99	20%	0.46	6.41
65	H90B	118.2	664	2.44	0.49	0.00	0.00	1.95	0.20	2.48	20%	0.45	6.07
66	H90A	179.1	645	2.95	0.59	0.01	0.00	2.35	0.24	2.62	20%	0.54	9.40
67	H80A	149.0	597	2.88	0.58	0.01	0.00	2.30	0.23	2.21	20%	0.53	7.22
68	J35D	507.2	407	5.58	1.12	0.01	0.12	4.33	0.45	1.09	20%	1.00	3.66
69	J35E	215.3	270	0.83	0.17	0.00	0.03	0.64	0.07	0.14	20%	0.15	0.88
70	J33F	365.8	343	1.77	0.35	0.01	0.75	0.66	0.14	1.16	21%	0.18	2.23
71	K60E	100.2	775	3.75	0.75	0.03	0.05	2.91	0.30	1.24	21%	0.67	3.91
72	J40B	222.0	431	1.65	0.33	0.02	0.00	1.30	0.13	0.41	21%	0.30	2.70
73	J25B	396.9	326	2.20	0.37	0.11	0.09	1.63	0.15	0.31	22%	0.37	1.34
74	K70A	170.3	920	11.75	2.35	0.22	0.12	9.06	0.94	3.24	22%	2.09	7.10
75	J40C	436.3	521	4.82	0.96	0.10	0.02	3.74	0.39	1.37	22%	0.86	6.64
76	J40A	453.6	418	2.25	0.45	0.08	0.02	1.70	0.18	0.79	23%	0.39	5.14
77	J22J	377.6	187	0.78	0.00	0.18	0.00	0.59	0.00	0.00	24%	0.12	0.00
78	J22D	680.5	162	1.10	0.00	0.31	0.00	0.79	0.00	0.00	28%	0.16	0.00
79	J33B	590.8	437	4.92	0.29	1.13	0.01	3.48	0.12	0.19	29%	0.73	2.36
80	J12A	180.8	437	1.61	0.00	0.48	0.00	1.14	0.00	0.00	30%	0.23	0.00
81	J33D	258.9	379	2.27	0.33	0.39	0.01	1.55	0.13	0.20	32%	0.35	1.57
82	J40D	655.0	446	5.79	1.16	0.70	0.18	3.75	0.46	1.00	32%	0.89	4.26
83	J25D	210.4	365	1.10	0.22	0.18	0.11	0.59	0.09	0.30	37%	0.14	0.77

No	Catchment	Area (km^2)	MAP (mm/a)	P_{50} Recharge (MCM/a)	GW Base flow (MCM/a)	GW Use (MCM/a)	BHNR (MCM/a)	GW losses (MCM/a)	EWR (MCM/a)	Total Reserve (MCM/a)	Stress Index (%)	GW Allocation (MCM/a)	GRAII GW BF (MCM/a)
84	J13A	518.0	295	3.00	0.03	1.10	0.00	1.87	0.01	0.02	38%	0.38	0.00
85	H90E	495.7	490	8.77	1.03	2.32	0.14	5.28	0.41	0.75	38%	1.18	5.26
86	J22E	833.9	159	1.06	0.00	0.41	0.00	0.65	0.00	0.00	38%	0.13	0.00
87	J11J	449.8	304	3.76	0.02	1.44	0.03	2.26	0.01	0.04	39%	0.46	0.00
88	K60G	166.6	860	7.30	1.46	1.40	0.00	4.44	0.58	1.90	39%	1.06	6.91
89	J35B	651.4	411	6.28	0.53	1.99	0.13	3.63	0.21	0.44	40%	0.79	2.66
90	K40E	267.6	864	19.10	2.40	5.60	0.00	11.10	0.96	2.40	42%	2.51	10.58
91	J33E	328.8	446	2.39	0.48	0.56	0.30	1.06	0.19	0.67	43%	0.27	2.45
92	K30C	190.1	805	12.70	2.40	3.80	1.30	5.20	0.96	2.80	49%	1.33	8.02
93	J33C	428.1	293	2.12	0.00	1.05	0.00	1.07	0.00	0.00	50%	0.21	0.13
94	J11E	812.2	188	1.22	0.00	0.62	0.10	0.50	0.00	0.10	51%	0.10	0.00
95	K20A	168.5	722	11.70	1.20	4.80	0.10	5.60	0.48	1.30	51%	1.26	6.08
96	K40B	111.6	846	7.30	1.20	2.60	0.00	3.50	0.48	1.20	52%	0.84	4.85
97	K50B	202.9	882	14.40	2.30	5.40	0.70	6.00	0.92	2.40	53%	1.48	8.77
98	K10A	177.5	450	2.50	0.50	0.90	0.80	0.30	0.20	1.80	56%	0.12	1.20
99	K30A	196.0	753	8.60	1.40	3.70	0.10	3.40	0.56	1.50	59%	0.85	7.23
100	J23J	228.6	308	0.35	0.05	0.16	0.00	0.13	0.02	0.03	61%	0.03	0.96
101	K10E	132.6	679	6.50	1.20	2.80	0.00	2.50	0.48	1.20	62%	0.64	4.26
102	K40A	87.5	706	5.50	0.80	2.70	0.00	2.00	0.32	0.40	64%	0.50	3.97
103	K40C	99.6	930	6.90	1.20	3.40	0.00	2.30	0.48	0.80	67%	0.00	4.41
104	J34F	320.1	415	2.21	0.28	1.26	0.06	0.60	0.11	0.23	70%	0.00	1.28
105	J21B	530.3	188	0.47	0.00	0.33	0.01	0.13	0.00	0.01	71%	0.00	0.00
106	J35F	500.4	341	2.30	0.46	1.20	0.06	0.58	0.18	0.53	72%	0.00	3.00
107	K50A	235.4	850	5.10	1.02	2.80	0.00	1.28	0.41	3.00	75%	0.00	10.05
108	J35A	427.6	418	4.55	0.91	2.53	0.68	0.43	0.36	1.43	76%	0.00	3.10
109	K10F	105.8	502	2.70	0.54	1.70	0.10	0.36	0.22	0.80	83%	0.00	1.03
110	K30D	177.9	724	6.90	1.38	4.60	0.00	0.92	0.55	1.70	87%	0.00	7.52
111	J11D	801.2	241	3.28	0.00	9.31	0.00	-6.03	0.00	0.00	>100%	0.00	0.00
112	J11F	344.4	209	0.43	0.00	1.16	0.02	-0.75	0.00	0.02	>100%	0.00	0.00
113	J11H	651.4	240	3.75	0.00	7.10	0.02	-3.36	0.00	0.02	>100%	0.00	0.00
114	J21A	854.4	230	2.85	0.02	5.89	0.76	-3.82	0.01	0.77	>100%	0.00	0.00
115	J21C	526.1	166	0.09	0.00	0.28	0.01	-0.20	0.00	0.01	>100%	0.00	0.00
116	J21D	649.6	155	0.30	0.00	0.86	0.00	-0.56	0.00	0.00	>100%	0.00	0.00
117	J21E	504.4	154	0.23	0.00	0.39	0.00	-0.16	0.00	0.00	>100%	0.00	0.00
118	J22F	295.9	118	0.10	0.00	0.84	0.03	-0.76	0.00	0.03	>100%	0.00	0.00
119	J22K	479.1	151	0.36	0.00	5.74	0.00	-5.38	0.00	0.00	>100%	0.00	0.00
120	J23A	762.1	127	0.29	0.00	10.96	0.05	-10.71	0.00	0.05	>100%	0.00	0.00
121	J23B	782.2	147	0.46	0.00	1.82	0.00	-1.36	0.00	0.00	>100%	0.00	0.00
122	J23E	225.1	329	1.54	0.20	2.43	0.01	-1.11	0.08	0.14	>100%	0.00	1.08
123	J23F	477.6	194	0.79	0.00	3.15	0.15	-2.51	0.00	0.15	>100%	0.00	0.00
124	J23H	264.2	199	0.50	0.00	0.56	0.00	-0.06	0.00	0.00	>100%	0.00	0.00
125	J24F	282.4	222	1.15	0.00	1.22	0.00	-0.07	0.00	0.00	>100%	0.00	0.00
126	K10B	171.2	446	1.60	0.32	1.30	0.00	-0.02	0.13	1.00	>100%	0.00	1.21
127	K10C	159.0	493	1.70	0.34	1.70	0.00	-0.34	0.14	1.00	>100%	0.00	2.32

No	Catchment	Area (km^2)	MAP (mm/a)	P_{50} Recharge (MCM/a)	GW Base flow (MCM/a)	GW Use (MCM/a)	BHNR (MCM/a)	GW losses (MCM/a)	EWR (MCM/a)	Total Reserve (MCM/a)	Stress Index (%)	GW Allocation (MCM/a)	GRAII GW BF (MCM/a)
128	K10D	164.0	454	1.80	0.36	1.60	0.00	-0.16	0.14	1.00	>100%	0.00	1.08
129	K30B	138.6	787	7.00	1.20	5.90	0.30	-0.40	0.48	1.50	>100%	0.00	5.07
130	K40D	129.8	757	9.00	1.30	7.80	0.10	-0.20	0.52	1.40	>100%	0.00	3.68
	Total	**52571.1**		**447**	**54**	**139**	**10**	**244**	**22**	**82**		**60**	**267**
	Avg	**404.4**	**398**	**3**	**0**	**1**	**0**	**2**	**0**	**1**		**0**	**2**
	mm/a			**8.5**	**1.0**	**2.7**	**0.2**	**4.6**	**0.4**	**1.6**		**1.1**	**5.1**

A.2 RAPID RESERVE BASED ON DROUGHT RECHARGE (LOWER P_{98})

No	Catchment	Area (km^2)	P_{98} Recharge (MCM/a)	GW Base flow (MCM/a)	GW Use (MCM/a)	BHN Reserve (MCM/a)	GW losses (MCM/a)	EWR (MCM/a)	Total Reserve (MCM/a)	Stress Index (%)	GW Allocation (MCM/a)	GRAII GW BF (MCM/a)
1	J32D	301.7	0.30	0.00	0.00	0.00	0.30	0.00	0.00	0%	0.06	0.00
2	J11A	437.6	1.71	0.00	0.01	0.00	1.70	0.00	0.00	0%	0.34	0.00
3	J12B	251.0	0.79	0.00	0.00	0.17	0.61	0.00	0.17	0%	0.12	0.00
4	J22A	436.1	1.88	0.00	0.01	0.00	1.87	0.00	0.00	1%	0.37	0.00
5	J32E	971.0	1.14	0.00	0.01	0.02	1.12	0.00	0.02	1%	0.22	0.00
6	J22B	321.6	0.71	0.00	0.01	0.00	0.71	0.00	0.00	1%	0.14	0.00
7	J22G	566.8	1.40	0.00	0.02	0.00	1.38	0.00	0.00	1%	0.28	0.00
9	J12G	760.9	2.02	0.01	0.01	0.01	1.99	0.00	0.02	1%	0.40	0.00
8	J25E	286.5	0.41	0.00	0.01	0.01	0.40	0.00	0.01	2%	0.08	0.04
10	J24A	926.0	1.35	0.00	0.03	0.00	1.32	0.00	0.00	2%	0.26	0.00
11	J11B	737.8	1.67	0.00	0.03	0.00	1.64	0.00	0.00	2%	0.33	0.00
12	J23G	240.6	0.30	0.00	0.01	0.00	0.29	0.00	0.00	2%	0.06	0.00
14	J12E	355.7	1.18	0.02	0.01	0.01	1.14	0.01	0.03	2%	0.23	0.00
13	J22C	364.3	0.64	0.00	0.02	0.01	0.62	0.00	0.01	3%	0.12	0.00
15	J23D	707.7	0.45	0.00	0.02	0.00	0.43	0.00	0.00	4%	0.09	0.00
18	J13C	435.1	1.28	0.03	0.03	0.00	1.21	0.01	0.03	5%	0.25	0.00
16	J32C	734.5	0.30	0.00	0.02	0.00	0.28	0.00	0.00	5%	0.06	0.00
17	J22H	807.3	0.98	0.01	0.05	0.02	0.91	0.00	0.03	6%	0.18	0.00
22	J31C	167.9	1.19	0.05	0.02	0.00	1.12	0.02	0.05	6%	0.23	0.38
26	J33A	449.4	2.01	0.12	0.01	0.00	1.88	0.05	0.13	7%	0.39	1.45
19	J24E	862.2	0.27	0.00	0.02	0.00	0.25	0.00	0.00	7%	0.05	0.00
29	H80E	373.4	4.79	0.34	0.01	0.01	4.43	0.14	0.35	7%	0.93	2.12
20	J24D	926.1	0.30	0.00	0.02	0.01	0.27	0.00	0.01	7%	0.05	0.00
31	J31B	200.5	0.87	0.06	0.00	0.00	0.81	0.03	0.06	8%	0.17	0.48
32	J34A	252.1	1.89	0.14	0.02	0.16	1.57	0.06	0.30	8%	0.33	1.50
21	J23C	514.4	0.15	0.00	0.01	0.00	0.14	0.00	0.00	8%	0.03	0.00
23	J11C	292.2	0.11	0.00	0.01	0.00	0.09	0.00	0.00	9%	0.02	0.00
34	J34B	341.5	3.00	0.26	0.01	0.04	2.69	0.10	0.30	9%	0.57	2.86
36	J34C	318.9	4.77	0.43	0.00	0.01	4.32	0.17	0.45	9%	0.92	3.46
38	H90D	602.1	6.06	0.55	0.02	0.04	5.45	0.22	0.59	9%	1.16	3.31
24	J12K	516.6	1.26	0.00	0.12	0.00	1.14	0.00	0.00	10%	0.23	0.00
39	H80F	203.6	3.29	0.33	0.01	0.01	2.94	0.13	0.34	10%	0.63	2.82
27	J12M	483.0	1.41	0.02	0.13	0.00	1.26	0.01	0.02	10%	0.25	0.00
25	J12F	709.9	3.10	0.00	0.33	0.01	2.77	0.00	0.01	11%	0.55	0.00
30	J12L	757.6	2.96	0.05	0.28	0.01	2.61	0.02	0.06	11%	0.53	0.00
42	J34D	354.3	2.01	0.23	0.01	0.04	1.73	0.09	0.27	12%	0.37	1.77
28	J12H	549.4	1.86	0.00	0.22	0.00	1.64	0.00	0.00	12%	0.33	0.00
37	J31A	446.8	4.42	0.21	0.32	0.00	3.88	0.09	0.21	12%	0.80	1.42
45	H80D	230.7	1.60	0.20	0.01	0.00	1.40	0.08	0.20	13%	0.30	1.23
47	J34E	258.1	1.39	0.18	0.00	0.03	1.17	0.07	0.21	13%	0.26	1.16
33	J12C	366.0	0.77	0.00	0.10	0.00	0.67	0.00	0.00	13%	0.13	0.00
41	J31D	303.6	1.22	0.07	0.10	0.01	1.05	0.03	0.07	13%	0.22	0.47

No	Catchment	Area (km^2)	P_{98} Recharge (MCM/a)	GW Base flow (MCM/a)	GW Use (MCM/a)	BHN Reserve (MCM/a)	GW losses (MCM/a)	EWR (MCM/a)	Total Reserve (MCM/a)	Stress Index (%)	GW Allocation (MCM/a)	GRAII GW BF (MCM/a)
48	J35C	264.6	0.84	0.11	0.00	0.08	0.65	0.04	0.19	14%	0.14	0.88
35	J12J	548.9	2.63	0.00	0.40	0.00	2.23	0.00	0.00	15%	0.45	0.00
53	H90C	217.6	2.13	0.34	0.01	0.41	1.38	0.14	0.75	16%	0.32	1.88
54	J25A	353.6	0.41	0.06	0.01	0.00	0.34	0.03	0.07	17%	0.08	1.02
40	J24B	767.7	0.30	0.00	0.05	0.03	0.21	0.00	0.03	17%	0.04	0.00
55	J40E	554.2	3.89	0.66	0.05	0.04	3.14	0.26	0.70	18%	0.71	3.48
57	H80C	284.8	2.52	0.46	0.03	0.22	1.81	0.19	0.69	20%	0.42	2.92
58	K70B	106.4	2.04	0.41	0.00	0.02	1.61	0.16	2.27	20%	0.37	4.58
59	K60D	292.5	8.90	1.78	0.00	0.01	7.10	0.71	6.99	20%	1.63	12.35
60	K60F	242.1	4.76	0.95	0.00	0.22	3.59	0.38	2.58	20%	0.83	9.39
61	K60C	160.8	3.81	0.76	0.00	0.04	3.01	0.30	3.09	20%	0.69	6.64
62	K60A	161.4	3.34	0.67	0.00	0.00	2.67	0.27	1.50	20%	0.61	4.15
63	K60B	143.2	2.78	0.56	0.00	0.00	2.22	0.22	2.61	20%	0.51	5.78
64	H80B	123.0	1.51	0.30	0.00	0.00	1.21	0.12	2.99	20%	0.28	6.41
65	H90B	118.2	1.47	0.29	0.00	0.00	1.17	0.12	2.48	20%	0.27	6.07
66	H90A	179.1	1.77	0.35	0.01	0.00	1.41	0.14	2.62	20%	0.32	9.40
67	H80A	149.0	1.73	0.35	0.01	0.00	1.38	0.14	2.21	20%	0.32	7.22
68	J35D	507.2	3.35	0.67	0.01	0.12	2.55	0.27	1.09	20%	0.59	3.66
43	J32B	642.8	0.06	0.00	0.01	0.02	0.03	0.00	0.02	20%	0.01	0.00
69	J35E	215.3	0.50	0.10	0.00	0.03	0.37	0.04	0.14	21%	0.09	0.88
70	J33F	365.8	1.06	0.21	0.01	0.75	0.09	0.09	1.16	21%	0.04	2.23
44	J24C	861.3	0.08	0.00	0.02	0.00	0.06	0.00	0.00	21%	0.01	0.00
46	J12D	830.9	3.85	0.00	0.81	0.01	3.02	0.00	0.01	21%	0.60	0.00
71	K60E	100.2	2.25	0.45	0.03	0.05	1.71	0.18	1.24	22%	0.40	3.91
72	J40B	222.0	0.99	0.20	0.02	0.00	0.77	0.08	0.41	22%	0.18	2.70
74	K70A	170.3	7.05	1.41	0.22	0.12	5.30	0.56	3.24	23%	1.23	7.10
75	J40C	436.3	2.89	0.58	0.10	0.02	2.19	0.23	1.37	23%	0.51	6.64
49	J13B	401.8	1.24	0.01	0.28	0.01	0.94	0.01	0.03	23%	0.19	0.00
50	J32A	415.2	0.04	0.00	0.01	0.00	0.03	0.00	0.00	25%	0.01	0.00
73	J25B	396.9	1.32	0.22	0.11	0.09	0.90	0.09	0.31	25%	0.21	1.34
51	J25C	180.6	0.46	0.00	0.12	0.03	0.31	0.00	0.03	25%	0.06	0.05
76	J40A	453.6	1.35	0.27	0.08	0.02	0.98	0.11	0.79	26%	0.23	5.14
52	J11G	604.3	0.06	0.00	0.02	0.00	0.04	0.00	0.00	26%	0.01	0.00
56	J11K	515.9	1.27	0.00	0.40	0.26	0.62	0.00	0.26	31%	0.12	0.00
77	J22J	377.6	0.47	0.00	0.18	0.00	0.28	0.00	0.00	39%	0.06	0.00
82	J40D	655.0	3.47	0.69	0.70	0.18	1.90	0.28	1.00	40%	0.46	4.26
81	J33D	258.9	1.36	0.20	0.39	0.01	0.77	0.08	0.20	43%	0.18	1.57
79	J33B	590.8	2.95	0.18	1.13	0.01	1.63	0.07	0.19	44%	0.35	2.36
78	J22D	680.5	0.66	0.00	0.31	0.00	0.35	0.00	0.00	47%	0.07	0.00
83	J25D	210.4	0.66	0.13	0.18	0.11	0.23	0.05	0.30	48%	0.06	0.77
80	J12A	180.8	0.97	0.00	0.48	0.00	0.49	0.00	0.00	49%	0.10	0.00
88	K60G	166.6	4.38	0.88	1.40	0.00	2.10	0.35	1.90	52%	0.53	6.91
85	H90E	495.7	5.26	0.62	2.32	0.14	2.19	0.25	0.75	56%	0.51	5.26
91	J33E	328.8	1.43	0.29	0.56	0.30	0.29	0.11	0.67	59%	0.09	2.45
89	J35B	651.4	3.77	0.32	1.99	0.13	1.33	0.13	0.44	61%	0.30	2.66

No	Catchment	Area (km^2)	P_{98} Recharge (MCM/a)	GW Base flow (MCM/a)	GW Use (MCM/a)	BHN Reserve (MCM/a)	GW losses (MCM/a)	EWR (MCM/a)	Total Reserve (MCM/a)	Stress Index (%)	GW Allocation (MCM/a)	GRAII GW BF (MCM/a)
90	K40E	267.6	11.46	1.44	5.60	0.00	4.42	0.58	2.40	61%	1.06	10.58
84	J13A	518.0	1.80	0.02	1.10	0.00	0.68	0.01	0.02	62%	0.14	0.00
86	J22E	833.9	0.63	0.00	0.41	0.00	0.23	0.00	0.00	64%	0.05	0.00
87	J11J	449.8	2.25	0.01	1.44	0.03	0.77	0.00	0.04	65%	0.16	0.00
92	K30C	190.1	7.62	1.44	3.80	1.30	1.08	0.58	2.80	69%	0.39	8.02
96	K40B	111.6	4.38	0.72	2.60	0.00	1.06	0.29	1.20	76%	0.30	4.85
97	K50B	202.9	8.64	1.38	5.40	0.70	1.16	0.55	2.40	78%	0.40	8.77
95	K20A	168.5	7.02	0.72	4.80	0.10	1.40	0.29	1.30	79%	0.37	6.08
98	K10A	177.5	1.50	0.30	0.90	0.80	-0.50	0.12	1.80	80%	-0.06	1.20
93	J33C	428.1	1.27	0.00	1.05	0.00	0.22	0.00	0.00	83%	0.04	0.13
94	J11E	812.2	0.73	0.00	0.62	0.10	0.01	0.00	0.10	84%	0.00	0.00
99	K30A	196.0	5.16	0.84	3.70	0.10	0.52	0.34	1.50	88%	0.20	7.23
123	J11D	801.2	1.97	0.00	9.31	0.00	-7.34	0.00	0.00	>100%	0.00	0.00
122	J11F	344.4	0.26	0.00	1.16	0.02	-0.92	0.00	0.02	>100%	0.00	0.00
120	J11H	651.4	2.25	0.00	7.10	0.02	-4.86	0.00	0.02	>100%	0.00	0.00
121	J21A	854.4	1.71	0.01	5.89	0.76	-4.95	0.01	0.77	>100%	0.00	0.00
105	J21B	530.3	0.28	0.00	0.33	0.01	-0.06	0.00	0.01	>100%	0.00	0.00
125	J21C	526.1	0.05	0.00	0.28	0.01	-0.23	0.00	0.01	>100%	0.00	0.00
124	J21D	649.6	0.18	0.00	0.86	0.00	-0.68	0.00	0.00	>100%	0.00	0.00
118	J21E	504.4	0.14	0.00	0.39	0.00	-0.25	0.00	0.00	>100%	0.00	0.00
128	J22F	295.9	0.06	0.00	0.84	0.03	-0.80	0.00	0.03	>100%	0.00	0.00
129	J22K	479.1	0.22	0.00	5.74	0.00	-5.52	0.00	0.00	>100%	0.00	0.00
130	J23A	762.1	0.17	0.00	10.96	0.05	-10.83	0.00	0.05	>100%	0.00	0.00
126	J23B	782.2	0.28	0.00	1.82	0.00	-1.55	0.00	0.00	>100%	0.00	0.00
119	J23E	225.1	0.92	0.12	2.43	0.01	-1.64	0.05	0.14	>100%	0.00	1.08
127	J23F	477.6	0.48	0.00	3.15	0.15	-2.83	0.00	0.15	>100%	0.00	0.00
116	J23H	264.2	0.30	0.00	0.56	0.00	-0.26	0.00	0.00	>100%	0.00	0.00
100	J23J	228.6	0.21	0.03	0.16	0.00	0.02	0.01	0.03	>100%	0.00	0.96
114	J24F	282.4	0.69	0.00	1.22	0.00	-0.53	0.00	0.00	>100%	0.00	0.00
104	J34F	320.1	1.32	0.17	1.26	0.06	-0.17	0.07	0.23	>100%	0.00	1.28
108	J35A	427.6	2.73	0.55	2.53	0.68	-1.02	0.22	1.43	>100%	0.00	3.10
106	J35F	500.4	1.38	0.28	1.20	0.06	-0.16	0.11	0.53	>100%	0.00	3.00
112	K10B	171.2	0.96	0.19	1.30	0.00	-0.53	0.08	1.00	>100%	0.00	1.21
117	K10C	159.0	1.02	0.20	1.70	0.00	-0.88	0.08	1.00	>100%	0.00	2.32
115	K10D	164.0	1.08	0.22	1.60	0.00	-0.74	0.09	1.00	>100%	0.00	1.08
101	K10E	132.6	3.90	0.72	2.80	0.00	0.38	0.29	1.20	>100%	0.00	4.26
109	K10F	105.8	1.62	0.32	1.70	0.10	-0.50	0.13	0.80	>100%	0.00	1.03
113	K30B	138.6	4.20	0.72	5.90	0.30	-2.72	0.29	1.50	>100%	0.00	5.07
110	K30D	177.9	4.14	0.83	4.60	0.00	-1.29	0.33	1.70	>100%	0.00	7.52
102	K40A	87.5	3.30	0.48	2.70	0.00	0.12	0.19	0.40	>100%	0.00	3.97
103	K40C	99.6	4.14	0.72	3.40	0.00	0.02	0.29	0.80	>100%	0.00	4.41
111	K40D	129.8	5.40	0.78	7.80	0.10	-3.28	0.31	1.40	>100%	0.00	3.68
107	K50A	235.4	3.06	0.61	2.80	0.00	-0.35	0.24	3.00	>100%	0.00	10.05

No	Catchment	Area (km^2)	P_{98} Recharge (MCM/a)	GW Base flow (MCM/a)	GW Use (MCM/a)	BHN Reserve (MCM/a)	GW losses (MCM/a)	EWR (MCM/a)	Total Reserve (MCM/a)	Stress Index (%)	GW Allocation (MCM/a)	GRAII GW BF (MCM/a)
	Total	52571.1	268	33	139	10	87	13	82		31	267
	Avg	404.4	2	0	1	0	1	0	1		0	2
	mm/a		5.1	0.6	2.7	0.2	1.6	0.2	1.6		0.6	5.1

APPENDIX B: GROUNDWATER RESERVE DETERMINATION – DATA SOURCES

	Model data input	Source
1	Catchment area	DWS spatial data website: https://www.dwaf.gov.za/iwqs/gis_data/
2	Protected Areas NSBA 2011	NSBA Formally Protected Areas, Type 1, 2 and 3. 2011. http://bgis.sanbi.org/nsba/terrestrialAreas.asp
3	Rainfall	WR2005
4	Recharge	Jia, 2007; Umvoto Africa, 2010; Xu *et al.* 2009; Parsons *et al.* (2007)
5	Dam seepage	WR2012/ WR2005
6	Geology	1:250 000 geology maps
7	Depth to water level (m)	Four different data sets as per Water levels sheet and GYMR footnotes.
9	Max aquifer depth (m)	GRA II
10	Water level management constraint (m)	Assumed 25% of aquifer thickness. Assumed 10% of DAGEOS confined aquifer
11	Aquifer storativity (1)	(Jia,2007:65)
12	Groundwater volume in storage (m3)	GRA II
13	Max usable groundwater volume in storage (m3)	GRA II
14	MAP (mm/a)	WR2005
15	MAE (mm/a)	WR2005
16	MAR (%)	WR2005
17	MAR (m3/a)	WR2005
18	MAR (mm/a)	WR2005
19	Dam Seepage Area (km2)	WR2005
20	General autho- rizations	DWS general authorisations gazetted (DWA,2013)
21	WARMS existing uses	DWS Western Cape office Sept 2013
22	Existing borehole abstraction (m3/a)	NGA database & Gouritz Hydrocensus: yields assigned based on equipment installed
23	Population per catchment	GRDM, 2013 & All towns study (DWA, 2014c)
24	basic human needs (BHN) Reserve (m3/a)	60 ℓ per person per day
25	Average Farm irrigation area (ha)	WR2005
26	Average Forestry area (ha)	WR2005
27	Average Riparian Alien veg (ha)	WR2005
28	Alien vegetation water use (m3/a)	WR2005
29	Wetlands (Ground water) (km2)	WR2005
30	Length of drainages (km)	DWS 1:500 000 Rivers

APPENDIX C: DATA INFORMATION AND THE DECISION-MAKING PROCESS WITHIN GYMR AND GRDM FRAMEWORK

C.1 INTRODUCTION

Groundwater evaluations and studies are prone to limitations on the availability of data and are associated with a high degree of uncertainty on the data that is available. Usually when scientists are faced with problems related to uncertainty, the instinctive reaction is to resort to a reductionist approach where more focus is put on detail and data collection in an attempt to reduce uncertainty (Vivier and Van Der Walt, 2011a). This leads to the introduction of complexity that mostly enhances uncertainty. There is an incorrect perception specifically in hydrogeology that "more data is better" and that "more detail" would reduce uncertainty. On top of this, the science of hydrogeology is not historically practised on e.g. quaternary catchment or regional scales where scaling of parameters creates problems such as "Wellfield Bias" (DWA, 2010).

The basis of the decision-making process within which the GYMR fits, was described in DWA (2010), which was reviewed in detail. The outcome of which partially led to the update of the GRDM 2007 method (Parsons and Wentzel, 2007), culminating in the 2012 GRDM method (Dennis *et al*, 2012). It is described in this section in more detail to clarify specific aspects that surfaced during the review phases of this project (**Appendix E**).

When scientific data that is sparse and associated with a high degree of uncertainty is considered on its own, it can often lead to confusion. What is required is a decision-making framework within which to put the scientific process that could account for the uncertainty to arrive at management decisions (Van Blerk, 2000). The aspects that are covered in section explains the decision-making methodology and covers the following points:

- Data, information and the decision-making process.
- The GYMR within the GRDM decision-making framework.
- The minimax principle and the minimum groundwater flow balance.
- Scale and resolution.
- Approach to quantification of groundwater (GYMR) as part of the GRDM.
- Application of conservatism.
- Groundwater balance approach and capture.
- Surface water catchments vs groundwater resource units.
- Shallow and deep groundwater.

C.2 DATA, INFORMATION AND THE DECISION-MAKING PROCESS

The basis of any decision process whether quantitative or subjective, is information. Information is based on data[7] and the quantity and quality of the data will influence the quality of information. Data

[7] In general, raw data that (1) has been verified to be accurate and timely, (2) is specific and organised for a purpose, (3) is presented within a context that gives it meaning and relevance, and which (4) leads to increase in understanding and decrease in uncertainty. The value of information lies solely in its ability to affect a behaviour, decision, or outcome. A piece of information is considered valueless if, after receiving it, things remain unchanged (www.businessdictionary.com).

and information are therefore the building blocks of the decision-making process (**Figure C.1**). It is important to consider the role or influence that data and information could have on the decision-making process. In this study, the adequacy of data in groundwater problems was investigated, to determine when it yields enough information for the purposes of decision-making.

When data is analysed, it becomes information which upon interpretation increases the level of knowledge and understanding that is used as the basis for management decisions (**Figure C.1**). The purpose of data collection e.g. a groundwater assessment such as to determine the Reserve must be to assist in decision-making such as on resource management for the purposes of Reserve determination. Although data is the building blocks of information, data in itself does not constitute information. It is the arrangement and meaning of data that constitutes information (Vivier, 2011). Just as bricks is not a wall. Data on itself could be like a pile of bricks that does not have value. It is only if the bricks are put together within a planned and meaningful way that it becomes a wall i.e. data to information.

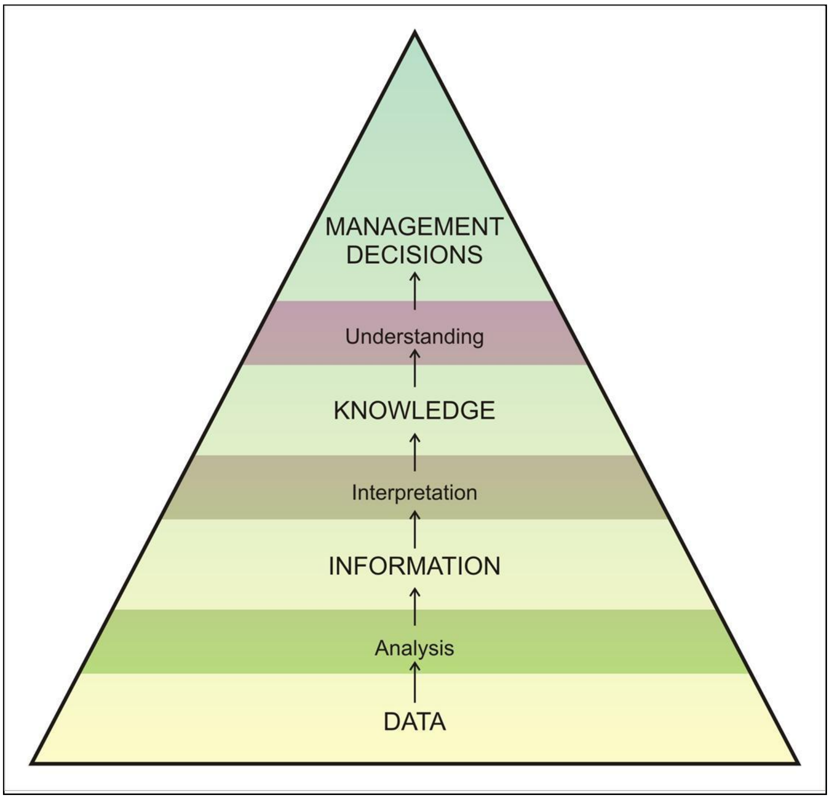

Figure C.1 The role of data in the decision-making process (Vivier and Van Der Walt, 2011a)

As more data is collected, the information curve follows a logarithmic trend similar to the law of diminishing returns in economics (**Figure C.2**; Mohr and Fourie, 2004). Perfect information would represent zero uncertainty, which is off course not possible – but provides a reference (Vivier, 2011). Thus "more data" is not necessarily better, but rather structured data that leads to *sufficient*[8]

[8] See (Vivier and Van Der Walt, 2011a) for a more detailed description of sufficient and optimal data and information.

and then *optimal* information, whichever is required by the analyst within the decision-making objectives.

C.3 THE GYMR WITHIN THE GRDM DECISION-MAKING FRAMEWORK

The GYMR methodology (DWA, 2010) fits within a decision-making process that was followed in this study based on the 2012 GRDM method (Dennis *et al*, 2012) from the Rapid/Desktop to Intermediate and eventually, proposed detailed GRDM (**Figure C.3**). The process starts on a regional quaternary catchment scale, which makes provision for differentiation, based on hydrogeological GRUs. The purpose is to start on a regional scale with a high degree of uncertainty which is iteratively reduced as more information is obtained and complexity is introduced from the Rapid through Intermediate to the detailed Reserve determination.

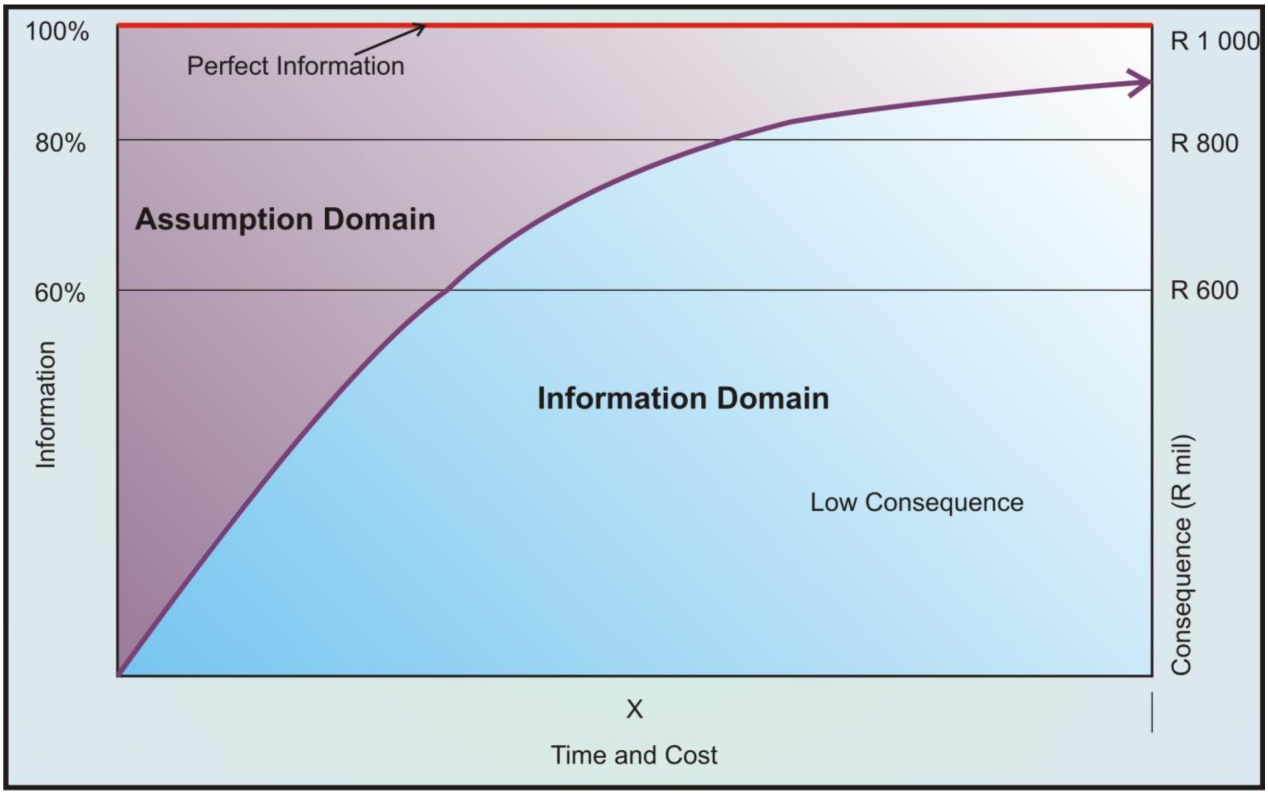

Figure C.2 The decision-making curve (Vivier and Van Der Walt, 2011a)

The GRDM process iterates through levels. Note that additions have been made shown in normal font and *italics are taken from the 2012 GRDM method* (*Dennis et al, 2012*):

1. **Desktop/Rapid Phase**: *Iterations 1 & 2*
   a. *Based on regional quaternary catchment scale, low intensity and low confidence.*
   b. The purpose of this phase should be familiarizing with the regional study area and to screen out catchments or areas that are unstressed vs moderately stressed and highly stressed. For this purpose, regional groundwater resource quantification (GYMR) is a requirement as the Reserve is a user of groundwater e.g. wetlands, riparian vegetation, BHN etc. It is important not only to evaluate the minimum yield but also the assured yield.

c. This phase would focus additional work on a smaller number of catchments for the Intermediate phase.
d. Groundwater hotspots should be focused on where known stress conditions exist.
e. Follow a conservative approach where the effects of groundwater storage are neglected as it is a known unknown or even unknowable parameter. Determine the minimum allocable groundwater component, maximum BHN volume and maximum groundwater contribution to base flow and the EWR. Provision should be made for normal or average (P_{50}) and drought (P_{95} or P_{98}) rainfall conditions. It is known and accepted that there is more groundwater available, but given the uncertainty and absence of knowledge of parameters in most areas, it is not known or knowable at this stage, how much more groundwater is available. Thus catchments that are flagged as "stressed" could be declassified if more work is done to collect more data by e.g. a developer or prospective groundwater user.
f. In this study, only 28 (21.5%) of the 130 quaternary catchments flagged as potentially stressed. The GRDM process should flag these and not prevent any licences to be issued but to ask for more detailed studies to prove the groundwater resource before any licences can be considered. Except for the hotspots, the other 106 quaternary catchments can be subjected to groundwater development and licensing at a low risk for the DWS as regulator, as it is known that there is surplus groundwater available. Note that some groundwork may still be required as part of the water use licensing process such as distance of borehole locations to wetlands etc, which cannot be determined on a regional scale during this phase.
g. Develop initial groundwater monitoring programme.

2. **Intermediate Phase**: *Iteration 3*
   a. *The purpose of this phase is to increase in confidence of the investigation and field investigations by groundwater specialists* and to focus on the catchments that were screened in the Desktop/Rapid phase.
   b. Field work such as hydrocensus and verification of abstraction rates in the field or from remote sensing.
   c. Limited credit can be taken for the minimum volume of groundwater in storage and some transient rainfall-recharge relationships where sufficient confidence in the data exists. The allocable groundwater and contribution to base flow should increase as credit is taken e.g. limited storage and higher recharge.
   d. Perform more detailed and Intermediate groundwater component of the Reserve (GCR) on the 28 quaternary catchments and/or GRUs identified during the Desktop/Rapid phase. This is done using the GYMR method to inform the GRDM process (DWA, 2010).
   e. This phase is used to further screen catchments or GRUs that should be investigated in detail in the Comprehensive Reserve determination phase. In this study, 8 of the "stressed" 28 catchments require a Comprehensive Reserve determination.
   f. Develop more focused and detailed groundwater monitoring program.

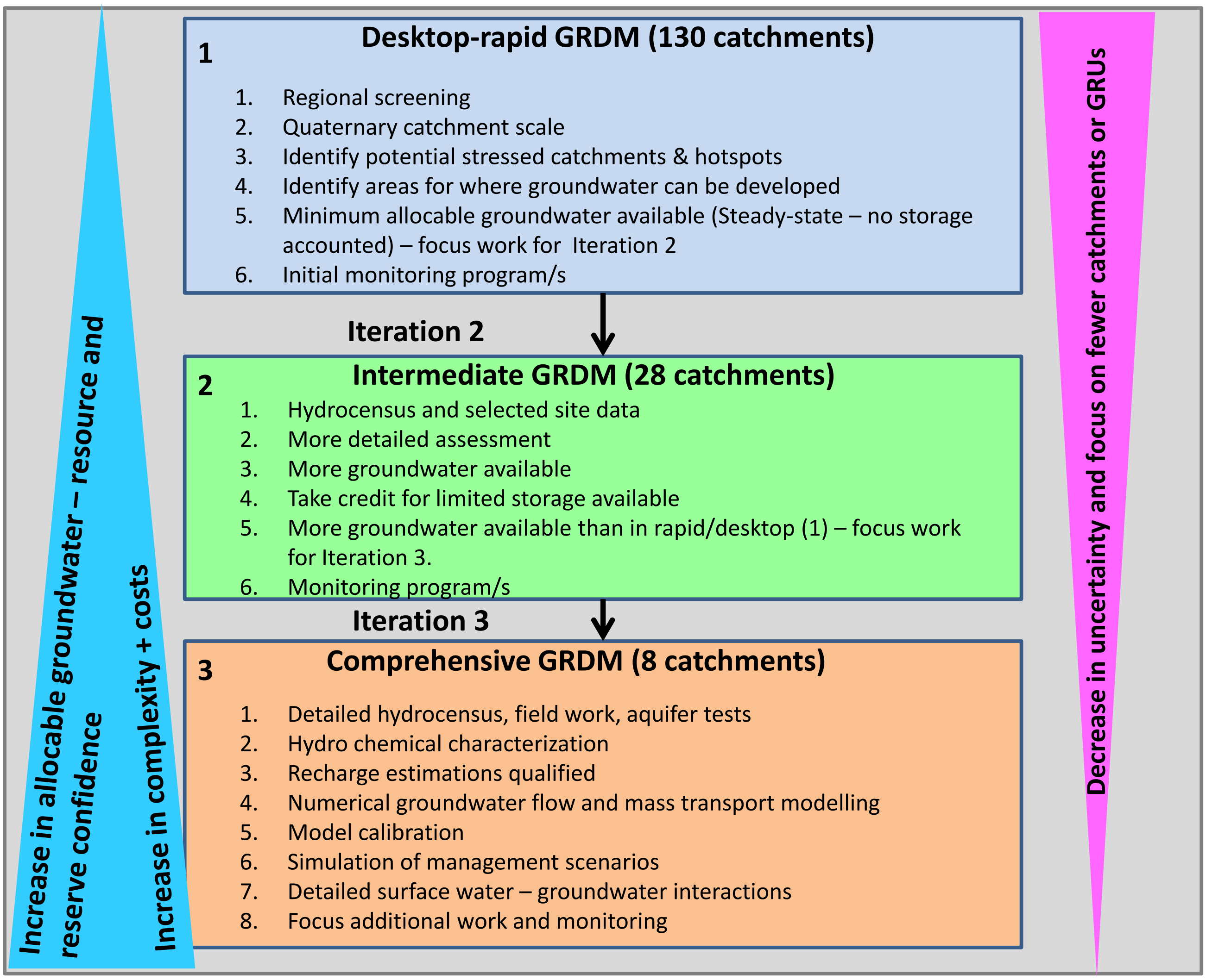

Figure C.3 The GYMR within the proposed GRDM decision-making process

3. **Comprehensive Phase**: Iteration 4
   a. *"Comprehensive GRDM determinations aim to produce high confidence results and are based on site-specific data collected by a team of specialists; used for all compulsory licensing exercises, as well as for individual licence applications that could have a large impact in any catchment, or a relatively small impact in ecologically important and sensitive catchments. It is important to note that a Comprehensive study does not GUARANTEE high confidence results – there might be more confidence in your DATA, but all that might achieve is increased appreciation of the COMPLEXITY of the system, and NO increase in confidence on what USE is SUSTAINABLE" (Dennis et al, 2012).*
   b. The purpose of this phase should be to determine the sustainability of the resource or the lack thereof. This is where the GYMR process differs from the 2012 GRDM method (Dennis *et al*, 2012) as the minimum volume of groundwater is determined, the sustainability of the "minimum allocable groundwater" should be high.
   c. Specific hydrogeological actions in this phase would include the following:
      i. Detailed hydrocensus, field work.
      ii. Site characterisation (drilling, aquifer tests etc.).
      iii. Hydro chemical characterisation.

iv. Recharge estimations qualified (isotopes etc.).
v. Numerical groundwater flow and mass transport modelling.
vi. Model calibration.
vii. Simulation of management scenarios.
viii. Detailed surface water – groundwater interactions, losses qualified.
ix. Groundwater contribution to base flow.

d. Detailed surface water, groundwater and rainfall monitoring program.

This process follows a Bayesian approach to decision-making where *prior* information associated with a high degree of uncertainty is used to focus the collection of posterior data so that uncertainty is iteratively reduced (Freeze *et al.* 1990; Freeze *et al.* 1992; Ellison, 1996). An important principle of the process that is followed here, is that it is a *bottom-up approach* which identifies the *minimum allocable* volume of groundwater available in line with the minimax and precautionary principles (National Environmental Management Act - NEMA, Act 107 of 1998). There is often an incorrect perception that more data is better and by going into the detail will reduce uncertainty. This is not true as more detail introduces more complexity which could increase uncertainty.

Only if the more allocable volumes of groundwater can be proven with more detailed information through additional iterations and groundwater resource determinations that is obtained with more detailed studies, can licences be allowed. This approach is described further in the next section.

C.4 THE MINIMAX PRINCIPLE AND MINIMUM GROUNDWATER BALANCE APPROACH

Due to the uncertainties associated with groundwater quantification and the Reserve determination process, it is not possible to determine e.g. the actual allocable volume of groundwater or the groundwater contribution to base flow. It is however possible to determine the minimum. The minimax[9] approach is based on a rule of decision theory to minimise possible losses in game theory (Quinlan, 1986). The minimax principle is superimposed on the Bayesian decision-making process to arrive at an assured decision-making method (**Figure C.4**, Vivier, 2011).

In line with the precautionary principle as described in the NEMA (NEMA, 1998), in this Preliminary Reserve a minimum groundwater balance approach is followed (Vivier, 2013). From the minimum amount of groundwater available one can always increase for example the percentage groundwater recharge from rainfall or decrease existing abstraction as more evidence and information becomes available to prove the yield of the resource and more confidence is built in the available volumes. If on the other hand the water availability is over-estimated and these volumes are used for national planning, it is very difficult and often embarrassing to reverse the planning and development time and cost spent on a resource if that resource later proves to be much less than expected. It is accepted that the uncertainty and data limitations on the scale of the assessment is of such a nature that the actual groundwater balance will never be known as it will be transient. The objective is therefore not to determine the actual groundwater balance as it cannot be known without long-term

[9] Minimax is a strategy of game theory to minimise a players potential losses while maximizing the potential gains. Maximin is the procedure of choosing the strategy that least benefits the most advantaged member of a group (http://dictionary.reference.com/browse/minimax). Of specific importance, is that the minimax approach is non-probabilistic and is used based on an evaluation of scenarios in the absence of sufficient data.

monitoring data. A minimum groundwater balance approach also ensures that aquatic ecosystems (EWR) and the BHNR are duly protected from precluded initial over-estimations.

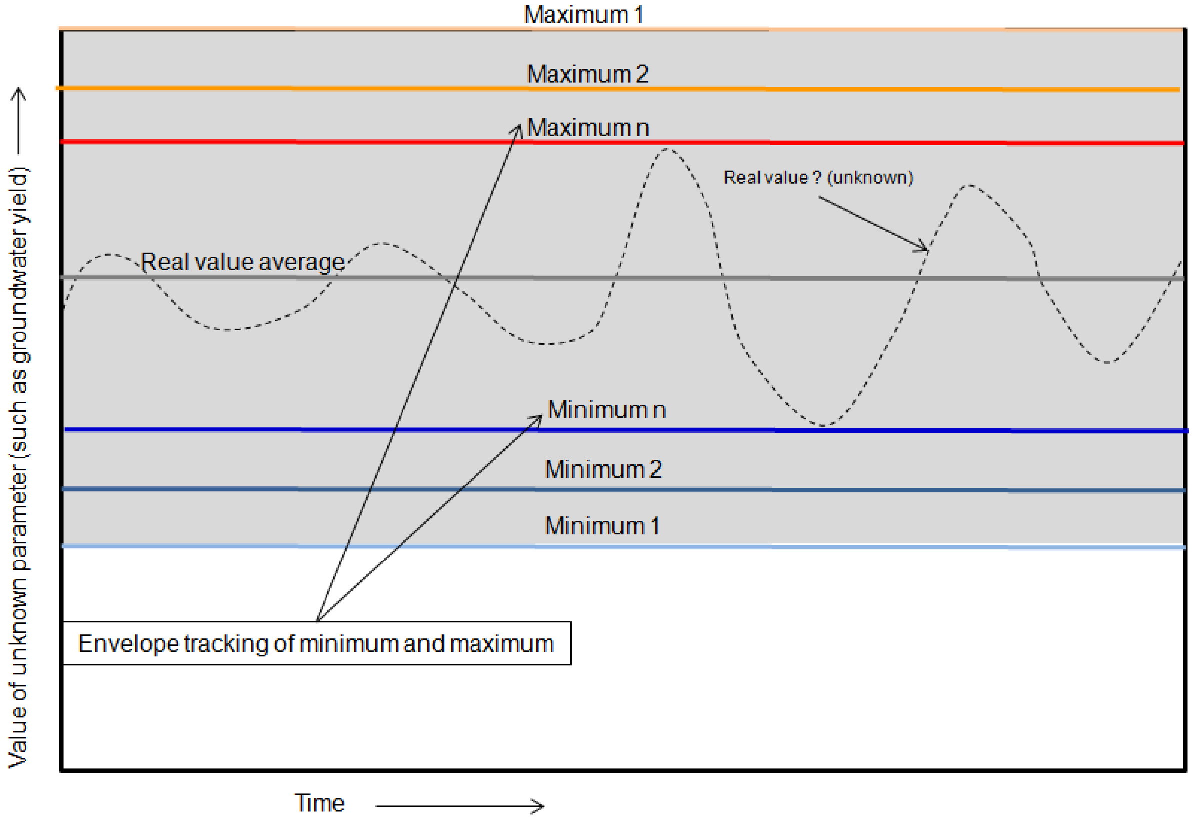

Figure C.4 The minimax decision-making principle used in the assured decision-making model (after Vivier, 2011)

C.5 GROUNDWATER RESOURCE EVALUATION AND THE RESERVE

The principle of sustainability is entrenched in the Water Act (NWA, Act 36 of 1998). The GRDM (Dennis *et al*, 2012) states;

Sustainability: Water use must promote social and economic development, but not at the expense of degrading the environment (technical component)

Groundwater resource evaluation should precede the determination of the groundwater component of the Reserve and should be an integral part of it. It is not possible to perform a Reserve determination without quantification of the groundwater resource and potential. If the groundwater resource and potential is not at least qualified, it will not be possible to determine the recharge and which fraction is available for contribution to base flow that potentially supports the Reserve.

C.6 SCALE AND RESOLUTION OF THE STUDY

Scale is an important aspect in the study. The objective of the study is to determine the amount of water required for the groundwater Reserve as well as the amount of groundwater that can safely be allocated to current/future groundwater developments. For the purpose of this study, the resolution that is used is the quaternary catchment scale, which is typically tens of kilometres in dimension. Should assessments be done on a smaller scale, such as the wellfield scale that ranges from hundreds of metres to kilometres or borehole scale than ranges between sub metres to several hundreds of metres or a couple of kilometres, then different conclusions may be reached. It is important to note that the scale of the assessment will have an influence on the assessments – a complex challenge that is associated with hydrogeology, especially in fractured aquifers (DWA, 2010; Bear, 1979; Steyl *et al.*, 2012 and Neuman, 2005).

A common mistake that is made is to take aquifer parameters that was determined on wellfield scale and extrapolate across e.g. larger quaternary catchments or GRUs. This is known as *wellfield bias* (DWA, 2010). The effect of scale is as such that *when we scale out (i.e. larger area), we should scale down* (i.e. lower recharge and transmissivity).

The process that is followed initially starts on a quaternary catchment scale that does make provision for internal hydrogeological units as required. As the iterations increase from Desktop/Rapid to Comprehensive, the scale should go to wellfield and individual boreholes or wetlands etc.

Selected inferred hotspot areas were evaluated in more detail where deemed necessary from the first iteration as these are known problematic areas.

C.7 SURFACE WATER CATCHMENTS VS GROUNDWATER RESOURCE UNITS

The approach in this study is to use mainly quaternary catchments as the resolution for the study (Dennis *et al*, 2012). The reason for this is that in previous studies and in this study there are good correlations between groundwater head elevation and topography for the shallow aquifers (see next section). The importance of geology is acknowledged and allowance is made for up to ten hydrogeological sub-units within a quaternary catchment.

Another reason why this approach is preferred is because it is the legal boundaries within which Integrated Water Resource Management (IWRM) is done (National Water Act no. 36 of 1998) and data such as rainfall, baseflow, etc. are available at this scale for the whole country (Middleton and Bailey, 2011; DWAF, 2006). Should a geological unit be used as a resource boundary, it should be done as a secondary assessment. If the TMG quarzitic sandstone is to be considered as a GRU, which stretches across tens or hundreds of kilometres, it must be considered that the rainfall and hence recharge will change across the length and breadth of the GRU and add uncertainty in terms of how to quantify the inflow and outflow of the GRUs.

C.8 SHALLOW AND DEEP GROUNDWATER

The study primarily focuses on shallow aquifers as these are the predominant aquifers from which current groundwater use is taking place in the Gouritz WMA as well as the predominant source that meet EWRs from the groundwater Reserve side within the WMA. Of the 3 395 boreholes used in the assessment, the mean borehole depth is 74.1 m and the upper 95th percentile 160 m. The zone shallower than 160 m is the focus of this study.

The DAGEOS was evaluated as a separate component in this study as it is the only deep confined groundwater system in the study area that is being developed and it receives inflow from the surface aquifer outcrop area in the Outeniqua Mountains.

C.9 APPLICATION OF CONSERVATISM

The proposed minimum groundwater balance approach can be perceived as being overly conservative. This is not the case as will be shown in the results. Even if the approach weighs in on the conservative side of the scale, only 28 (21.5 %) of the 130 quaternary catchments were flagged as potentially stressed during the first iteration which is the Desktop-Rapid Reserve. If the approach is overly conservative, this figure would be expected to be much higher. The 28 potentially stressed catchments are modelled in the second iteration, the Intermediate Reserve level at a higher confidence level with groundwater storage taken into account. The Rapid Reserve iteration was also used to focus not only which catchments should be used for more detailed modelling but also where the hydrocensus field surveys should be focused. This Intermediate Reserve or second iteration indicated that there are 8 quaternary catchments which really require more detailed studies.

The approach is that if any potential developer can prove with field data that e.g. wetlands that were conservatively flagged as being potentially supported by groundwater are in fact not, then the additional groundwater can then be allocated to that developer if it can be shown that the groundwater yields are sustainable. This leaves the burden of proof on the potential water user and not on the regulator.

The philosophy of *all models are wrong but some are useful* (Poeter, 2006) is acknowledged and the chosen decision-making method is to be *wrong on the right side*. The effects of uncertainty mean that the environment and the Reserve would receive the benefit of the doubt, which is much more advantageous than the other way around.

C.10 GROUNDWATER BALANCE APPROACH AND CAPTURE

The volume of groundwater available for future use, known as the allocable groundwater is constrained by the requirements of the riverine EWR. The EWR is the volume, quality and timing in which water is required in a stream or river to sustain the system in a particular state so as to support ecosystem function and other users. Base flow consists of a combination of surface water low flow and groundwater inflow. It is often difficult or impossible to distinguish which fraction of base flow constitutes groundwater although base flow separation techniques (Hughes *et al.*, 2003) and chemical mixing models can be used to obtain a qualified estimate (Steyl *et al*., 2012).

In a natural system un-impacted by any anthropogenic effects, the groundwater component of base flow is equal to recharge minus losses due to spring flow, and evapotranspiration in the riparian zone. It is expected that the groundwater component of base flow will increase relative to runoff and interflow during drought or low flow periods. It may even be that there could be no actual flow in a surface stream while groundwater seepage continues to support the riparian vegetation along drainages and downstream wetlands that are supported by springs. The steady state groundwater flow balance for a specific catchment or aquifer can be given by:

$$Q_R - Q_{BHN} — Q_W - Q_P - QEVL = 0$$

Where Q_R is recharge, Q_{BHN} is the BHNR, Q_W, the wetland water use and Q_{EVL} is the evapotranspiration losses. To change the balance from steady-state to transient, the effects of storage over time dV/dt is added as follows:

$$Q_R - Q_{BHN} — Q_W - Q_P - QEVL = dV/dt$$

The groundwater balance approach has been criticised by Bredehoeft *et al.*, (1982) and Bredehoeft, (2002). This is because virgin recharge across an aquifer area cannot be used to determine the groundwater potential or yield. The volume of groundwater that can be abstracted using boreholes is mostly constrained by the hydraulic diffusivity, which determines the capture zone. The capture principle determines that when groundwater abstraction takes place, it results in an increase in recharge, a decrease in discharge and release of water from storage. Capture could be temporarily bigger than the recharge, but it is only a matter of time for capture to converge to the recharge as storage and discharge is depleted (Zhou, 2009). There are only two source of groundwater namely, recharge from rainfall and infiltration from surface water. The capture principle also focuses on abstraction from boreholes and does not recognize other environmental sinks such as wetlands and riparian vegetation that are important for the groundwater component of the Reserve (Devlin and Sophocleus, 2004).

Only in the exceptional case (for South Africa at least) when there is vast surface water resources available from where infiltration is enhanced by reducing groundwater head, capture is ultimately dependent on recharge and not that unique as the groundwater flow components has to balance. It can be considered as a refined groundwater balance that can only be determined through numerical groundwater flow modelling.

The significance for capture in the GRDM process is that it can only be introduced in the detailed phases of the Comprehensive Reserve (**Figure C.3**). Capture can only be determined using numerical modelling, which is impractical on e.g. 130 quaternary catchments and would be a waste of time and budget. The capture principle introduces the use of aquifer storativity, which is a known unknown and an unknowable parameter (Vivier, 2011). Storativity is an important parameter as it can buffer dry cycles and increase the aquifer yield and reduce the impact of e.g. abstraction on the Reserve. As storativity cannot be known, the best that can be done is to simulate how it improves the groundwater yield by running management scenarios based on the *minimum storativity* in either the Intermediate and/or Comprehensive Reserve determination phases. It is however important at the correct stage at e.g. the eight catchments that were identified for detailed studies using the GYMR method. It is therefore not the one or the other, but rather which method at which stage and scale.

The other two components of capture, mainly the reduction in discharge and increase in recharge can also only be determined using numerical groundwater flow modelling. Discharge cannot be bigger than recharge in the long-term and is dependent on it. Recharge is already an uncertain parameter and the increase in recharge due to abstraction would be important and can be simulated within a range of minimum and maximum to illustrate the effect in the Comprehensive Reserve determination phases. However in the long-term, capture would converge to the recharge and as a method is only a subset of a more detailed groundwater balance and not something entirely different as some authors aim to state. It is not useful in the decision-making process to introduce detail and complexity as it does not necessarily reduce uncertainty, in fact it could enhance it.

C.11 APPROACH TO QUANTIFICATION (GYMR) OF THE GROUNDWATER COMPONENT OF THE RESERVE – HISTORICAL PERSPECTIVE

Several Water Availability Assessment Studies (WAAS) were done for the DWS, Directorate Water Resources Planning on a regional, primary catchment scale since 2005 (AGES, 2005; AGES, 2007 and AGES, 2008 and DWA, 2010). When the projects were initiated, it was realised that the usual application of numerical flow models could not be applied as the scale was too large to address the project objectives. A list of specific projects that were done for the DWS are:

- 2005 Crocodile River (West) regional groundwater quantification. In conjunction with AECOM (BKS at the time of this study).
- 2007 Olifants River regional groundwater quantification. In conjunction with Royal Haskoning DHV (SSI engineers at the time this study).
- 2007 Upper Vaal regional groundwater quantification project. For DWS.
- 2010 Reserve determination studies for selected surface water, groundwater, estuaries and wetlands in the Outeniqua catchment: Technical component – Knysna and Swartvlei. In conjunction with Scherman Colloty & Associates cc.

During these projects, several shortcomings of the existing methods (GRDM, 2007) were identified as they vastly overestimated the allocable groundwater component and the groundwater component of baseflow. The main reason for this is (DWA, 2010):

- It used recharge as a function of MAP (i.e. P_{50}) and not an assured lower recharge that could take account of drought conditions (i.e. P_{95} or P_{98});
- Did not account for groundwater flow losses due to evapotranspiration in the riparian zone;
- Utilised too high recharge values when the system was up-scaled from wellfield to regional areas – known as wellfield bias; and
- Did not sufficiently account for environmental groundwater components such as wetlands, alien vegetation, forests etc.

In part due to the project to determine the groundwater component of the Reserve for the Outeniqua Catchment (K) (DWA, 2010), the GRDM method was revised and updated (Dennis *et al.*, 2012). The GRDM, 2012 method entails most of the important principles used in the Groundwater Yield model for the Reserve (GYMR) method (DWA, 2010). The GYMR method was subsequently updated to produce monthly as opposed to annual groundwater volumes for both average and dry cycles for selected quaternary catchments based on stochastic simulations of groundwater volumes available.

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APPENDIX D: DEVELOPMENT OF A CONCEPTUAL NUMERICAL GROUNDWATER FLOW MODEL FOR THE SHALLOW AND DEEP PENINSULA AQUIFERS (RU 1 & RU 2) AT OUDTSHOORN TO SIMULATE THE ABSTRACTION AND POTENTIAL IMPACTS ON THE WATER RESERVE

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D.1 INTRODUCTION

Following the Reserve determination that was done in 2014 on the Gouritz WMA and reference to the hydraulics and sustainability of the TMG Peninsula shallow semi-confined (RU 1) and deep confined (RU 2) aquifers, an initial conceptual numerical flow model was developed. The purpose of the model is to determine (i) the interactions between the shallow and deep aquifers (ii) evaluate the influence that storage can have on the aquifer yield with sustainability and (iii) to evaluate the potential impacts on the water Reserve. The model should serve to qualify the yield of the aquifers and environmental impacts as discussed in Exigo memo (2014) and Umvoto, 2014.

This modelling is an initial evaluation based on existing data which can be viewed as a prior estimation of the system response to abstraction. Development of a numerical model is the best tool to determine the potential yield of the system and to determine the interactions with environmental components. The model has a complex geometry and input variables, but the description in this memo will be limited to the most important aspects.

D.2 MODELLING OF THE SHALLOW AND DEEP TMG AQUIFERS AT OUDTSHOORN

The conceptual models that were developed for the aquifer system is described in Exigo, 2014. The pre-development steady-state flow is simulated as Scenario 1. The base case for abstraction that will be simulated is Scenario 2 representing Conceptual Model 2, which includes the deep flow component (**Figure D.1**) with a Scenario that includes assumed stream leakage (Conceptual Model 4) to demonstrate the potential effects.

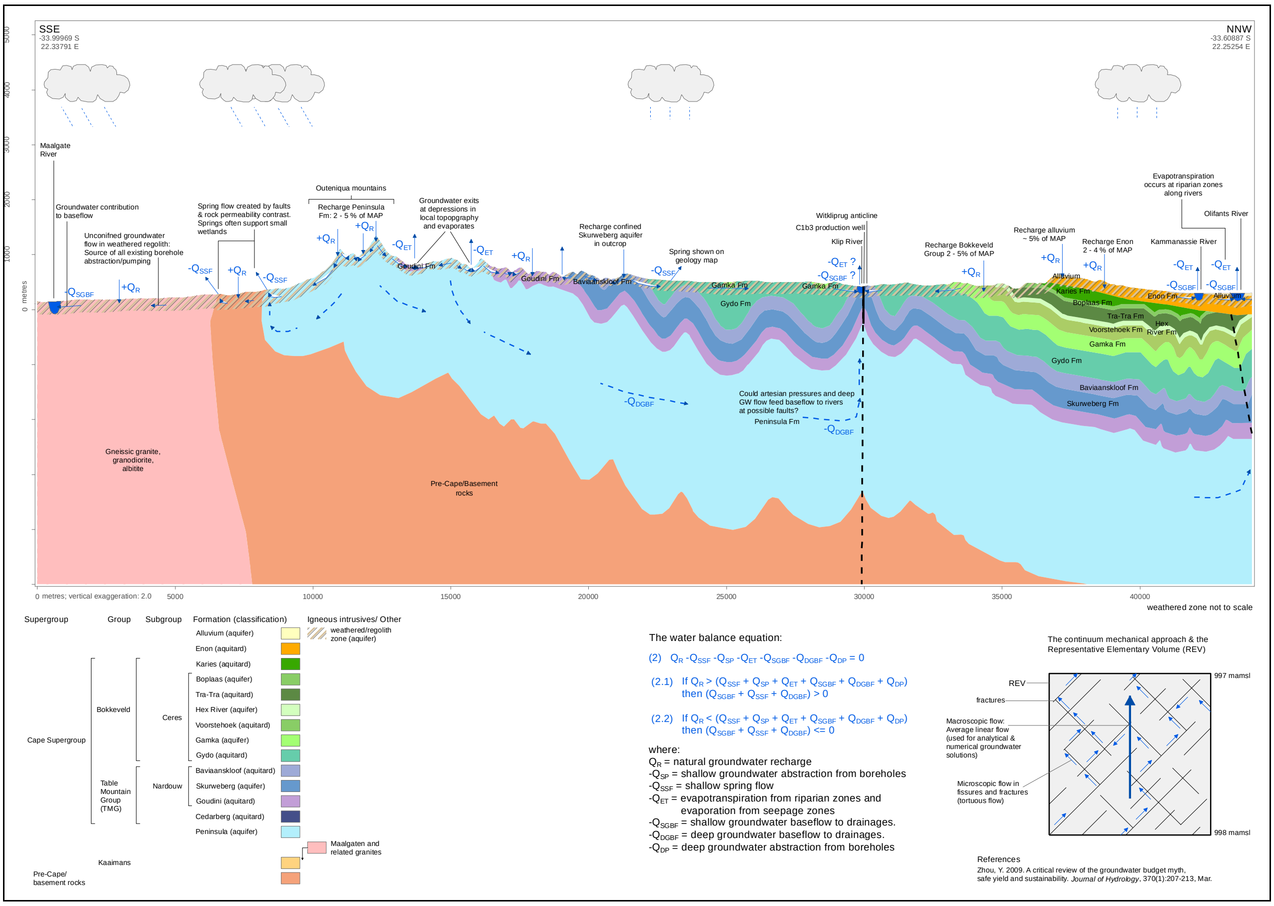

Figure D.1 Gouritz groundwater – Conceptual Model 2

D.2.1 MODEL GEOMETRY

The model geometry was obtained from the regional geological cross-sections developed by Chevallier *et al.*, (2004). The three-dimensional geometry of the model layers are shown in **Figure D.2**. Although all the important layers (6 in total) were included in the model, it is mostly the TMG Peninsula Aquifer that was focused on. The model can be used in the future to simulate potential interactions with the surface aquifers via e.g. the Skurweberg Aquifer and fault zones as per Conceptual Model 3 (Exigo, 2014).

D.2.2 MODEL QUALIFICATION AND AQUIFER PARAMETERS

The regional aquifer has a complex geometry and is associated with a high degree of uncertainty. The approach that is followed would be to determine the minimum or assured yield and the maximum potential impacts on the Reserve. The influence of uncertainty on the modelling process and decision-making is described in detail in Exigo, 2014. The only known parameters are:

1. Rainfall and runoff.
2. Regional groundwater levels with a regional head gradient at borehole C1b3.
3. Flow rate and head at borehole C1b3 during a 38 day free flow test (Hartnady *et al.*, 2014). The transmissivity values for the fractures are derived from these tests.

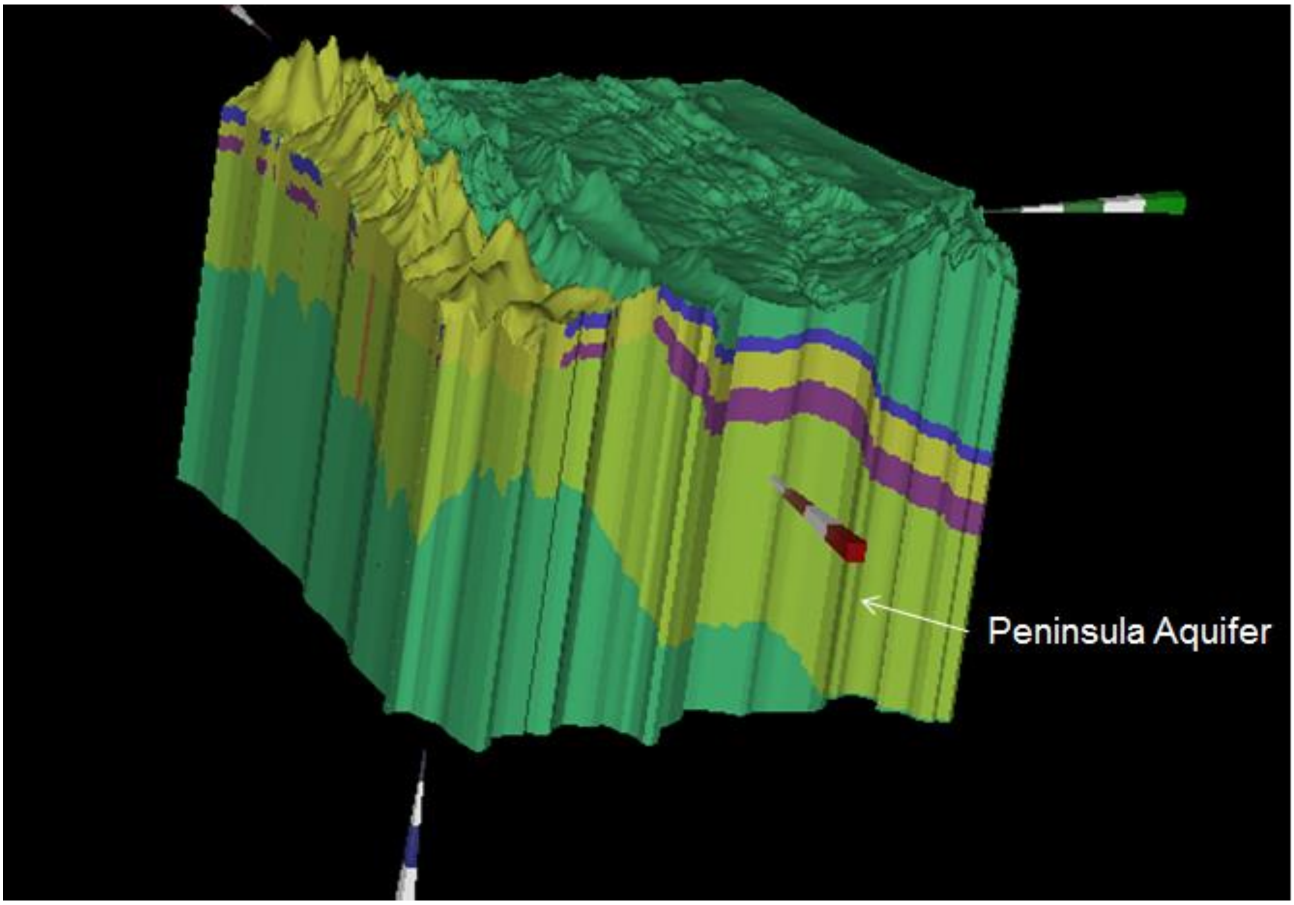

Figure D.2 Oudtshoorn aquifer three-dimensional model geometry

The mapped fracture zones were included as assumed linear features with a higher hydraulic conductivity (**Table D.1**, **Figure D.3**).

Figure D.3 Oudtshoorn aquifer – Layer 5 Peninsula Aquifer hydraulic conductivity distribution

D.2.3 SCENARIO 1 – STEADY-STATE FLOW AND FREE FLOW TEST

A regional steady-state model was developed with recharge on the shallow semi-confined Peninsula Aquifer (RU 1) to simulate the regional flow. The aim was to be able to simulate the recharge on the Outeniqua Mountains that are balanced by outflow under the head gradient that would produce a head at around 501 mamsl at Borehole C1b3, which is 80 m above surface (**Figure D.4**). The hydraulic parameters that were used to be able to simulate this scenario is shown in **Table D.1**. The model is considered as qualified and not calibrated.

The groundwater balance indicate that the average recharge on the shallow semi-confined aquifer (RU 1) is in the order of 32 250 m^3/d, which is balanced mostly by outflow of 30 500 m^3/d at the streams and springs as base flow and riparian losses on RU 1. The deep flow to the north under natural conditions is simulated at 1750 m^3/d, which represents only 5% of the recharge (**Table D.2**Table , **Figure D.4**). This supports the assumption made in DWA (2009) that most of the groundwater flow in RU 1 is towards the south.

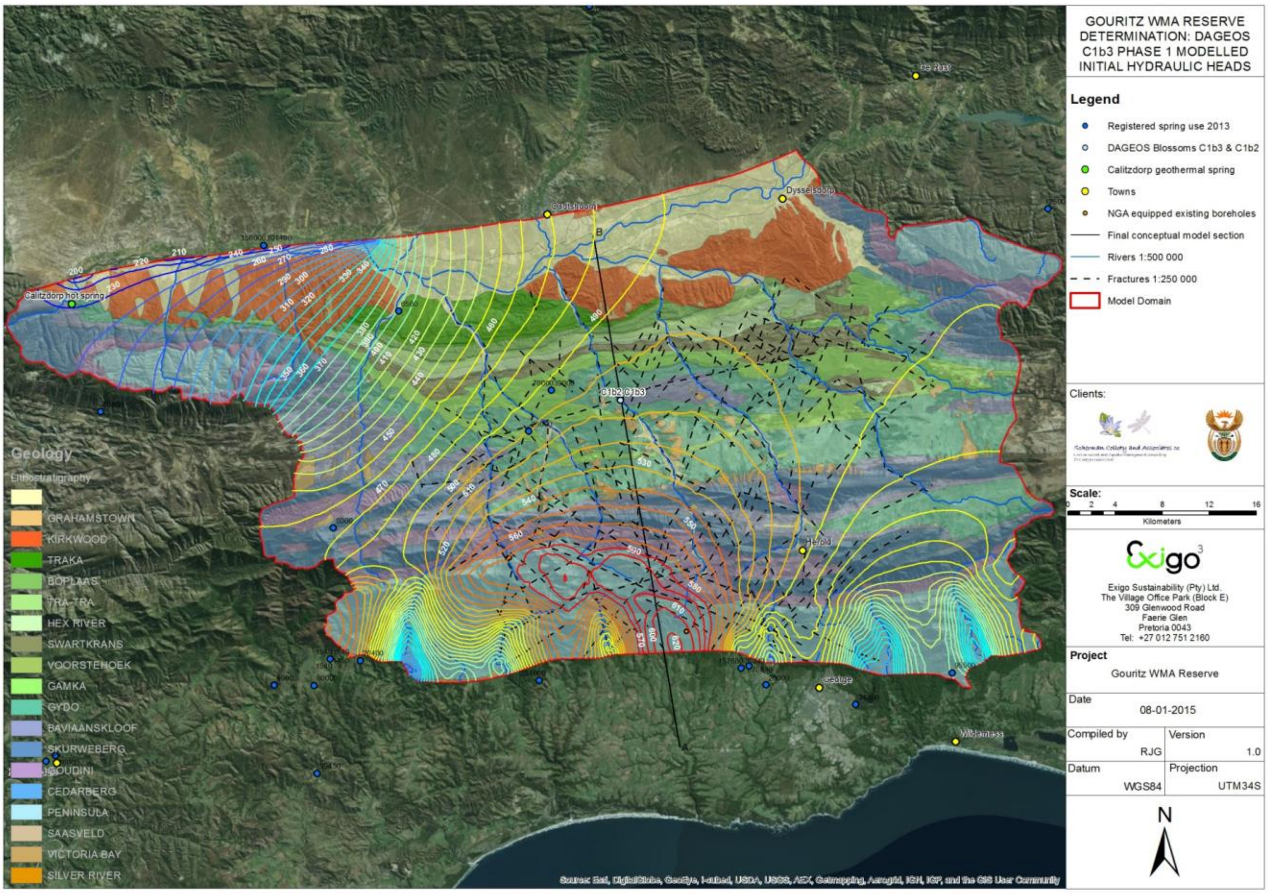

Figure D.4 Peninsula Aquifer – regional groundwater initial head contours (steady-state)

Table D.1 Layers and parameters for model qualification

No	Formation	Type	Thickness (m)	K (m/d)	T (m^2/d)	Faults K (m/d)	Fracture /Fault T (m^2/d)	Ss (1/m)	S (1)	Recharge (m/d)
1	Pre-Cape Basement	Aquitard	800	1.00E-03	8.00E-01			1.25E-08	1.00E-05	
2	TMG Peninsula - Shallow semi-confined	Aquifer	200	0.02	4	0.5	100	1.00E-05	2.00E-03	7.77E-05
3	TMG Peninsula - Deep confined	Aquifer	2000	0.0025	5	0.025	50	1.00E-06	2.00E-03	
4	TMG Peninsula - Deep confined - Blossoms Fault Zone	Aquifer	2000			0.1	200	1.00E-06	2.00E-03	
5	Goudini	Aquitard	300	1.00E-07	3.00E-05			3.33E-08	1.00E-05	
6	Skurweberg	Aquifer	250	0.005	1	0.2	50	4.00E-06	1.00E-03	
7	Baviaanskloof	Aquitard	150	1.00E-07	1.50E-05			6.67E-08	1.00E-05	
8	Gydo, Gamka to Enon	Aquitard	300	1.00E-04	3.00E-02			3.33E-08	1.00E-05	

Table D.2 Scenario 1: Steady-state pre-development groundwater flow balance

Scenario 1 – steady-state pre-development				
No	**Component**	**Inflow (m^3/d)**	**Outflow (m^3/d)**	**Balance (m^3/d)**
1	Recharge - rainfall	32 250.0		32 250.0
2	Abstraction shallow boreholes			
3	Leakage from rivers and dams			
4	Abstraction deep boreholes			
5	Water from storage			
6	Deep base flow, springs + losses		-1 750.0	-1 750.0
7	Shallow base flow, springs + wetlands + losses		-30 500.0	-30 500.0
	Total	**32 250.0**	**-32 250.0**	**0.0**
			Imbalance (%)	**0.0%**

The model qualification was expanded on a local scale by simulating the free flow test that was done over 38 days in 2010 (**Figure D.5**). The model provides a reasonable approximation of the transient free flow test, although the borehole in the model does perform better with a lower time drawdown gradient than the actual case. It would be expected that the simulated outcomes would be better than the expected actual case.

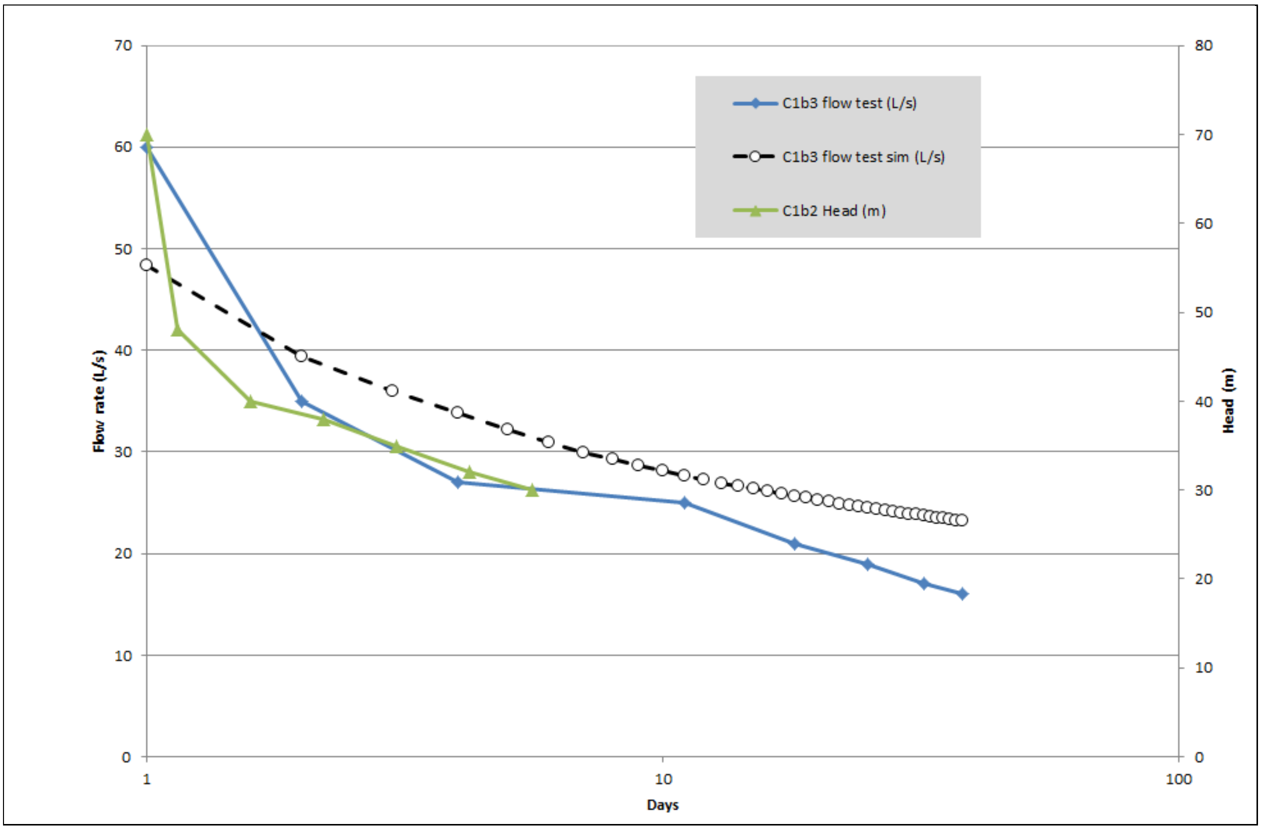

Figure D.5 Scenario 1: Borehole C1b3 free flow test simulated

To simulate the long term aquifer performance and sustainability, two scenarios were evaluated, one during which it was assumed that the streams and rivers are not in hydraulic connection with the shallow and deep aquifers (RU 1 and RU 2) and one which assumes a hydraulic connection on the shallow semi-confined Peninsula Aquifer (RU 1) only.

D.2.4 SCENARIO 2 – LONG TERM GROUNDWATER ABSTRACTION NO STREAM LEAKAGE

The qualified model was used to simulate the potential to supply 120 ℓ/s (3.28 Mm^3/a) from borehole C1b3 at the Blossoms Wellfield (Hartnady *et al*., 2014) and to evaluate the long-term impacts over a period of 50 years. This scenario corresponds to Conceptual Model 2 in Exigo (2014). The simulation indicated on the following:

1. The cone of depression is likely to reach a distance of 15 - 20 km after 20 years of abstraction (**Figure D.6**). This reaches the northern portion of RU1 is expected to induce leakage on the Doring River. The simulated cone of depression reaches the southern limit of the shallow semi-confined Peninsula Aquifer after 50 years, which would induce impacts on the river base flow and is expected to induce leakage of dams (**Figure D.7**). The leakage of dams were not included in the simulations.
2. The time drawdown curve shows that the head decline to below the borehole depth to an elevation of approximately -280 mamsl, within the first 2 - 3 years of abstraction (**Figure D.8**). It seems that the abstraction rate of 120 ℓ/s is too high for one borehole. The model was not constrained for the borehole depth and was allowed to abstract the required volume of water to observe the drawdown effect. It can be updated to impose a constraint, which will require a more detailed qualification or calibration.

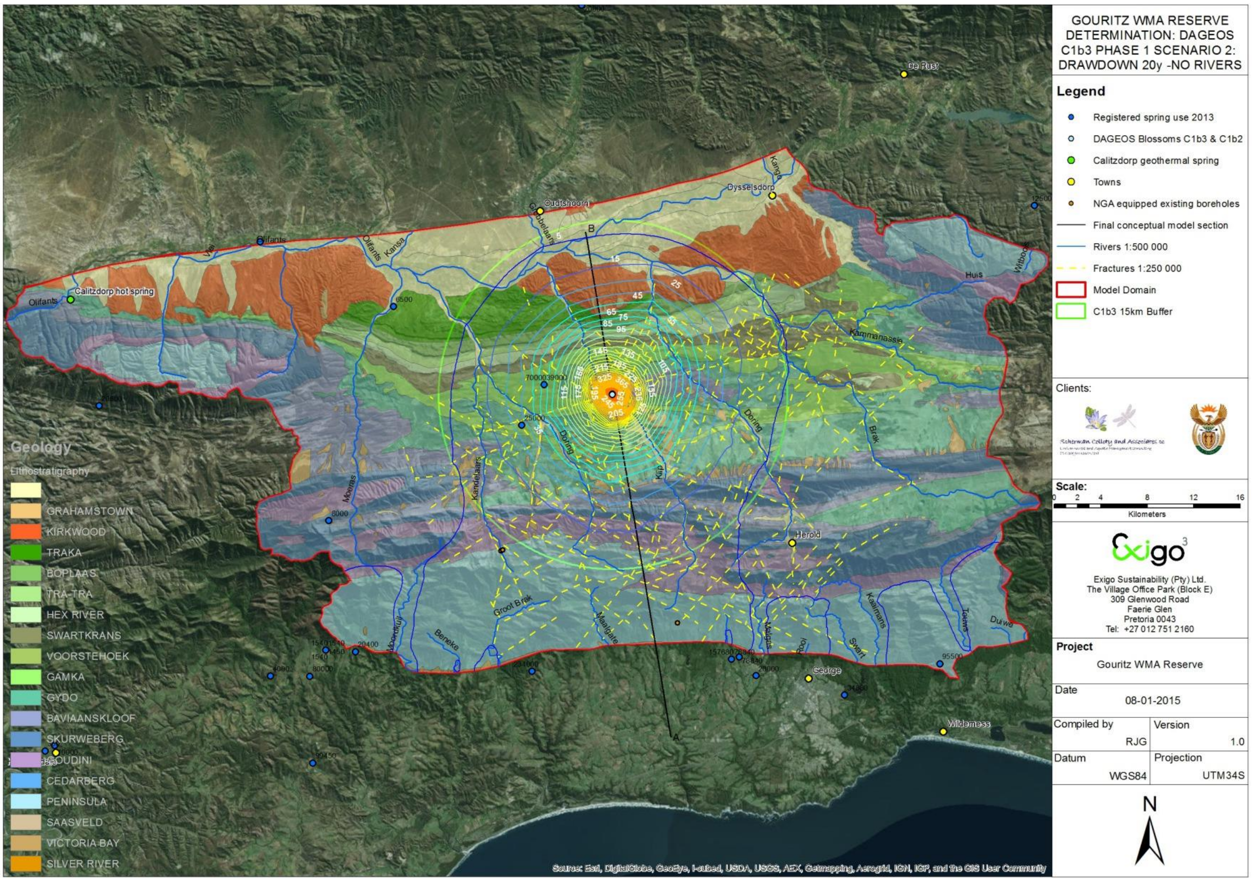

Figure D.6 Scenario 2: Peninsula Aquifer – regional cone of depression after 20 years at 120 ℓ/s

Table D.3 Scenario 2: No stream leakage groundwater flow balance 1 - 50 y of abstraction

Scenario 2 – Abstraction no river leakage				
No	**Component**	**Inflow (m^3/d)**	**Outflow (m^3/d)**	**Balance (m^3/d)**
1	Recharge - rainfall	30 686.0		30 686.0
2	Abstraction shallow boreholes		-1 369.9	-1 369.9
4	Leakage from rivers and dams			
5	Abstraction deep boreholes		-10 368.0	-10 368.0
6	Water from storage	10 368.0		10 368.0
7	Deep base flow, springs + losses		-1 730.0	-1 730.0
8	Shallow base flow, springs + wetlands + losses		-27 586.0	-27 586.0
	Total	**41 054.0**	**-41 053.9**	**0.1**
			Imbalance (%)	**0.0%**

3. The groundwater balance indicates that the average inflow from recharge of 30 686 m^3/d is mainly balanced by outflows to shallow streams and springs with associated losses amounting to 27586 m^3/d. Abstraction of 10 638 m^3/d from borehole C1b3, which is obtained from storage. The outflow of 1 750 m^3/d reduces by an insignificant volume to 1 730 m^3/d. This is due to the

low elevation and distance of the outflow boundary relative to the abstraction location. The exact outflow boundaries are not known but the Calitzdorp hot spring reportedly flows at 950 m^3/d (11 ℓ/s).

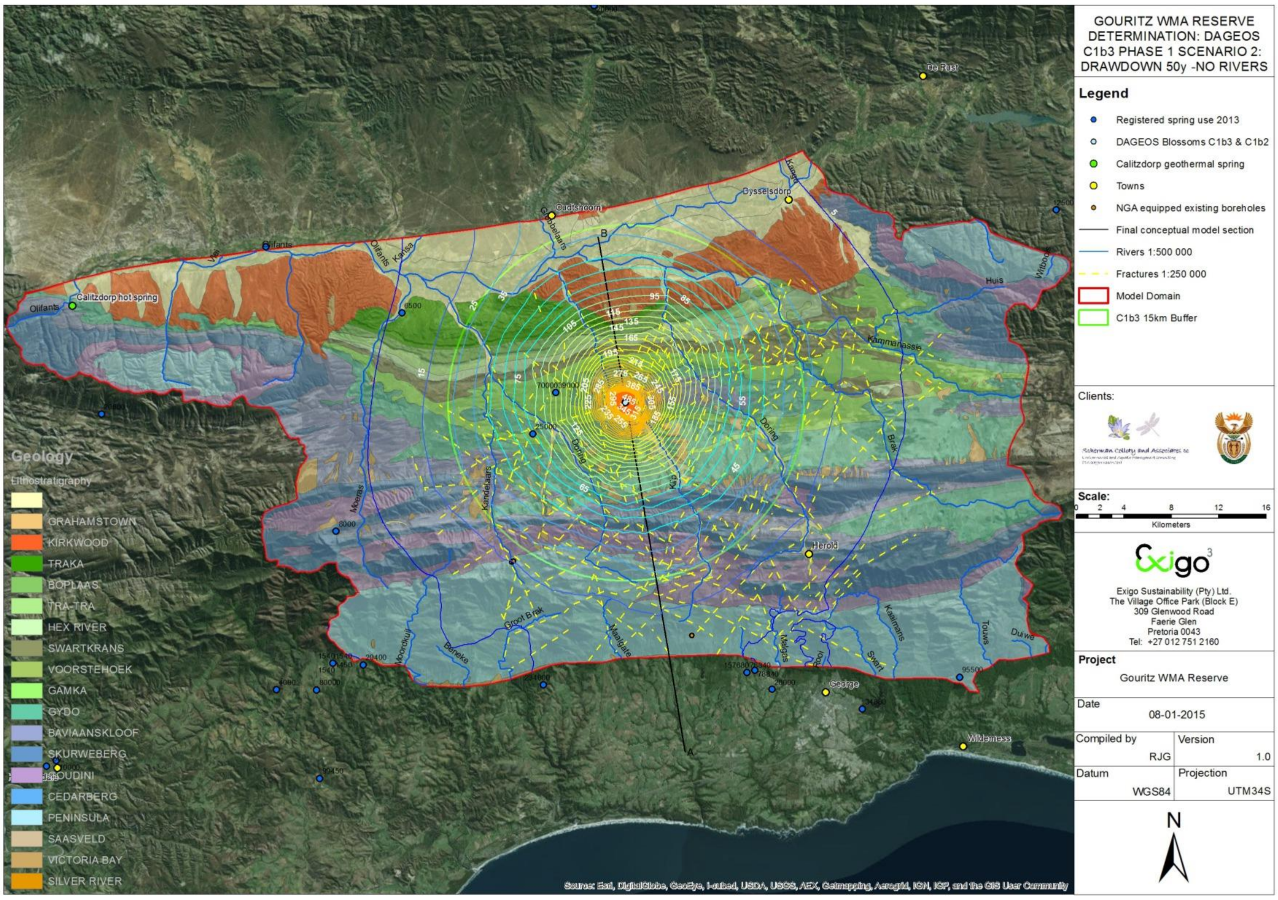

Figure D.7 **Scenario 2: Peninsula Aquifer – regional cone of depression after 50 years at 120 ℓ/s**

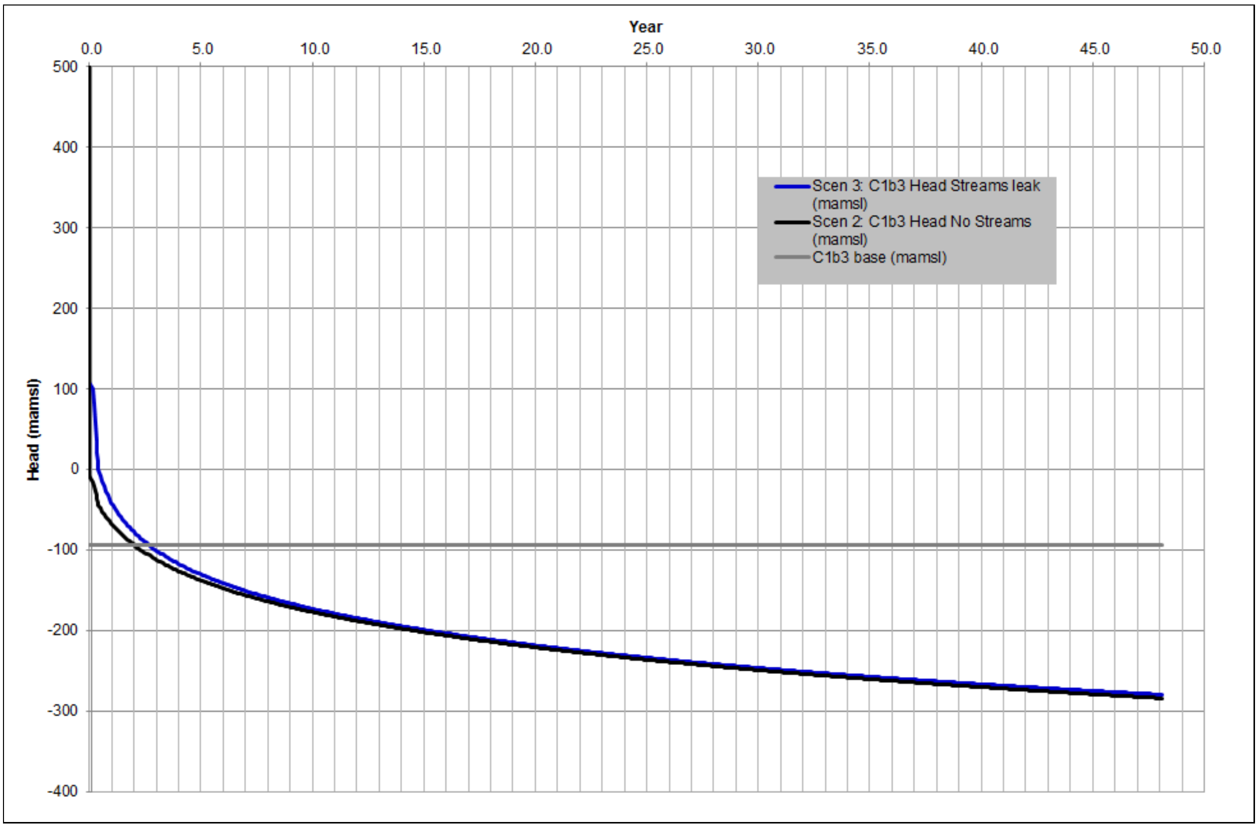

Figure D.8 Scenarios 1&2: Peninsula Aquifer – Borehole C1b3 time head curve after 50 years at 120 ℓ/s

D.2.5 SCENARIO 3 – LONG TERM GROUNDWATER ABSTRACTION WITH STREAM LEAKAGE

Scenario 2 was updated and the streams on the shallow semi-confined Peninsula Aquifer (RU 1) was assumed to be able to leak into the aquifer. This scenario partially corresponds to Conceptual Model 4 in Exigo, 2014. The simulation indicated the following (**Table D.4**, **Figure D.9**, **Figure D.10**):

- The cone of depression is smaller as the development slows down once it reaches the northern parts of the shallow semi-confined Peninsula Aquifer (RU 1) as streams start to leak into the aquifer.
- The groundwater balance indicates that inflow from recharge of 30 686 m^3/d is mainly balanced by groundwater baseflow, springs and losses along streams of 32 338 m^3/d. The stream leakage into the aquifer totals 9 595 m^3/d.
- The component that is derived from storage decreased to 5 525 m^3/d, which means that on average the abstraction induces increased stream leakage of almost 5 000 m^3/d that results in a 15% decrease in the groundwater base flow and spring flow on RU 1.

It must be noted that only streams were included in this initial model and that dams would also contribute to induced leakage as the head in the aquifer is dropped.

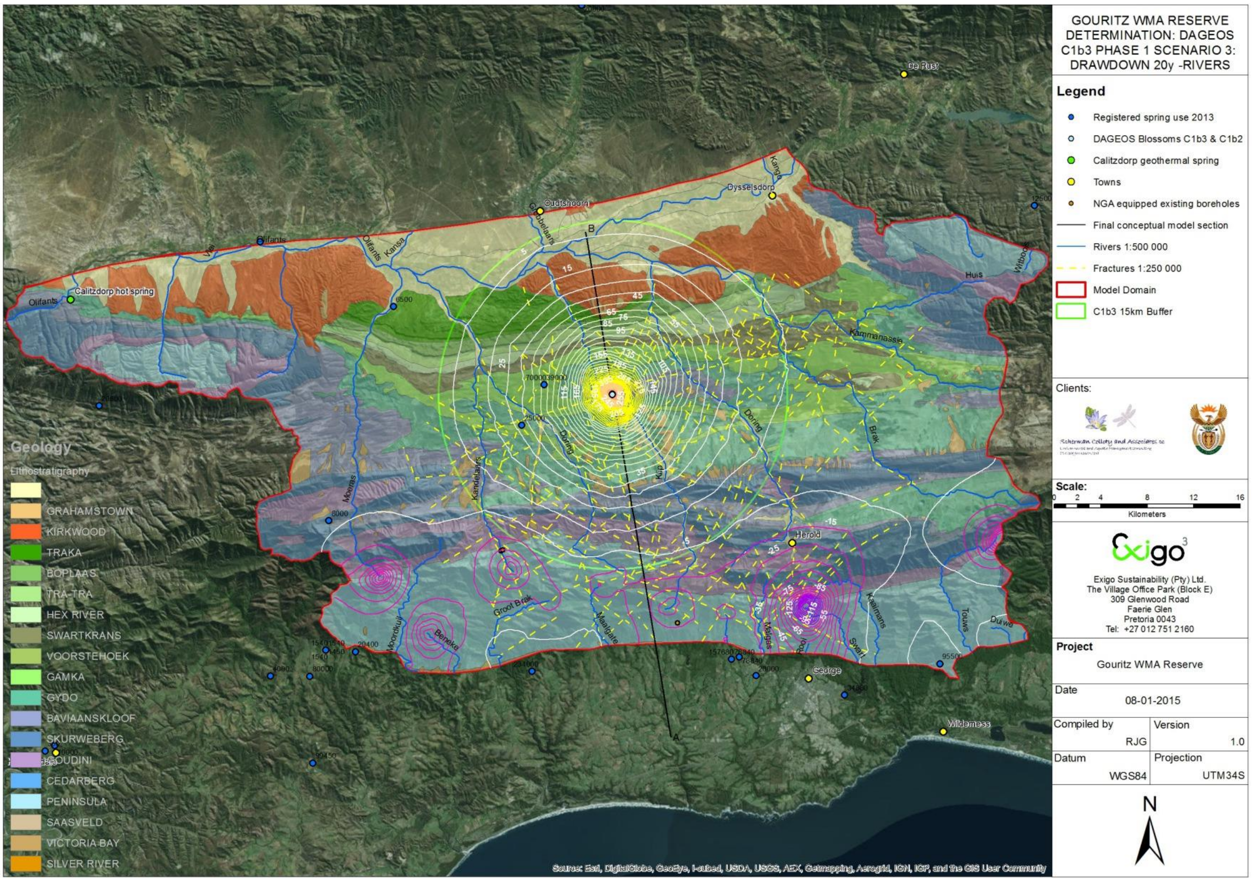

Figure D.9 Scenario 3: Stream leakage Peninsula Aquifer – cone of depression after 20 years at 120 ℓ/s

Table D.4 Scenario 3: Stream leakage groundwater flow balance 1-50 y of abstraction

Scenario 3 – Abstraction with river leakage				
No	**Component**	**Inflow (m³/d)**	**Outflow (m³/d)**	**Balance (m³/d)**
1	Recharge - rainfall	30 686.0		30 686.0
2	Abstraction shallow boreholes		-1 369.9	-1 369.9
4	Leakage from rivers and dams	9 595.0		9 595.0
5	Abstraction deep boreholes		-10 368.0	-10 368.0
6	Water from storage	5 525.0		5 525.0
7	Deep base flow, springs + losses		-1 730.0	-1 730.0
8	Shallow base flow, springs + wetlands + losses		-32 338.0	-32 338.0
	Total	**45 806.0**	**-45 805.9**	**0.1**
			Imbalance (%)	**0.0%**

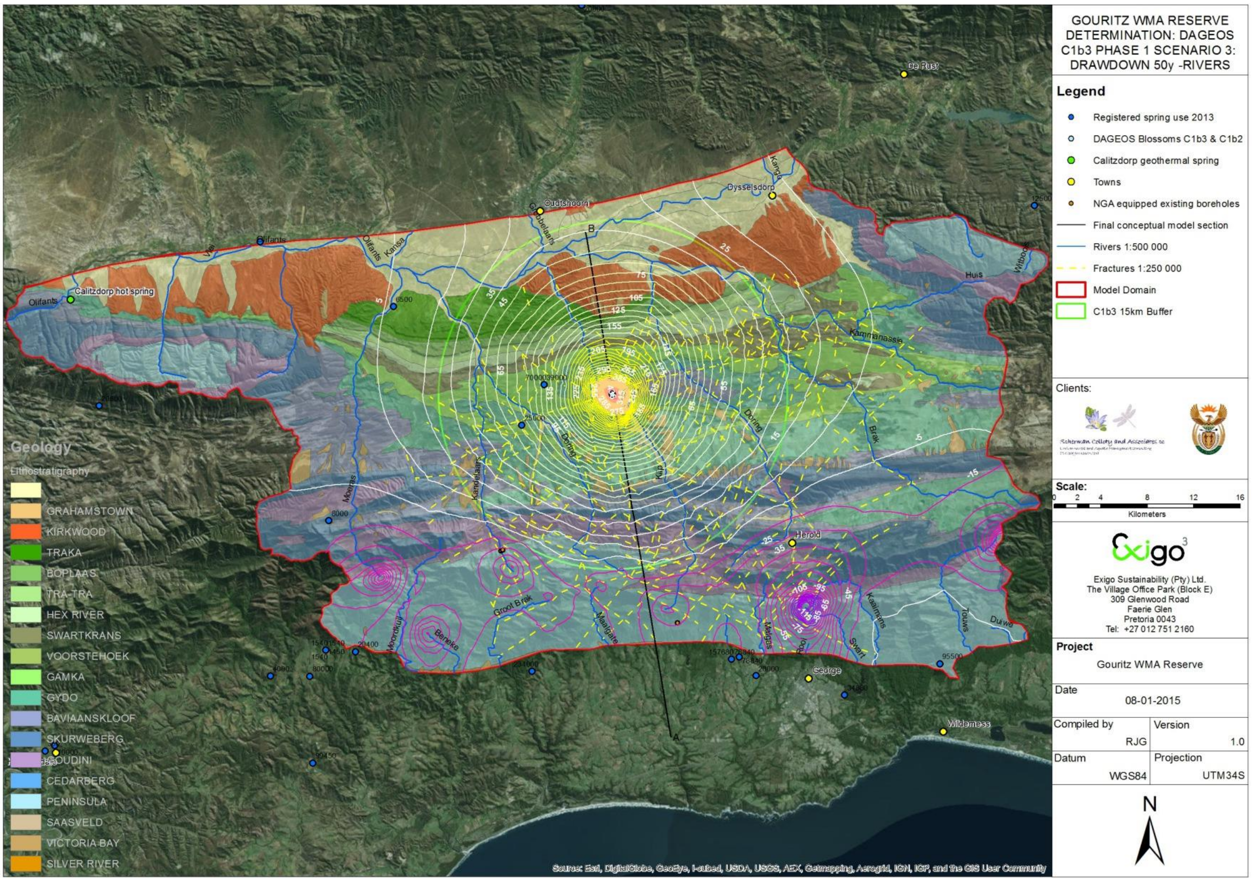

Figure D.10 Scenario 3: Stream leakage Peninsula Aquifer – cone of depression after 50 years at 120 ℓ/s

D.3 CONCLUSIONS

1. The initial conceptual numerical groundwater flow model shows that the abstraction of 120 ℓ/s (3.8 Mm^3/a) from borehole C1b3 (or a collection of wells) is not expected to be regionally sustainable beyond a 15-20 year period of abstraction. Initially, all the water can be obtained from storage, but it is expected to induce leakage initially at the Doring River and associated cold springs then impact on other streams and springs, depending on the magnitude of the leakage. Should the Doring River and other surface water features not leak due to the presence of assumed colmation layers (i.e. clay), then the drawdown at the borehole would be higher and would reach the southern limit of the shallow semi-confined Peninsula Aquifer (RU 1). The model that relies on groundwater storage for long-term yield is not sustainable. Recharge is the most important basis for long-term aquifer sustainability and not storage. Storage can buffer dry periods but it's effect must be evaluated using modelling.
2. The model indicated that most of the flow under natural conditions (pre-development) occurs in the shallow semi-confined aquifer (RU 1) as 95% of the recharge of 32 250 m^3/d exits the aquifer as shallow base flow, spring flow and riparian losses towards the south of the Outeniqua Mountain water shed. The deep flow component towards the north can be explained by the hydraulic parameters and the regional head gradient. The flow component is in the order of 1750 m^3/d.

3. In Scenario 2, which represents abstraction with no assumed stream leakage, the recharge from rainfall of 30 686 m^3/d is mainly balanced by outflows to shallow springs, wetlands and streams with riparian zones of 27 586 m^3/d. The borehole abstraction of 10 368 m^3/d is obtained from storage. The simulated cone of depression reaches 15 - 20 km from the borehole after 20 years which is the northern part of RU 1. After 50 years, the simulation indicates that the cone of depression is likely to reach the southern limit of RU 1 where groundwater base flow and springs are important. The outflow from the deep aquifer is not impacted significantly as it reduces marginally from 1 750 m^3/d before abstraction to 1 730 m^3/d after abstraction. This is due to the low elevation of the outflow boundary and distance relative to the abstraction location. The model indicated that the planned Phase 1 abstraction of 120 ℓ/s may be feasible from one borehole but that it will have to be drilled very deep, which would have practical implementation challenges.
4. In Scenario 3 that represents assumed stream leakage on RU 1, the water obtained from storage due to deep well abstraction reduces to 5 525 m^3/d, which indicates that almost 5 000 m^3/d is expected to be enhanced stream leakage to balance the abstraction. This volume represents 15% of the net groundwater base flow, springs and riparian loss volumes from groundwater. The cone of depression is smaller than in Scenario 2 as the streams provide additional water. This simulates the increased recharge of the capture principle.
5. The significance of the groundwater impacts simulated on the Reserve and environment depends on the contribution to the EWR, which must still be determined. These impacts and the management strategy of the catchment and not only the groundwater would determine the volumes of groundwater that can sustainably be abstracted from the shallow and deep Peninsula Aquifers (RU 1 and RU 2). The delineation of RU 1 and RU 2 as a resource, should be integrated as it is actually one unit that interacts. The future management strategy for the deep aquifer could be sustainable if artificial recharge and conjunctive use are considered and not only groundwater from storage.
6. There are a number of uncertain parameters in the model that would influence the result. The most important of these are recharge, storativity, the regional hydraulic conductivity of the aquifer matrix and fractures, stream leakage and possible presence of aquifer boundaries that are not known. The most important parameters that determine the aquifer sustainability are; storativity, recharge and stream leakage. Regional recharge in the shallow semi-confined aquifer (RU 1) was assumed to be 3.5% of rainfall and storativity was assumed at 0.002. As these parameters have not yet been verified in the field it would be difficult to assume higher values. Even if some field tests could be done, these parameters would be known at the specific locations and not the spatial variation. It is reasonable to expect that the hydraulic conductivity and specific storativity of the deep Peninsula Aquifer (RU2) would decrease with depth. These details were not included in the model, but certainly should be included in similar models in the future to re-evaluate the aquifer sustainability.

D.4 RECOMMENDATIONS

1. The yield of the shallow semi-confined and the deep confined aquifers (RU 1 and RU 2) and environmental impacts on the water Reserve must be quantified more accurately with a detailed numerical groundwater flow model that is calibrated based on regional monitoring data.
2. Based on 1 above, the utilisation strategy for the deep confined Peninsula Aquifer (RU 2) should be redefined. One option to increase sustainability may be to make use of artificial

recharge and take advantage of reduction in evaporation from surface water resources during surplus flow events to increase the yield of the aquifer.

3. Borehole C1b3 should be subjected to a long-term stress test during which the head is drawn down to at least 150 m below surface to test the performance of the borehole with the main aim to determine the storativity of the deep confined aquifer at that point. The planned abstraction with the number and locations of boreholes must be determined and abstraction rates optimised before further implementation is planned.
4. The Reserve determination of RU 1 should be finalised to determine the significance of the SANBI protected areas and the requirements of the surface water EWR, which will determine how much groundwater can be sustainably abstracted from both RU 1 and RU 2.
5. The dams on RU 1 should be included in an updated calibrated model to simulate the potential impacts of long-term abstraction on dam leakage and yield.
6. A management strategy may be to induce leakage in some areas as a form of artificial recharge. The implications of this must be evaluated and modelled in more detail.

D.5 REFERENCES

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Umvoto Africa. 2014. Umvoto Response to Ages – Fractured Aquifer Hydraulics And Hydrogeology of the Confined Oudtshoorn Basin. Letter dated 18 August 2014 by Dr C Hartnady.

APPENDIX E: COMMENTS AND RESPONSE REGISTER

Page	Report Statement	Comments	Addressed in Report?	Author Comment
Introductory pages: Addressed various editorial comments relating to report numbering, PSC members, authorship etc. Applicable to all reviews.				
Whole document: Addressed various editorial comments including updating or adding references, revising sentences. Applicable to all reviews.				
J. Conrad: External Reviewer Gouritz WMA Groundwater Reserve report comments - May 2015				
xiv	Static water level is the level of water in a borehole that is not being affected by withdrawal of groundwater.	Static water level is the level of water in a borehole that is not being affected by withdrawal of groundwater. Also known as a “rest water level”	Yes	
1	Introduction: …equal…	Explain what this means ….	Yes	close to being equal (in balance), meaning the volume of water that can currently be supplied is almost completely used up by water users.
	It has been recognised that some parts of the WMA are severely affected by invasive alien vegetation	What is the relevance of alien veg right up in the Introduction?	No	This provides background information to the reader about water use within the WMA.
	Preliminary Reserve	Clarify the use of Reserve, preliminary Reserve, Desktop, Rapid Reserve etc. Consistency	Yes	The entire document has been standardised to refer to desktop-rapid level Reserve for the screening Reserves done for the entire Gouritz WMA. Other terms explained.
	…hotspots	What are these?	No	Hotspots are clarified within the document.
2	low groundwater Reserve availability	The Reserve always has priority … this should be re-phrased.	Yes	It also serves to guide the selected field hydrocensus surveys to hotspots and areas classified as priority through the Reserve.
	…areas of importance within the WMA	What does this mean? Expand ….	Yes	Subject was expanded on p. 2.
	…hydrological data	Geohydrological?	No	Hydrological data is what is meant.
	all sources and sinks important to the reserve	What are “sources and sinks”? Expand or rather use hydrogeological terms. I really think a better term than “sink” should be used. … include all “recharge and discharge zones” that are …	Yes	Changed to discharge and recharge zones
3	The official text box received explaining that the Gouritz WMA will be grouped with Breede WMA	This text box talks about the Breede – Gouritz WMA… the report only describes the Gouritz WMA … this needs to be explained.	No	Text box received from Project management team.
4	Figure 1.1	The map doesn’t show provincial boundaries. Coordinates of the centre of the WMA: Centroid. The map itself says Fig 1.2. Towns aren’t included in the Legend. In the legend what does Sub-management mean? These areas should be labelled on the map.	No	No changes. Map used by PM team.
6	followed for the selection of priority/hot spot locations for hydrocensus as well as determining selected GRUs	Why selected? Wasn’t the study for WMA16?	Yes	To provide effective groundwater Reserve determination assessments on selected/priority GRUs, a selection and delineation process is required. If one reads further on this page

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				it becomes evident a desktop-rapid level Reserve determination process is used to evaluate all of the 130 WMA quaternary catchments at desktop-rapid level. Using this screening process, only the stressed/ strategic priority GRUs/catchments are selected for intermediate groundwater Reserve assessments, as evident from title of the GRDS.
	A three step delineation process was followed as described in the Outeniqua Reserve Determination Study (ORDS; DWA, 2010a) and the new GRDM manual (Dennis *et al*., 2012)	What's the value of including this?		References updated as stated above. No further changes. The value of including these references is that the methodology in these references is used as the basis for the entire GRDM process for the Gouritz WMA Reserve determination.
7	…that can be safely allocated to the groundwater reserve components.	Does groundwater get allocated to the Reserve? The Reserve is the priority…	Yes	The objective of the study is to determine the amount of water required for the groundwater Reserve as well as the amount of groundwater that can safely be allocated to current/future groundwater developments.
8	Selected inferred hotspot areas were evaluated in more detail where deemed necessary.	This needs more explanation …	No	A hydrocensus was performed for hotspots such as Waboomskraal and detail evaluation performed for hotspots is described further on in the report.
	The study primarily focuses on shallow surface aquifers	Why?	Yes	Updated to explain that most of existing abstraction and losses are from shallow (<200 m) aquifers.
9-10	2.1.5.1 Minimum flow balance approach	Is "flow" the best term? Why not "water"balance?	Yes	Updated to minimum water balance throughout document.
10	evapotranspiration in the riparian zone	What about groundwater that recharges deeper?	No	Groundwater that recharges deeper in deep aquifer case at Oudtshoorn was taken into account.
11	..regional catchments classified as high during the rapid Reserve	What does this mean? Reference to "classified as high"	Yes	Classified as stressed during the desktop-rapid Reserve.
11-12	role of storage is to buffer the aquifer volume during drought	What does this mean? Comment on "buffer"	Yes	Storage acts as a buffer to the volume of groundwater available in the aquifer during drought conditions.
12	power function that reduces recharge for below average rainfall seasons and increases it for above average seasons	Make it clear you are not talking about a recharge threshold	No	Author believes full sentence is clear. If required by DWS comments can be updated.
	…observed in terms of number of failures of the system allowed for a given assurance level, which is typically to a 1:50 year drought.	1:5 year would be better	No	A 1:50 year drought is more intense and puts more pressure on system. Hydrologists typically work on 98% (1:50) assurance of supply.
	The WMA can be divided into two major climatic zones based on two inland areas and a coastal belt	Doesn't add up	No	The two inland areas have a similar dry climate whilst the coastal belt has a wet and humid climate.
13	classified as one of the most temperate climates in the world with…	Are you sure? Reference to "world".	Yes	The word "world" removed.
	comparably large elevation range	What does this term mean?	Yes	Over a large elevation range compared to some of the other WMAs in South Africa.
	boundary of which the Gouritz River is the main	An explanation will help.	No	Strahler order is typical hydrological term that can be looked up.

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	drainage with a Strahler order of 5			
13-14	Table 2.1: Secondary drainage regions and associated main rivers (Figure 1.1)	Would be good to have a column of the primary catchments as well.	No	No changes due to time/budget constraints. Can be updated after DWS comments
18	Figure 2.1: Regional hydrogeological map of the Gouritz WMA	The map legend doesn't correlate with Table 2.2	No	No changes due to time constraints.
29	Figure 2.5: Gouritz groundwater – Conceptual Model 2-1	Text on the cross-section is difficult to read.	No	One can zoom into conceptual model a lot in PDF or in Word.
33	2.2.9 Hydraulic fracturing (fracking) in the Karoo formations - potential impacts on the groundwater component of the Reserve	Explain why this is included in the Reserve study.	No	This brief section was requested by the Project Management team and questions about fracking in the Karoo also came up during stakeholder meeting.
36	Table 2.4: Quaternary catchment hydraulic head-topography correlations: 33 randomly selected quaternary catchments	Why randomly?	No	Randomly is the statistically accepted approach. If the approach was not randomly Exigo could be accused of selecting only catchments with data favourable to its argument.
43	Table 2.6: Summary table of geology, hydrogeology and GRUs based on geology	Why are some GRUs sub-divided into a and b. Why are some missing e.g. GRU8?	Yes	Table updated and now includes GRU8.
44	Figure 2.13: GRUs delineated based on geology shown in grouped colours	Can the legend be linked to Table 2.6? i.e. have the GRU labels in the legend?	No	No changes in this version. Can be updated after DWS comments are received.
45	Figure 2.14: GRUs delineated based on geology shown in grouped colours.	Same as map above?	Yes	Map removed.
46/47	Figure 2.15:Example of one of the groundwater hot spots, namely Waboomskraal area which was delineated based on watersheds	Why show just the one?	Yes	No changes to map. Another map is included further on in the report that shows the other hotspots as well.
47/48	All Town Reconciliation Strategies: towns with higher risk of water supply failure	Is this groundwater related risk?	Yes	All Town Reconciliation Strategies: towns with higher risk of surface water or groundwater supply failure.
48/49	Figure 2.16: Quaternary catchments for GRU delineation with hotspots and areas of interest	In the legend - what does green/red/yellow etc. mean	No	No changes in this version. Can be updated after DWS comments are received.
8-1	DWS Western Cape office Sept 2013	Other provinces? Comment with reference to report statement	No	This is from where the WARMS data was obtained.
	60 ℓ per person per day	Where does this come from? I thought it was 25?	No	This volume was used per capita/day for basic human needs. There is also indication from NWRS discussions that the 25 ℓ/person/day should be 60 ℓ/person/day.
Comments: Gouritz (GRDS) Groundwater Report Technical Workshop outcomes - Reserve Determination – Groundwater				
NOTE: The summarised comments are after considering the DWS regional office comments:				
Comments: DWS				
1. TOR specified that the groundwater component of GRDS determine, through the updated method (2012), the groundwater Reserve ($Groundwater_{ewr}$ and groundwater Basic Human $Needs_{gw}$) for the Gouritz.				Noted. Both Basic Human Needs (BHN) and EWR_{gw} were included in this study. EWR (assumed 40% of baseflow in this study) should be updated in next phase of Gouritz WMA Reserve (or after DWS report comments received) to include

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				surface water study findings.
2. The expected results will supersede all existing Reserves. Use data and information from other studies that have been done in the area to update the existing groundwater Reserve. Substantiate through recommendations any differences.				This has been performed. Groundwater Reserves and EWRs determined should be finalised during next RQO's phase of study.
3. Of importance is to determine groundwater base flow that can be used when the EWR volumes, determined by the surface water specialists, such that the EWR are not negatively impacted.			Noted	
4. Based on point 3 above, update and recommend measures to be put in place such the EWR are protected, when there is any water use license applications.			Noted	
5. Exigo[3] will need to provide reasons as to why their proposed GRU are to be considered when determining the Reserve when comparing to the existing Reserve by Umvoto.				Exigo used Umvoto's deep confined aquifer GRU delineation for DAGEOS Reserve and model. Please see GW in relation to topography section and consider meaning of correlation at the macroscopic scale within which GW flow equations are applied. Also see Umvoto response to Exigo (AGES) 15-08-2014. Figure 3. Upper panel GW flow paths follow rivers and topography
6. Existing data and information, based on collected data previously will need to be used optimally so that realistic results are arrived at in determining the groundwater Reserve.				Done. The minimum groundwater balance/assured approach.
7. As soon as the groundwater Reserve has been determined, it is the responsibility of the DWS regional office to allocate water for use, taking cognisance of the determined Reserve.				
8. As it were, there is monitoring network within the Oudtshoorn Local Municipality. These networks must be optimised by considering the modelled scenarios monitoring information gaps or as soon as there is increase in groundwater use, when any developer applies for water use to the regional office.			Noted	Also see GEOSS presentation and KKRWSS monitoring reports. Exigo will update Gouritz Reserve GW monitoring report component.
Other important technical matters and concluding remarks, as compiled by Mike Smart are of crucial importance and it is recommended that Exigo[3] take heed of these. The DWS Reserve office will expect to see these matters addressed and reasons provided where these matters are not taken into consideration.				
General: Any groundwater reserve determined needs to take into consideration that groundwater held in storage may be allocated if an aquifer is recharged directly and it has been proven, through monitoring data that recharge is not lagging after rainfall event and baseflow is impacted minimally.			Noted	No changes to report.
Based on Exigo report and presentation, the following are worth consideration:				
Conclusions				
Umvoto need to consider points 1 to 4				
Will the EWRs be reasonable and will groundwater baseflow be of long term to avail water for the EWRs, point 6			Noted.	EWR (assumed 40% of baseflow in this study) should be updated in next phase of Gouritz WMA Reserve (or after DWS report comments received) to include surface water study findings.
Points 8 and 9 need to be considered when building a numerical model for further development studies				
Recommendations				
Refer to 3rd bullet above.				
Points 3 and 6 are of crucial importance when new water use applications are considered by the DWS regional				

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office.				
Based on Umvoto report and presentation, the following are worth consideration by Exigo team:				
Question 3	Noted	Groundwater Dependent Ecosystems/EWR_{gw} zones will be more clearly described in report. There are registered springs uses (2013 survey) obtained from DWS within RU1 and RU2 (see 1st map in presentation). Stream flows are also partially dependent on springs. It is clear that RU1 will also be impacted by abstraction from RU2. Calitzdorp hot spring is expected to have vegetation dependence and socio-economic dependence.		
Question 4a and b	Noted. No changes.	a) Each flow component has been described in the report. GW flow components are used for conceptual model to enhance conceptual understanding of the system and what flows could be possible. Shallow aquifer spring flow not flowing overland to create baseflow to a drainage is found in nature, e.g. numerous springs in TMG mountains (RU1) where flow is such that it supports vegetation/small wetlands, but evapotranspiration is such that GW does not reach drainage. If it can be proven that flows in conceptual model do not occur in nature, groundwater flow components can be updated, but until then the benefit of the doubt must be given to the environment. b) Coordinates of C1b3 indicate that it is located next to drainage, however this drainage is not the basis of deep GW baseflow (Q_{DGBF}) argument. Is Calitzdorp hot spring not fed by deep GW baseflow?		
Question 5 and 6	Noted	Consultant's conceptual model in previous Reserve determination study is correct with regards to TMG southwards and northwards flow. Exigo agreed with this point on their conceptual model. KKRWSS monitoring reports indicate recharge in Peninsula Fm overestimated. Given consultant's recharge estimate of 9% of MAP, we regard this as an overestimate for abstractions mentioned and planning purposes. Note final recharge estimates obtained from various recharge methods applied by Xu *et al.* (2007) in Kammanassie case study.		
Question 8, 9 and 10		Exigo requested all data from consultant that performed studies in the Gouritz WMA in e-mail December 2013. Not all of Oudtshoorn GW development reports or data was supplied, hence the information could not be used. Exigo queried where Oudtshoorn report referenced in DAGEOS Reserve report is during this meeting as well.		
NOTE: Umvoto presentation was stopped as there was not enough time to do justice to their presentation and Exigo had left. Presentation by the appointed reviewer for the study need to be deliberated on as there was no time for him to present.				
Round 2 Review: August-September 2015				
Document version: Gouritz _Groundwater Rep FINAL July 2015_ed PS_editted_MikeSmart_edittedJConrad31Aug2015.docx				
Reviewers: J. Conrad – JCD; M. Smart – MS; Dr P. Scherman – PS.				
xi	during the winter months	Why winter months? [JCD15]	Yes	Removed, winter months, added "dominant source"
	…Only source…	????check [MS]	Yes	Changed to dominant source especially during drought cycles when dams dry up
	assumption was made that 10 - 15% of all irrigation comes from groundwater	For the irrigation schemes the proximity to surface water dams should be checked. In other areas extensive irrigation can occur from groundwater. Are there any references for where the "10-15% irrigation comes from groundwater"? Check ISPs; WAAS etc. [JCD]	Yes	GYMR Reserve groundwater balance was re-checked after comments.
	assumption was made that 10-15% of all irrigation comes from groundwater	Was there any differentiation made between the dry Karoo or wet coastal areas? Consider in future. [MS]		GYMR Reserve groundwater balance was re-checked after comments.
xii	…6 catchments… desktop-rapid level Reserve iteration.	So where does this leave us? [JCD18]	No	It means 6 catchments that were flagged during the desktop-rapid level screening, are actually not as severely stressed even under drought conditions.
	A numerical conceptual model was developed	Doesn't a conceptual model lead into a numerical model?	No	It was a less detailed numerical groundwater flow model only to

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	for…	[JCD19]		qualify the flow volumes that could be expected. For this reason we do not want to call it a fully-fledged detailed numerical groundwater flow model.
	(Resource Unit 1)	How does an RU relate to a GRU? [JCD20]	No	RU is the same as GRU. RU is simply used here to be consistent with existing DAGEOS Reserve determination where these RUs were delineated and to not cause confusion when referring to RU1 and RU2.
	would in time reduce the baseflow contribution of Resource Unit 1 by the same amount for the system to balance	(Not same amount – why only baseflow reduction? What about EVT reduction and reduced discharges from the confined aquifer. What about the contribution made by recharge to Unit 1 that does not manifest as baseflow in Unit 1 but goes directly to the RU2 deeper system etc. i.e. Not necessarily a 1:1 impact on baseflow in Unit1 only. [MS] If this comment is true the text should be adapted so as to clarify why there is not 1:1 impact. [JCD]	No	The potential flow from the shallower semi-confined aquifer (RU 1) to RU 2, under conditions of abstraction would in time reduce the baseflow contribution of Resource Unit 1. We do not know by how much EVT may be reduced, so how can credit be taken for it? It is one of those unknown parameters that we take into account as a sink but not as a source as EVT may be linked to natural wetlands or sensitive riparian vegetation. If the system is much better understood and the environmental impacts can be demonstrated in terms of trade-offs, then EVT can be brought in. The discharges from the confined aquifer are inevitably linked to the recharge and together with storage do not constitute an addition to the resource yield in the long-term.
	…Increased leakage from surface streams.	(there are likely to be other contributions to the deep system as well as suggested above)	No	Leakage is expected from several surface streams that would likely be intersected by the cone of depressions once it reaches RU1. This includes the Doring River and possibly the upper reaches of the Maalgate after 20 years of abstraction and after 50 years, it would include the Kandelaars River (Fig 1-6 Exigo, 2015). As this is a conceptual or high level model which represents a "best case" aquifer meaning that the actual aquifer is expected to have a lower yield. The impacts on surface water features should have been done prior to yield determination of the RU2. Where would the water in RU2 come from? It has to come from storage and some discharge reduction.
	due to abstraction may negate the dewatering of the deep confined aquifer but with an impact on the surface water streams	How do surface streams recharge a deep confined aquifer?? [JCD23]	No	RU1 and RU2 are essentially the same aquifer and GRU since they are formed by the same Peninsula Formation lithological unit. It is physically the same lithological continuous quartzitic sandstone unit. Hence what happens in RU2 will affect RU1 in time.
xiii	General comment	Detailed hydrogeological evaluations are currently underway in the area as part of the Blossoms RBIG funded water supply project for Oudtshoorn Municipal supply (Umvoto). There appears to be a wide discrepancy between resource estimates made by Umvoto and those made by Exigo for this same area. If the Exigo numbers for RU2 are provided in the reserve report, a very clear explanation for an Umvoto/ Exigo discrepancy would be required, and the legal standing well explained, so as to	Yes	Statement added in report and recommendations to say that detailed follow up study/studies should be done to better quantify allocable volumes obtained during this Reserve for the DAGEOS aquifer.

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		ensure that the wellfield license is not unnecessarily brought into question. [MS]		
	can be replenished via surface water artificial recharge during flood peaks.	(Won't this enhanced recharge happen anyway if the groundwater levels are dropped in RU1?) [MS]	No	No, what this refers to is artificial recharge obtained from a planned strategy where flood peaks are banked. Enhanced leakage from streams could entail environmental impacts as well as reduced availability for downstream users. If enhanced leakage from streams is a strategy is to be followed, then the impacts must be quantified and demonstrated in terms of significance before resource development.
xvi	Conjunctive use strategies between surface water and groundwater should be investigated and a guideline document be compiled that would account for the constraints in each catchment	Would this be part of RQOs? [JCD28] (Unclear what is meant by this sentence). (Also -– do you suggest a guideline document for each quaternary catchment?) [MS]	No	This recommendation is not specifically written with RQOs in mind no. This recommendation simply suggests integrated use of groundwater and surface water resources in each catchment. A general guideline document on how integrated water resource use can be realised can be compiled that is generic and applicable to all catchments.
xvii	Artificial recharge should be considered as a future water management option.	Dr Ricky Murray and GEOSS have already done quite a lot of work on this as part of the National AR Strategy. This should be referenced. [JCD29]	Yes	
	The water management strategy for the deep confined TMG aquifers should be reviewed…	Ddoes one exist? [MS]		Noted.
	Detailed groundwater investigations and baseline monitoring data must be collected for 2-5 years before exploratory work is done.	This probably contradicts the Draft Regulations. Should there not be alignment with Regs? Best not to specify timeframe? Preferably in excess of one hydrological year. [MS]	No	Detailed groundwater investigations and baseline monitoring data must be collected before exploratory work is done.
	General comment on Executive Summary	This project is all about the Reserve … This Executive Summary to my mind basically ignores the Reserve. It seems as if the project objectives have got lost and the focus has turned to resource quantification and water balances. Where is the Reserve information in the Executive Summary?? [JCD31]	Yes	
1-28	Objectives: The study resolution and management unit was based on surface water quaternary catchments with hydrogeological units differentiated within the quaternary catchments	Is this an objective? Its more about methodology [JCD32]	No	Noted.
	10 to 20…	The exact number is known – otherwise rephrase the tense of the paragraph [JCD35]		Changed to 10.
1-32	Study area map Figure 1.1	The map says Fig 1.2. Can the resolution be improved? I like to see the ocean in light blue and inland areas not part of the study can be a light buff colour …it gives the study area a better context. [JCD37]	No	

Page	Report Statement	Comments	Addressed in Report?	Author Comment
2-2	The EWR was assumed to be 40 % of the quaternary baseflow estimate	Is there a basis for this? [MS] Please explain further about this 40%…. [JCD40]	No	This was an assumption made for the desktop-rapid level screening based on previous project experience. The EWRs were updated and calculated for the intermediate Reserve determinations.
	Formally protected areas are protected against any further abstraction as well as any reduction in baseflow, thus they cannot be included in further calculations of allocable groundwater.	This is not necessarily correctly applied. What if recharge within the protected area doesn't report to baseflow within the protected area. Surely groundwater recharging within protected area, but discharging outside the protected area (e.g. feeding the deep system) can be allocated? [MS] Agreed [JCD41]	No.	NSBA 2011 formally protected areas are to be excluded from Reserve determination calculations according to the GRDM methodology and Manual Dennis *et al*. (2012). There is however exceptions to the rule as described. Note effective areas were used for the desktop-rapid level Reserve and not the Intermediate Reserve for this reason.
2-5	If the approach is overly conservative, this figure would be expected to be much higher.	Logical argument? [MS]	Yes	Sentence construction changed. The core of the argument remains the same: If the approach is too conservative and we are wrong, more water is available in reality as opposed to the other way around.
2-6	In a natural system un-impacted by any anthropogenic effects, the groundwater component of baseflow is equal to recharge minus losses due to spring flow, and evapotranspiration in the riparian zone.	What about losses via deep flow? [MS]	.	
2-12	The Table Mountain Group was deposited directly on granites of the Cape Granite Suite	And Namibian era sedimentary rocks? [MS]	Y	Included Namibian era sedimentary rocks.
2-19	Gouritz groundwater – shallow surface aquifers Conceptual Model 1-2.	Dykes are rare – occur only in extreme north [MS]	No	Noted. It is only the first generalised conceptual model. A number of study area specific conceptual models follow.
2-20	In the case where there is outflow (Conceptual Model 2-2), the yield and Reserve must decrease	Explain why? [MS]	No	For the conceptual model with no faulting to allow for deep groundwater circulation, none of the Recharge then goes to deep flow to geothermal springs or losses along faults, hence more recharge reports as shallow spring flow and baseflow to drainages in RU1.
2-21	In the absence of prior abstraction there must be a flow component that would be controlled by the discharge rate, given that the discharge is smaller than the recharge.	In the absence of prior abstraction there must be a flow component that would be controlled by the discharge rate, ? given that the discharge is smaller than the recharge is it? [MS]	Yes	In the absence of prior abstraction there must be a flow component that would be controlled by the discharge rate, given that the deep discharge is smaller than the total recharge to RU2 due to lateral outflow constraints.
	Where Q_{DP} is pumping from the deep aquifer. In the case that, $Q_{DGBF} + Q_{DP} > Q_R$ let's call it Scenario 2-2b1, then Q_{SSF}, Q_{SP}, Q_{ET} and Q_{SP} would eventually decrease with time and cease as the deficit can only be balanced by the confined storativity of the aquifer.	What about increased recharge and reduced evapotranspiration balancing the abstraction to some extent? [MS]	No	If only Q_{DGBF} and Q_P are already > Q_R then for Scenario 2-2b1, only a decrease in former mentioned outflow components can cause Q_R inflow component to be greater outflow components.
2-24	Figure 2.4: Gouritz groundwater – regional hydrogeological cross-section C (modified after	This cross-section differs significantly to what is presented in the following diagrams and in the Umvoto	No	Although the part of the section from the Outeniqua mountains to the Kammanassieberg (R. Newton) is being disputed, the rest

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	Tankard *et al*., 2009)	report (Riemann & Blake, 2010). Is it worth including? [JCD43]		of the geological model is good and backed by seismic data and expert seismic analysts. We also believe the regional conceptual model provides regional perspective that the local models do not.
2-59	For this study no groundwater qualities were available from the NGA database, where normally at least a few boreholes with water qualities are available to apply the chloride mass balance (CMB) method in areas of interest.	I assume you mean Chloride analyses? [MS] (Hydrochemistry data are in the WMS database, not the NGA – there would most likely have been data available there.) [MS] Did Umvoto not have any Chloride analyses available?. [MS]	No	Noted. Normally the NGA has groundwater quality data for the WMA, but none were received upon the georequest for all NGA data for the Gouritz WMA. Water qualities from numerous existing studies were used as stated in the next sentence.
	Assumptions of recharge based on lithology were made where recharge was unavailable for a specific formation.	What source was used for RU1 Outeniqua? [MS]	No	Various references and recharge figures were reviewed Jia, 2007; Umvoto Africa, 2010; Xu *et al*. (2009); Woodford (2001); Parsons *et al.* (2007). Xu (2009) and Jia (2007) found recharge of Peninsula window Kammanassie max 2%. A recharge of 5% was selected based on figures reviewed (Exigo, 2015).
2-60	Table 2.14: Table of recharge values according to geology and GRU grouping used in GYMR Reserve calculations.	Did Umvoto have any site specific recharge determinations available / chloride data? The recharge to RU1 looks very low – realistic?	Yes	Table error updated to indicate 5% recharge for Peninsula Fm. DAGEOS Peninsula Fm recharge might be higher, we used 5%, but this is site specific. For Peninsula in Vermaaks River Valley recharge calculated 1.6-3.3% Wu (2005) and Jia (2007) 0.2-2%
2-61	Rainfall data was obtained from the WR2005 dataset…	Has this been verified by E. Van Niekerk? The rainfall presented in the GW report should be the same as that used for surface water? [ALG]	No	Noted. The source of the rainfall data is WR2005, which is in most cases similar to what E. Van Niekerk used, after electronic correspondence with her.]
2-67	Wetlands section in the Reserve Determination.	What % of wetlands is groundwater fed? [JCD48]		Sentence added that assumption was made that all NFEPA wetlands are groundwater fed. This is a comparably small volume in the groundwater balance.
2-86	assured yield (P98) at 4.7 million m^3/a .	In the ES 5.2 million m3/a was given. [JCD50]	Yes	Changed to 5.2 million m^3/a
	This figure is much lower than the current expected yield of 19.7 million m^3/a (Riemann and Blake, 2010).	Is this yield for both RU1 and RU2? This summary will be easier to read if tabulated. [JCD51]	No	Noted. This is the combined yield (Allocable GW) of RU1 and RU2.
3-2	resource quantification and impacts on the Reserve must be determined adequately prior to large scale development.	Does a deep confined aquifer have a Reserve? [JCD55]	No	Good question. The National Water Act (NWA) however states before Any water resources can be assigned to water uses, the Reserve needs to be determined and provided for (subtracted from yield of aquifer).
3-3	An assumption was made that 10-15% of all irrigation comes from groundwater.	How was an actual number chosen? [JCD56]	Yes	GYMR numbers were re-checked after these comments An assumption was made since the WR2005 figures do not differentiate between irrigation from surface water and groundwater.
	The current management strategy is to utilise storage and dewater the aquifer over a period of time.	Confirm with Umvoto whether they plan to dewater the aquifer over time. My understanding is that they plan to optimise scheme management by making use of the abundant storage buffering capacity.	No	This “storage model approach” was stated in their letter response to Exigo Aug 2014.

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	the volume in storage.	I think the recharge volumes used are too low. [JCD57]	No	Noted.
	between 6-20 years to deplete the volume in storage? before adverse impacts is are expected.	Do you mean till the cone of pressure reduction reaches RU1? [MS]	No	Yes. Also refer to Exigo (2015) for numerical modelling results.
	Initial evaluations indicated that the zone of influence from abstraction at the Blossoms wellfield could reach the semi-confined, surface aquifer within 10-20 years.	There are so many assumptions in this paragraph. Note earlier comments on the sensitivity of providing such low confidence figures in the Reserve report. Furthermore - an impact on surface flow is not necessarily an "adverse effect". Impact on the reserve / environmental flow component of surface flow is considered an adverse effect. [MS]	No	Noted.
	Surface water features such as the George Dam is located on the shallow surface aquifer (RU1) and may experience accelerated leakage or reduced yield from baseflow and surface runoff should the groundwater head in the shallow surface aquifer be reduced via abstraction.	This is a very "far-fetched" idea. All the rivers on the northern slopes would surely dry up before the George Dam is impacted. Early warning monitoring will be in place and action taken long before the George Dam is impacted. [MS].	Yes	Noted. Conclusion will be reviewed and deleted.
7-1	Appendix A; Desktop Reserve and groundwater potential	The Reserve quantities do not change between P50 and P98. I would like to see far more detail on how the Reserve was calculated. [JCD60]	Yes	New appendices added on Methodology.
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Additional external reviewer: Dr K.T. Witthüser – KTW.				
1-28	A maximum of 10 to 20 quaternary catchments was selected to do a hydrocensus.	Limited based on available budget? [KTW1]	No	There are known stressed areas and there was budget constraints.
2-3	Should a geological unit be used as a resource boundary, it should be done as a secondary assessment.	Why, if this is the functional unit??? [KTW8]	No	The quaternary catchment is a functional management unit. Any inflows from or outflows to hydrogeological units can be taken into account. Should GRU's be used, more variables are imposed.
	If the TMG quartzitic sandstone is to be considered as a GRU, which stretches across tens of kilometres, it must be considered that the rainfall and hence recharge will change across the length and breadth of the GRU and add uncertainty in terms of how to quantify the inflow and outflow of the GRUs.	Not that we have a higher certainty on a quat scale [KTW9]	No	This is debatable. It depends whether or not the groundwater head correlates with the topography or not.
2-4	It used recharge as a function of MAP (i.e. P50) and not an assured lower recharge that could take account of drought conditions (i.e. P95 or P98)	Please give function as there is usually a non-linear relationship [KTW11]	No	In the GYMR, a minimum recharge rate is used. Non-linearity would be introduced in the comprehensive reserve phase. The decision-making process refrain from adding complexity just because it seems to be "good science". It is added when it makes sense to do so in the decision-making process. See new Appendix C that was added.

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2-5	…actual groundwater balance will never be known as it will be transient.	This statement undermines anything below! [KTW12]	No	No it does not. While there is great uncertainty as to what the rainfall (i.e. recharge) would be in any given year, the lower 98th percentile can be determined with a high level of confidence.
	A minimum groundwater balance approach also ensures that aquatic ecosystems (EWR) and the BHN Reserve are duly protected from precluded initial over-estimations.	So while one cannot determine the actual balance, but the minimum one with additional uncertainties due to non-linear rainfall-recharge relationships and even less monitoring data for drought cycles? [KTW13]	No	Non-linear recharge is not applicable as the minimum is used. Adding complexity such as non-linear recharge would not reduce uncertainty, it will actually increase it. The minimax approach is described in more detail in Appendix C as the decision-making approach and what this aims to achieve is misunderstood.
	…with rainfall probability and groundwater storage taken into account.	How does storage feature in steady-state simulations? Or are these transient? [KTW15]	No	These are transient, but due to budget constraints could not be fully applied in this study.
	This leaves the burden of proof on the potential water user and not on the regulator.	Easy way out for DWS, likely to preclude many smaller scale developments as they will be unable to afford such investigation. [KTW16]	No	Disagree as this is the best decision-making alternative. Small scale developments are not expected to have high impacts. If the developer cannot afford the study then sure they should not even attempt to develop the resource as how will they manage it? It is common practise for the developer to do EIAs, an important part of this is the resource sustainability.
	The effects of uncertainty mean that the environment and the Reserve would receive the benefit of the doubt, which is much better than the other way around.	Is the same principle applicable to SW models? This puts gw models on a massive backfoot and disregards adaptive management principles. [KTW17]	No	No it does not. Rather get trust into groundwater sustainability than try to take risks on the resource sustainability. A trusted resource is one that will be on the forefoot. An yes the exact same approach should be used for surface water as this is about water management regardless from where it comes. Surface water however has the advantage of having measurements on available volumes which groundwater does not always have.
2-6	It may even be that there could be no actual flow in a surface stream while groundwater seepage continues to support the riparian vegetation along drainages…	A point to consider is why the EWRs must be maintained by gw baseflow only. [KTW18]	Yes	EWRs is expected to be dependent on groundwater for drought low flow conditions. Clarification added.
	The desktop-rapid level Reserve was based on desktop and literature data taken from the available databases (Dennis *et al.*, 2012)	Elaborate where and why GRAII or GRDM data are used [KTW19]	Yes	The GRA II and GRDM (2013) data sets were used for the desktop-rapid phase, which was supplemented and reviewed in the intermediate phase with field data.
	The modelling and decision-making approach is based on a Bayesian method…	Consultants advice only, DWS decides	No	This process advises the DWS on decision-making process. A decision-making process is a formal process that puts the DWS in a position to make a decision. Not taking the decision for them.
	…so more groundwater volumes would be allocable as conservative assumptions are replaced with measured or acquired field data…	Agreeable approach, but adaptive management could unlock limited resources. [KTW20]	No	Yes the approach that was followed here was not communicated clearly, see Appendix C. An adaptive management process is acceptable but it must not lead to a downwards revision of groundwater yield but to an upwards revision in line with the minimum groundwater flow

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				balance approach as this builds confidence. See Appendix C. To have a system that needs to constantly adapts the yield downwards puts groundwater on the back foot – not the conservative approach.
	…catchments that have surplus groundwater potential and those that are at risk due to overexploitation.	Based on a simplified water balance approach. [KTW21]	Yes	Clarified in Appendix C.
2-7	The transient simulations are done for periods that range from 50-100 years, which is typically a simulation of current discharge zones vs. past rainfall.	Any climate change considerations? [KTW24]	No	No but an important point to consider as a recommendation especially for these 28 areas.
	…a simulated representative water level.	A single water level representative of a GRU / quaternary catchment? [KTW26]	No	This was done for a number of selected catchments but limited due to the budget cut back.
	The MAP in the coastal catchments where orographic rain occurs, ranges between 679 mm/a, and 882 mm/a.	Please provide a map for the MAP in the area of interest. Rainfall stations used for the interpolation as well as the interpolation method should be indicated/described. [KTW28]	Yes	The MAP data was obtained from WR2005 data sets and GRA II data set. A map will be included to show this. For GRU annual volumes, MAP per quaternary catchment from WR2005 was used.
2-18	This means that fracture orientations perpendicular to this direction would be expected to be either closed or less permeable than the other fracture orientations.	Is this considered in the conceptual model? [KTW30]	No	This is too detailed for this study. A conceptual numerical groundwater flow model was done for the Dageos Aquifer as an additional component. This should be relevant in more detailed, comprehensive reserve phases.
2-19	The model was adapted to allow for groundwater flow losses as follows…	In a nutshell: What flows in, must contribute to baseflow or evapotranspirate within the surface water catchment boundaries. This is an unrealistic oversimplification. [KTW37]	No	If it can be shown that the groundwater head follows topography as has been done in this study, then this simplified conceptual model is mostly valid. Adding complexity is not necessarily better science. Any suggestions on how to improve on this?
	Where Q_{GFL} represents the groundwater flow losses, which can be significant. It was found that 70% to >90% of the groundwater recharge could be lost in the evapotranspiration zone along stream drainages (DWA, 2010)	Where, for what catchment size and based on what actually measured (not modelled) data? [KTW38]	Yes	On the scale of consideration, this could be local wellfield or quaternary catchment scale. Based on the fact that groundwater head is positively correlated to topography.
2-20	Figure 2.3: Gouritz groundwater – shallow surface aquifers Conceptual Model 1-1	What is meant by the K equals infinity below the river stage? Do you suggest that all (and only the) gw above the stage of a surface water course reports to the river? This contradicts any hydrogeological and hydrological (there should be unlimited seepage under a dam wall) knowledge! [KTW39]	No	No changes to Figure 2.3. Figure 2.4 added to illustrate flowlines. No, this figure is misinterpreted. The infinite K value shows the maximum possible transmissivity as a reference see the dotted line? Why not see the solid line represented in the figure??
2-21	Since K, D and the head gradient can be measured, a steady-state model can be calibrated by changing the recharge value until the measured and simulated head gradients have a small (or acceptable) error.	You should mention that the ratio of the recharge and T (with a virtually unlimited range of recharge and hydraulic conductivity values) controls to a large degree the fitting of observed water levels, so one parameter needs to be fixed (within reasonable limits) to arrive at a potentially unique solution. The bet is out if the estimates of T; R are	Yes	Since K, D and the head gradient can be measured from field tests (i.e. aquifer tests), a steady-state model can be calibrated by changing the recharge value until the measured and simulated head gradients have a small (or acceptable) error.

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		more uncertain [KTW42]		
	An acceptable error is usually less than 10 % of the aquifer thickness.	Note: 10% of the observed head gradient. Otherwise you could be out by 100 m for 1000 m thick aquifer. [KTW43]	No	Noted. See literature on criteria used to measure goodness of model fit.
	A perfectly flat head gradient of 0, will e.g. imply an infinite hydraulic conductivity.	Or stagnant water. However, we are not talking dams but aquifers, which do not have an infinite hydraulic conductivity (even karst pipes have friction losses) on a regional scale. [KTW44]	No	Yes this is a maximum condition reference. The concept of an ideal gas in physics is the same. It provides a reference.
2-22	Shallow aquifers footnote: These are typically shallower than 200 m and represent the area where most of the boreholes and hence groundwater abstraction takes place.	200 m is usually not referred to as shallow gw flow, which is linked to the thickness of the shallow weathered aquifer. [KTW46]	Yes	Footnote corrected to 150 m
2-26	In the absence of prior abstraction there must be a flow component that would be controlled by the discharge rate, given that the discharge is smaller than the recharge.	Surely not evapotranspiration losses in the riparian zone for fault guided springs. [KTW52]	Yes	No, due to upwards or outwards flow pathways. [
	This scenario excludes potential direct inflow from surface streams, which will be included in Conceptual Model 2-4.	To the shallow aquifer only [KTW53]	Yes	This scenario excludes potential direct inflow from surface streams to the shallow aquifer, which could also supplement the deep aquifer will be included in Conceptual Model 2-4.
2-27	Several important surface streams and dams such as the George Dam are located on the southern slopes of the Outeniqua Mountains.	Provide map and discuss why and when southern slopes could be impacted [KTW55]	Appendix D	See Appendix D, Exigo, 2015 model.
2-32	2.2.9: Hydraulic fracturing (fracking) in the Karoo formations - potential impacts on the groundwater component of the Reserve	While really appreciated, the whole section might not be applicable (or rather suitable) for the current Reserve determination (maybe an outlook section?). DWS should provide guidance. [KTW58]	No	Agree that this is a difficult and conceptual subject. It was required from the public meetings.
2-30	A total of 33 quaternary catchments were randomly selected from the 130 quaternary catchments in the WMA for hydraulic head-topography comparison.	Why? What is the rationale for this limitation? [KTW61]	Yes	To perform full statistical analysis on each of the 130 quaternary catchments to prove the point would have been overkill given the objectives of the Reserve determination. 33 catchments were randomly selected to avoid claims of bias and “choosing” of catchments that favour a positive hydraulic head-topography correlation.
	For the NGA geosites, a very good correlation is found with a minimum R2 of 0.0054 (no correlation), a maximum R2 of 0.9987 and a mean R2 value of 0.9198 (good correlation) for the selected quaternary catchments.	Meaning no correlation [KTW62]	Yes	
	The 5th percentile of the data (95% of the correlations are higher) indicates a R2 of 0.61, which is still a positive correlation.	Not so clear what this juggling of statistical data means? [KTW63]	No	Not clear why this is not clear? This means that there is in general a good correlation between topography and groundwater head elevation for 95% of the catchments in the population sample. P50, P75 etc.

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	Similar results are obtained from the GRA II study's 1x1 km interpolated hydraulic head grid clipped from the national GRA II grid that was interpolated from a cleaned database of a 126 263 NGDB boreholes with measured groundwater levels (DWA, 2006).	More statistical data based on interpolated data from interpolated data? [KTW64]	No	Statistical data from interpolated data based on actual measured data.
2-31	A minimum R2 of 0.75 (n = 16), a maximum R2 of 0.9965 (n = 5) and mean R2 value of 0.88 was calculated for the 7 quaternary catchments and 86 Geosites.	Please consider the assumptions for calculating R2 and associated uncertainties, n=5 will not cut it [KTW65]	Yes	Added: It is however noted that the sample size for the former mentioned maximum correlation (n=5) is too small to provide a statistically representative correlation.
	Results from the evaluation of town hotspots and preliminary problem catchments are graphically portrayed and summarised in Figure 2.11	Values not reviewed (verified) due to budget and time constraints! [KTW66]		It was not the scope of this project to get into a comprehensive Reserve determination.
2-38	Table 2.7: Exigo, Umvoto, DWS & GEOSS Groundwater specialist meeting: January 2014. Could affect the Waboomskraal Aquifer in the future.	Unconfined parts? [KTW68]	No	Exigo, Umvoto, DWS & GEOSS Groundwater specialist meeting: January 2014. Could affect the Waboomskraal unconfined/semi-confined Aquifer in the future. The "unconfined" part is actually expected to be semi-confined as it is a fractured system i.e. the head level rises above the water strike when drilled.
2-40	The final GRUs and quaternary catchments for GRU delineation and intermediate Reserve determination are graphically illustrated in Figure 2.15 and selected quaternary catchments are shown in Table 2.10.	Why quats instead of GRUs [KTW69]	No	GRUs were included as sub-units in the quats as described in section 2.1.4.1.
2-42	Quaternary catchments that form a major part of the basins that overlie the shallow part (RU1) of the DAGEOS aquifer were thus also included as GRUs for the Intermediate Reserve Determination.	!!! [KTW71]	No	Quaternary catchments that form a major part of the surface water drainage basins above the DAGEOS aquifer were thus also included as GRUs for the intermediate Reserve Determination.
2-49	The two active boreholes with groundwater levels deeper than 100 m were included as water levels of 100 mbgl in the statistics.	How did you know that the ones below 100 mbgl were not dry for that matter? [KTW76]	No	These boreholes were equipped and in use.
2-46	Table 2.11	Add ion balance error and report 0 as < LoD for Fe and CO3 [KTW78]	Yes	Table updated to show LoD.
2-50	This is expected to be due to the more abundant CO_3 present in the rocks as the cementing material.	This is a coastal sand aquifer [KTW79]	No	Although it is a coastal sand aquifer, visual inspection has shown that there is already some cementing that causes low level consolidation.
2-54	Springs and the groundwater component of baseflow are not unrelated in a number of the rivers in the Gouritz WMA	Please explain where they are unrelated. [KTW85]	No	Flow from springs and non-perennial springs not forming or reaching a drainage due to evapotranspiration cannot be considered as baseflow
2-53	Table 2.13	EN? Please report 0 as < LoD [KTW87]	Yes	Table updated.

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2-55	Assumptions of recharge based on lithology were made where recharge was unavailable for a specific formation.	Please specify assumptions. [KTW88]	No	Please see Table 2.14 and selection of recharge methodology on p. 2-55
	Allowance was made for up to 10 different sub-hydrogeology zones in each quaternary catchment	Why such limit for a GIS exercise, how are these zones related to the GRUs? [KTW90]	No	10 units were found to be more than sufficient. Most areas used less.
	Rainfall data was obtained from the WR2005 dataset and were statistically analysed to calculate the 95% and 98% assurance of supply rainfall.	Used where [KTW91]	Yes	98% was used, not 95%.
2-57	Table 2.14:	Omit 2nd decimal place. Are these percentages of MAP or P_98? This needs also be discussed in the context of the low values for the contentious GRU1a. [KTW94]	Yes	
2-58	Table 2.15	Source/assumptions? Please define storativity and if it is only used for confined conditions (S = S_s * b), otherwise S = S_y – I am a bit confused with the presented values [KTW95]	Yes	
2-61	The mean water levels were further used to calculate groundwater volumes in storage per quaternary catchment.	Please elaborate on the significant implications of assuming a single water level for an entire quaternary catchment (e.g. implications for storage in fractured vs. weathered aquifer). Why were no interpolated wl used? Was this average water level was used to calculate gradients towards surface water courses? [KTW100]	No	No water level gradients were determined from this data set. The correlation was done to the topography in a Bayesian decision approach. Storage was neglected for the yield and groundwater component of the reserve although some indications were given as to what the storage effects could be. There are only positive influences of these on the groundwater balance in terms of the allocable and EWR components.
	The WR2005 dataset was used to obtain farm dam area information.	Please give assumptions regarding leakage coefficient and gradients. [KTW101]	Yes	The leakage coefficient was calculated on hydraulic conductivity value of fine silt 0.001 m/d.
2-62	A total of 83 registered springs and 413 registered borehole volumes were incorporated.	Was this added first to baseflow and then to abstractions from sw or straight to abstractions from GW? [KTW103]	No	Only the WARMS groundwater volumes were used and applied as a groundwater outflow component.
2-64	Table 2.16	This was also done in GRAII! To what extent did your calculations deviate from them? Define water level management constraints for weathered and fractured zones. Quite thick weathered zone aquifers are noted, how were they delineated?	No	The main focus of this study was not to take credit for the volume in storage. This is merely an indication of the usable volume in storage.
2-62	2.7.6: Existing borehole abstraction	Please specify your assumptions – as at least myself cannot reliably estimate this from the NGA data (duty cycle, pump rates etc.) [KTW104]		
2-65	2.7.10: Irrigation water use: … it was assumed that 10-15% of all irrigation water is obtained from groundwater	Based on what? Was this reconciled with WARMS and NGA BH yields? What is it now? [KTW105]	No	10-15% of irrigation volume obtained from WR2005 dataset.
	2.7.11: Forestry water use: A groundwater use figure of 20 mm/a was used.	So was this figure subtracted from rainfall in the catchment area or from recharge [KTW106]	No	The volume of water from rainfall recharge was first calculated, the forestry water use volume calculated and subtracted from

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				recharge.
	2.7.12 Alien vegetation:… to better quantify actual alien vegetation water use	What is assumed here? [KTW107]	No	It is assumed that all alien vegetation area use groundwater. This means it is assumed that all alien vegetation roots reach the groundwater level.
	2.7.12: Alien vegetation is a potentially very large user of groundwater in the riparian zone and it can have a significant effect on reducing recharge.	Was this reconciled with the forestry water use above or simply added as another sink? [KTW108]	No	It was included as a sink.
	…riparian vegetation is however already accounted for in the evapotranspiration losses component in the GYMR and the riparian vegetation water use component was consequently not included as a separate component.	Was this reconciled with the forestry and alien vegetation losses? [KTW110]	No	Reconciled from surface water component? Not sure with what to reconcile these figures.
	2.7.15: Evapotranspiration section: A width of 5 m on each side or bank of the drainage was then used to calculate, with the cumulative drainage length, the total evapotranspiration for each quaternary catchment.	Again, reconciliation with forestry and alien vegetation needs to be explained. Furthermore, the approach assumes that all secondary drainages represent gaining rivers, that the ET demand of all plants is solely met by GW, and that the GW level are generally shallow. This needs to be put into context with the shallowest measured water level of 9.7 mbgl and a mean water level of 23.9 mbgl for the selected GRUs (chapter. 2.7.2.2). Certainly some of the NGA BHs must be in close proximity to secondary drainages. All the above might lead to a significant overestimation of these losses. [KTW111]	No	See conceptual models. Groundwater becomes shallow at the drainage zones where decant occurs. The average water level cannot be used to explain this. Not sure what is meant with the recon? Is it with surface water? It has been shown that the groundwater follows topography and hence it can be expected that on a regional scale, groundwater would be shallow along drainages.
2-66	Table 2.17	Does the total abstraction entail capture of spring discharges? [KTW114]	No	Spring discharges were not included in total abstraction. Registered spring use was received from DWS and included in WARMS.
2-67	Table 2.18: Groundwater discharge components within the Gouritz WMA as calculated for the GYMR table 2 of 2	So the alien vegetation consumes on average 6.3 times more water per hectare and year than forestry (with often alien plants). Please substantiate and reconcile. It appears also that forestry, alien vegetation and wetlands are discharge components BEFORE ET losses along river stretches. Highly likely to be double accounting. Units in last column are wrong Mm^3/a! [KTW114]	None	There are up gradient alien veg that is not in the discharge zone that reduces recharge and then there is alien vegetation in the discharge zones. Both were accounted for. This is not double accounting.
2-72	2.7.18: Groundwater Reserve Scenarios: The GYMR groundwater balance was set up in steady-state to assess potential groundwater balances…	What is it now, a statement regarding consideration of storage (transient model) was made earlier. [KTW115]	No	Storage was not taken into account. The section on storage was to indicate how much groundwater storage is likely to be./ it is such an uncertain parameter that it is not taken into account in the rapid and intermediate. For a more detailed iteration yes. See new Appendix C.

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2-75	Table 2.22: Summary table of GYMR results for Scenario 1: Present day with MAP rainfall	Are these maximum registered and inferred/assumed abstractions? [KTW116]	No	Included in the total outflows in this table yes. Note if the comment refers to Allocable GW then no this is not abstraction. Note that these are negative values and means that there is shortage of base flow i.e. the rivers would be losing –according to the model. However in the updated section these will be clarified.
		Presented values exceed generally any GRAII baseflow estimate by Schultz, Pittman or Hughes – Reconciliation is urgently required. Even the EWRs exceed their estimates [KTW117]	Yes	No, see new benchmarking section. These are negative base flows!
	Net Baseflow before EWR (million m3/a): -11.15 mcm/a	Exceeds any GRAII baseflow estimate (Schultz, Pittman or Hughes) – Reconciliation is required. [KTW118]	Yes	Table will be rechecked.
	Table 2.22: J11F. Net Baseflow before EWR 0.20 mcm/a	The river is losing to the aquifer but we have an EWR fed by GW? [KTW119]	No	This is a negative EWR? Check questioned calculation again.
	Table 2.22: DAGEOS Resource Units	How can that happen for abstractions from a confined aquifer? Steady-state assumption/ complete capture from RU1 need to be discussed. [KTW120]	Yes	Table updated to exclude DAGEOS RUs. DAGEOS cannot be correctly modelled with analytical GYMR. Exigo 2015 model performed. See Appendix D.
2-78	Table 2.23: Groundwater sources within Scenario 2 Present day 98% assurance intermediate Reserve	Dam seepage independent of rainfall, unlikely to be filled to the brim in a 1:50 year drought? [KTW121]	Yes	Table 2.23 and calculations corrected to show zero dam seepage for drought conditions.
2-79	Table 2.24: Summary table of GYMR results for Scenario 2: Present day with 98% assured rainfall for drought cycles. Total outflow before losses (mcm/a); ET (mcm/a)	All constant despite lower rainfall recharge and subsequently water levels. Justification? [KTW122]	No	Evapotranspiration was not programmed to vary based on rainfall for this phase of the study. This is applicable in a comprehensive Reserve determination or perhaps the next phase of the study. This would also be possible in a numerical model, which is outside the scope of this study for 28 quaternary catchments.
	Table 2.24: Summary table of GYMR results for Scenario 2: Present day with 98% assured rainfall for drought cycles. EWR (mcm/a)	Major flaw in the model outputs: Why do the calculated Baseflow and EWRs values INCREASE (almost 3 times!) in times of drought?? Does not make any sense and points to either typing errors or serious flaws in the model calculations. [KTW123]	Yes	Updated table. Model is misread, these are more negative values. Will include clarification and make the shortfall as Not Possible (NP).
2-83	This shows that the methodology de-flagged six catchments that were analysed too conservatively in the desktop-rapid level Reserve iteration.	Why if lower rainfall is considered. Highlight catchments and discuss in more detail. While 6 were taken out, 14 were added in comparison to the MAP scenario. However, as discussed above the model results are flawed. [KTW125]	No	The model results are not flawed, it was misread.
2-84	…estimated that a yield of 1.5 million m3/a, during average conditions and 1.0 million m3/a during drought conditions, may be applicable for RU2, the deep confined aquifer.	Based on? [KTW130]	No	Based on a minimum recharge and a conceptual numerical model.
2-86	…to not incur excess mixing of oxidising waters with reducing waters.	Please elaborate. Do you consider lowering of the potentiometric surface in the confined aquifer or	Yes	This is to minimise the iron mobilisation.

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		converting it to unconfined conditions only? [KTW134]		
3-2	12. The intermediate Reserve was completed for the 28 catchments…	Flawed [KTW138]	No	Not flawed. Base flows were misread.
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xi	An assumption was made that 10-15% of all irrigation…	On what grounds? [CH5]	No	When a water use is calculated assumptions will be made somewhere along the line, whether it is for the irrigation schedule, the type of crop on each farm, amount of water used, etc. It is impractical and outside the scope of such a study to visit each farm in the WMA to determine each crop type and from where their irrigation water comes. Thus an assumption was made regarding irrigation water use.
xii	Most of the groundwater quality problems can be overcome with the latest water treatment technologies.	But at what energy expense? [CH6]	No	The consideration of energy expenses is outside the scope of this project. It is well worth knowing that treatment tech is available. It does not mean that it solves all problems.
	The potential flow from the shallow semi-confined surface aquifer (RU 1) to RU 2, under conditions of abstraction would in time reduce the baseflow contribution of RU 1	But only on a time-scale of decades to centuries, which is partly conceded in item b below. As the planned Blossoms wellfield.is midway between recharge and discharge boundaries, the same time-scale to impact applies to the down-gradient boundary along the northern fault zone. [CH7]		This comment is inaccurate. Storage will not last centuries, see Exigo, 2015. The conceptual numerical groundwater flow model represents a best case aquifer and starts to impact RU1 after 15-20 years. A century is far-fetched. Please show your calculations to back up these figures.
	The potential flow from the shallow semi-confined surface aquifer (RU 1) to RU 2, under conditions of abstraction would in time reduce the baseflow contribution of RU 1	(only baseflow reduction? What about EVT reduction and reduced discharges from the confined aquifer. What about the contribution made by recharge to Unit 1 that does not manifest as baseflow in Unit 1 but goes directly to the RU2 deeper system etc. etc. i.e. Not necessarily a 1:1 impact on baseflow in Unit1 only. [MS] Other comments by MS already added and addressed in the comments register and report earlier on together with the review of the external reviewer [JCD].		We do not know by how much EVT may be reduced, so how can credit be taken for it? It is one of those unknown parameters that we take into account as a sink but not as a source as EVT may be linked to natural wetlands or sensitive riparian vegetation. If the system is much better understood and the environmental impacts can be demonstrated in terms of trade-offs, then EVT can be brought in. The discharges from the confined aquifer are inevitably linked to the recharge and together with storage do not constitute an addition to the resource yield in the long-term.
	expected that it would take 15-20 years for the planned abstraction of Phase 1…	This aspect properly belongs with the resource assessment for the Blossoms wellfield (RBIG study), not in this Reserve Determination. [CH15]	No	This view is incorrect as how can resource quantification be divorced from the Reserve? Is this not why Riemann and Blake, 2010 attempted to perform the groundwater component of the Reserve for RU1 and RU2. The Reserve constrains the availability of the water resource as it has to be allocated to BHN and environmental water users. Resource quantification forms the basis of the Reserve. Fundamental difference in view.
	The deep confined Peninsula Aquifer (RU2) is analogue to a very big dam with very limited	An early MODFLOW model (Umvoto, 2010) indicated a deep throughflow greater than 5 million cubic metres per	Yes	Sentence changed. This modflow model was not provided so we cannot comment on this. If such a model exist, it would be good

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	inflow from recharge.	annum. This amount is hardly 'very limited'. [CH17]		to review it, as it should have indicated on the environmental impacts of abstraction of 3.8 Mm^3/a from RU2 on RU1 or that such a yield would not be possible. Critical questions are: Where was the "5 Mm^3/a" flow through going before any development? There is no evidence of hot springs that flow at such a high rate. It cannot just flow into the depth of the earth and cannot be assumed to be a reality. The conceptual numerical model in Exigo, 2015 was qualified using the free flow test which corresponded to a fracture transmissivity of 200 m/d and a matrix transmissivity of 50 m/d. The natural flow in RU2 as simulated using the regional head gradient qualified from the Outeniqua Mountains with a head at borehole C1b2 of 80 m above ground level, which indicated on natural flowthrough of 0.6 Mm^3/a. A flowthrough of 5 Mm^3/a would require transmissivity values that is 10 times higher than the values from the Exigo, 2015 model. This would mean a fracture transmissivity of 2000 m/d and a matrix transmissivity of 500 m/d, which is impossible.
	Increased leakage from surface streams due to abstraction may negate the dewatering of the deep confined aquifer but with an impact on the surface water streams.	From what locations? This can only happen following a substantial degree of recharge 'capture' at the RU1/RU2 boundary. [CH21]	Yes	Leakage is expected from several surface streams that would likely be intersected by the cone of depressions once it reaches RU1. This includes the Doring River and possibly the upper reaches of the Maalgate after 20 years of abstraction and after 50 years, it would include the Kandelaars River (Fig 1-6 Exigo, 2015). As this is a conceptual or high level model which represents a "best case" aquifer meaning that the actual aquifer is expected to have a lower yield. The impacts on surface water features should have been done prior to yield determination of the RU2. Where would the water in RU2 come from? It has to come from storage and some discharge reduction.
	It is estimated that a yield of 1.5 million m^3/a, during average conditions and 1.0 million m^3/a during drought conditions, may be applicable for RU2, the deep confined aquifer.	What methodology justifies this 'estimate'? [CH23]	No.	See recommendations provided with these estimates. The GYMR methodology, which was up scaled with the conceptual, numerical feflow model. There were simply not enough of the correct data (recharge, storativity, modelling) gathered during previous studies to justify a more accurate yield. With these estimates given: follow up studies are recommended to firm up (better bound) the actual yield. The RBIG studies currently being conducted should provide better estimates.
	It is estimated that a yield of 1.5 million m^3/a, during average conditions and 1.0 million m^3/a during drought conditions, may be applicable for RU2, the deep confined aquifer. This will however need to be proven with more detailed	(Does this point belong in this Reserve report?. A more thorough resource assessment is underway (RBIG funded study) to provide these estimates. Surely the "Reserve" study should be providing the groundwater contribution required by the ecological reserve. It would be a	Yes	Note estimates in Conclusions and Recommendations in report are only provided with the requirement that additional monitoring and modelling work be done to verify and 'firm up' these calculated estimates. Additionally a statement was added to mention the RBIG study that is currently underway to better

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	follow up monitoring and modelling.	licensee's responsibility to ensure that their approach does not impact on the environmental water requirement /reserve. Currently adaptive management approach is envisaged. Will the above statements impact in any way on the licensed volume? Isn't there a danger the public latch on to this pure estimate as having some legal standing – being in a Reserve document. [MS]		constrain the yield of the system. Yes it does. This is why it is the GYMR. One cannot divorce the yield from the reserve. See previous comment. The reserve study imposes constraints on the resource that should be taken into account in a study such as the RBIG. The scope and objectives of the RBIG study was not available at the time of the reserve determination. RBIG should definitely aim to identify uncertainties and potential environmental impacts that was flagged in the reserve determination. An adaptive management approach is good on the premise that the yield of the resource becomes higher as more data is gathered and uncertainty reduced. It seems that the current yield determinations will have to be reduced, which indicates on a problematic decision-making process. That is why the "minimum groundwater flow balance" method is used in the GYMR. As more data become available, the yield should increase.] This is a decision for the DWS. New information is available that raised a flag for further investigations. What is important is to prove a resource within the constraints of the Reserve before it is licensed and developed and not the other way around. The NWA and NEMA are clear on this. If the yield and environmental impacts are not determined before resource development, and a retrospective approach has to be followed this is a risk yes. The upside is that it is still early days and corrective actions can be taken.
xiii	Artificial recharge during times of flood or surplus flow conditions into deep aquifers could be a useful future strategy to store water for drought conditions.	But this can only occur after a substantial interval of development and usage of the deep aquifer/s to map its/their extent/s and hydraulic properties [CH31]	No	Correct, this is a recommendation on the what and not the how. The how will have to be done via a full feasibility study involving surface water and groundwater modelling.
xvi	The deep confined Peninsula Aquifer will require a detailed three-dimensional numerical groundwater flow model to refine and verify the yield.	Already being undertaken under the RBIG study. [CH33]	No	Noted, the recommendation is still valid.
	The yield of the semi-confined shallow aquifer (RU1) and the deep confined Peninsula Aquifer (RU2) must be quantified using detailed 3D numerical groundwater flow models based on the latest data sets. The potential constraints of protected areas and surface water features e.g. streams and dams such as the George Dam must be evaluated and environmental impacts qualified.	See preceding comment. [CH34]	No	George dam removed in recommendation. Noted, the recommendation is still valid.
1-30	Point 6.c)…Reference (Vivier, 2013)	Methodology based on conference abstract only? [CH40]	No	The decision-making method works very well. The fact that it

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				was presented at a conference does not make a difference.
2-1	project by Riemann and Blake (2010) was evaluated and redone independently. This is the first deep Table Mountain Group (TMG) Aquifer planned to be developed and the first deep (500+ m) groundwater component of the Reserve that has been done in South Africa.	Rationale for redoing R&B 2010? [CH42]	No	We have reason to believe that the sustainable yield and potential impacts on the environmental components were not addressed sufficiently.
2-3	Should assessments be done on a smaller scale, such as the wellfield scale that ranges from hundreds of metres to kilometres or borehole scale than ranges between sub metres to several hundreds of metres or a couple of kilometres, then different conclusions may be reached	Important caveat? [CH44]	No	The caveat is when more detailed studies are done, it should confirm more and not less water. To reduce yield is a problem.
	Section 2.1.4.1…If the TMG quartzitic sandstone is to be considered as a GRU, which stretches across tens of kilometres, it must be considered that the rainfall and hence recharge will change across the length and breadth of the GRU and add uncertainty in terms of how to quantify the inflow and outflow of the GRUs.	Is this a valid excuse for not adopting an aquifer-specific methodology? I think not. [CH46]	No	A hydrogeological approach is accommodated within the surface water catchment where important sub-units were included. The correlations between topography and hydraulic head is the main aspect here.
	Sec 2.1.4.2: The deep confined Peninsula Aquifer at Oudtshoorn (DAGEOS) was evaluated as a separate component in this study as…	Should not have been included at all? [CH49]	No	Why not?? It forms part of the hydrological cycle and the potential impacts on the Reserve have not been determined.
2-5	Sec 2.1.5.1. It is accepted that the uncertainty and data limitations on the scale of the assessment is of such a nature that the actual groundwater balance will never be known as it will be transient. The objective is therefore not to determine the actual groundwater balance as it cannot be known without long-term monitoring data.	Artificial distinction between ‘minimum’ and actual groundwater balances? [CH52]	No	Not correct, the minimum balance can statistically be determined to e.g. 95% assurance, while the actual is not known and the average in general has a large standard deviation.
2-6	Even if the approach weighs in on the conservative side of the scale, only 28 (21.5 %) of the 130 quaternary catchments were flagged as potentially stressed during the first iteration which is the desktop-rapid Reserve. If the approach is overly conservative, this figure would be expected to be much higher.	On what grounds? [CH55]	No	If it were to be overly conservative, then more catchments would have been expected to flag. 80% did not.
2-5	The philosophy of all models are wrong but some are useful (Poeter, 2006) is acknowledged and the chosen decision-making method is to be wrong on the right side.	Garbled statement. [CH60]	No	Only if decision-based modelling is not understood. It is also in line with environmental legislation contained in the Precautionary Principle in NEMA.

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2-13	The TMG forms a regional major aquifer where it is faulted and fractured…	Actually consists of two regional aquifers separated by a major aquitard [CH61]	Yes	Accepted suggestion: The TMG contains two regional major aquifers (the Peninsula- and Skurweberg-Formations) separated by a major aquitard (Goudini Formation).
	There are however zones where lower yields occur where there it is unfractured…	Bizarre generalization? TMG is nowhere unfractured at any scale, and shale aquitards are stratigraphically restricted. [CH62]	Yes	Accepted: There are however zones where lower yields occur where there is absence of major fractures.
2-17	Sec. 2.2.5: Most of the groundwater development takes place on fault and dyke zones	Not true. Most development takes place on master-joint sets well away from faults, and dykes are only targeted in shallow regolith (weathered-and-fractured) Karoo aquifers [CH63]	No	Noted.
2-18	It is inferred that although seismicity can change hydraulic parameters over time, it does not have a significant influence on groundwater in the study area during recent times.	inferred on what basis? [CH65]	No	Inferred based on existing studies such as those summarised in Woodford and Chevallier (2002). They state thus far no direct scientific evidence has been found that shows fracturing created under the prevailing crustal-stress regime significantly affects groundwater occurrence.
	Still Sec. 2.2.5::…it does not have a significant influence on groundwater in the study area during recent times.	What about hot springs as indicators of recent palaeo-earthquakes; e.g., Toorwater? [CH66]	No	Hot springs indicate deep seated flow probably along fractures. Seismicity mentioned here is in the context of e.g. changes in spring or borehole flow. No information on this existed that the authors know about.
2-19	It was found that 70% to >90% of the groundwater recharge could be lost in the evapotranspiration zone along stream drainages (DWA, 2010)	If 70->90% is EVT, what is the balance (apart from base-flow)? [CH71]	No	10% - 30%.
2-22	This scenario is partially depicted in Riemann and Blake (2010, table 4-6) where no allowance was made for any outflow from RU 2	Is this an accurate reflection? I think not. [CH75]	No	The only outflow depicted is if RU2 groundwater rises into RU1 and overflows at RU1 at the Outeniqua mountains. Thus (Riemann & Blake, 2010) conceptual model shows no explicit outflow mechanisms for confined RU2 to justify any through flow.
	These two conceptual models cannot be true at the same time .	But the first one is a straw man. [CH76]	No	The first one is based on assumptions of Riemann & Blake, 2010 – to show that it cannot be true.
2-27	Deep groundwater baseflow or outflow via springs would be possible via fault zones that link the deep confined Peninsula Aquifer with surface streams as it would be inferred that the surface streams would follow or at least cross deep seated fault zones.	actually occurs? [CH79]	No	As it has not been proved that it does not happen, this scenario must be evaluated.
	as it would be inferred that the surface streams would follow or at least cross deep-seated fault zones.	and also through the pervasive, percolating fracture net-work within the aquifer [CH80]	No	As it has not been proved that it does not happen, this scenario must be evaluated.
	so this is a possible but maybe improbable scenario	Text highlighted [CH83]	No	As it has not been proved that it does not happen, this scenario must be evaluated.

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	2.2.8.2.2 pnt 5. Under stressed conditions induced by pumping, the natural flow fields can be changed to force the flow northwards (Riemann and Blake, 2010).	Is this what was actually implied in R&B 2010? [CH84]	No	Not sure, will have to ask them or they will have to clarify.
2-29	In this case, the pumping from the deep aquifer could impact on the shallow springs, shallow base flow from groundwater and all the other balance components as recharge from rainfall (QR) has a certain maximum value and is the ultimate constraint on the groundwater resource	False statement. Does not understand the significance of the Water Budget Myth [CH86]	No	In this case, the pumping from the deep aquifer could impact on the shallow springs discharges, shallow baseflow from groundwater as well as all the other balance components such as natural recharge from rainfall (QR) (which has a certain maximum value and is a major the ultimate constraint on the availability of groundwater resources). Depends on what is meant with recharge. Inducing infiltration from surface water streams is not seen as natural recharge.
2-30	Sec. 2.2.8.2.4 Pt 6. The groundwater balance principle dictates that the water must come from somewhere.	Initially storage change, and often so for a considerable time [CH90]	No	Only a limited amount of time, which is not sufficient for long-term sustainable yield determination or the potential environmental impacts on the reserve.
	Following the principles of sustainability, the socio-economic-environmental and development potential or impacts needs to be determined on the Water Reserve before the sustainable yield of an aquifer can be determined (Vivier, 2013; NWA, 1998)	Debatable and certainly contradicted by Vegter (2001) and Seward et al (2006) [CH92]	No	It is important that each expert choose their own decision-making philosophy. The Water Act and NEMA are clear on this. It's also called duty of care.
2-37	Figure 2.10 shows a scatter plot of the hydraulic head and elevation of each NGA geosite in the Gouritz WMA with a measured groundwater level. The regression line was also drawn for the dataset indicating an R2 of 0.99.	Meaning? [CH95]	Yes	This shows that groundwater head elevation follows topography.
2-39	The low correlation in catchment K30B indicates that groundwater does not always follow topography and that deviations need to be taken into account.	Explain? [CH96]	Yes	This catchment is classified as part of the 28 stressed catchments so it is expected that over-abstraction is the reason for the lower correlation.
2-37	It must be noted that all the hydraulic head observations used in all of the correlations performed are from the unconfined to semi-confined aquifers situated in aquifers up to 160 mbgl.	i.e., no relevance whatsoever to deep confined Peninsula Aquifer [CH98]	No	It must be noted that all the hydraulic head observations used in all of the correlations performed are from the shallow surface unconfined to semi-confined aquifers situated in aquifers up to 160 mbgl.
2-42	Sec.2.3.3. The following criteria were used to identify hotspots for hydrocensus as well as in final delineation of GRUs…	Rationale? [CH99]	No	Most of the selection criteria used is quite standard, such as review of existing data and information, stakeholder meeting, etc. Most of these criteria can be found in the GRDM manual as well (Dennis *et al.* 2012).
2-71	Sec. 2.7.7 Apart from the pristine scenario, an abstraction rate of 120 ℓ/s was used to evaluate the sustainability of the resource (Hartnady *et al.*,	? [CH107]	No	If referring to the reference, it is freely available on the internet upon performing a search for DAGEOS related info. At least it was during the time of this study.

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	2014)			
2-73	Table 2.16: Table with groundwater levels and calculated groundwater volume in storage	Ridiculous to assign 0 m to DAGEOS water levels. These are >60 m ABOVE ground level! No understanding of the meaning of artesian?	[RJG]	Noted, the static water level was not used in the calc. RU1 and RU2 details removed from GYMR tables as they were treated in the conceptual numerical model (Exigo,2015). Understand that Artesian does not mean infinite.
2-76	Table 2.18: GW discharge components GYMR table 2 of 2	Rationale for total Blossoms outflow is obscure [CH110	Yes	DAGEOS components removed and treated in model in (Exigo, 2015).
2-82	2.7.18: Groundwater Reserve Scenarios. Pt 6: Since this is a strategic groundwater resource in the WMA it must be included in the intermediate Reserve. Scenarios of both MAP and lower P98 assured rainfall applied with best estimates of groundwater recharge to unconfined DAGEOS Resource Unit 1 was performed. The semi-confined shallow RU 1 is assumed to be the only source of groundwater to the deep confined RU 2 (Section 2.2.8).	! [CH112]	No	This means that e.g. inflow from leakage of surface water from the surface streams and the Skurweberg Aquifer via inferred faults were not considered or included.
2-83	Table 2.21: Groundwater sources within Scenario 1 Present day MAP intermediate Reserve	Elevation of RU2 figures? [CH113]	Yes	DAGEOS components removed from table: treated in model in (Exigo, 2015)
2-92	a) A numerical conceptual model was developed for the shallow and deep aquifers (RU1 and RU2) to determine the regional groundwater flow balance (Exigo 2015)	Numerical = FEFLOW? [CH115]	Yes	a). A FEFLOW conceptual numerical conceptual model was developed for the shallow and deep aquifers (RU1 and RU2) to determine the regional groundwater flow balance (Exigo, 2015).
	The potential flow from the shallower semi-confined surface aquifer (RU 1) to RU 2, under conditions of abstraction would in time reduce the baseflow contribution of RU 1…	Several decades? [CH116]	No	No, 15 - 20 years.
	b. From the groundwater modelling, it is expected that it would take 15-20 years for the planned abstraction of Phase 1 at 3.8 million m^3/a (120 ℓ/s)	Uncalibrated and not available for validation? [CH118]	No	It is a best case scenario.
	1.5 million m^3/a, during average conditions and 1.0 million m^3/a during drought conditions, may be applicable for RU2, the deep confined aquifer	No basis for these figures. MODFLOW modelling in 2010 indicated deep through-flow at ~14 million m^3/a, not far below Riemann & Blake estimate. [CH121]	No	The 15 million m^3/a is not proven? What if it's less?
	An option for long-term sustainable use of the deep confined aquifer is to utilise storage which can be replenished via surface water artificial recharge during flood peaks.	On basis of similar large confined aquifers, there will be a lead time of least 50 years, during which such an "exit strategy" can be studied at leisure. [CH124]	No	Sustainable yield must be prospectively determined using the minimum groundwater flow balance approach and not retrospectively reduced.
3-3	Conclusions: 12a. Based on the current information, the average yield (P50) of the deep confined Peninsula Aquifer (RU2) is 1.5 million	Conclusion not supported by sound science re large-scale artesian systems [CH127]	No	Not accurate – as "Large Artesian" does not mean that more water than recharged can be abstracted sustainably. The conceptual numerical model took the large artesian basin

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	m^3/a, and the assured yield (lower P98) at 1.0 million m^3/a. The yield takes account of the interaction with the semi-confined surface aquifer and existing discharges as deep-seated springs and baseflow. This deep aquifer system is entirely reliant on recharge from the semi-confined surface aquifer (RU1) for its long-term sustainability.			effects into account. What is not supported by sound science is the inference that it has infinite volumes of water in storage.
	The current management strategy is to utilise storage and dewater the aquifer over a period of time. This strategy is not recommended as the secondary impacts on the EWRs are not known.	Not true. It is geophysically impossible to 'dewater' a deep confined aquifer. [CH129]	No	There are many examples of confined aquifers that were dewatered on a basin scale. Numerous mines developed in confined aquifers have been dewatered e.g. Orapa Diamond Mine in Botswana. Incorrect management proposals and over-estimation of the yield will lead to dewatering of the aquifer.
	c. However, should this be the accepted strategy an option, then the time to depletion, impacts on other Reserve components and the alternative or fall back water supply option once the resource has been depleted must be determined.	Management has zero to do with "dewatering". [CH132]		
	d. The usable (i.e. drainable) volume in storage was calculated during this study at 130 Mm^3 based on a 10% groundwater in storage use as a constraint	Complete lack of scientific understanding of how confined aquifers yield water. [CH133]		
	d. …From Conceptual Models 2-2 & 2-3, if it is assumed that a maximum of 20%-30% of this volume in storage could be accessible via boreholes at the current recommended abstraction of 3.8 Mm^3/a, then it would take depending on the actual recharge between 10 - 20 years to deplete the volume in storage before adverse impacts is expected.	Fallacy. [CH134]	No	A confined aquifer is more sensitive to over-exploitation than an unconfined system as it is not recharged where the abstraction is taking place. The lack of understanding is not with these conclusions but rather in the development of boreholes with high yields and thinking that recharge is not important.
	Initial evaluations indicated that the zone of influence from abstraction at the Blossoms wellfield could reach the semi-confined, surface aquifer within 10 - 20 years.	Possibly a bit shorter for RoI intersection, but storage change in deep confined zone remains dominant contribution to wellfield for long after 20 years and the rate of capture from source is very slow. [CH137]	Yes	Strongly recommend that a numerical yield model is developed for the aquifer as from this study it is unclear where the quoted sustainable yields will come from.
4-1	Recommendations: pt 4. The deep confined Peninsula Aquifer will require a detailed three-dimensional numerical groundwater flow model to refine and verify the yield.	Already part of OGP protocols for water-use licence (WUL) process [CH139]	No	This should have been done before the "yield" was estimated.
	6. The yield of the semi-confined shallow aquifer (RU1) and the deep confined Peninsula Aquifer (RU2) must be quantified using detailed 3D numerical groundwater flow models based on the latest data sets.	Function of current OGP WUL process [CH140]	No	Should have been done before development takes place to get an idea of the potential aquifer yield and environmental impact constraints.

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4-2	13. The water management strategy for the deep confined TMG aquifers should be reviewed and a guideline document be compiled to ensure sustainable development and utilisation of the deep groundwater systems.	This is function of existing WUL process. [CH143]	No	It is an important recommendation from this study.
6-3	Hartnady, C.J.H, Hay, E.R., Riemann, K. 2014. Strategy for groundwater development in a confined artesian basin, Oudtshoorn area, South Africa. Draft article. Groundwater Division (GWD) of the Geological Society of South Africa (GSSA).	Is this source open and accessible? [CH146]	No	Yes
6-5	Von Neuman, J. 1928. Zur Theorie der Gesellschaftsspiele. Mathematische Annalen, 100(1):295-320.	What relevance is this? [CH147]	No	Jon Von Neuman was the first to prove and publish the Minimax principle in this publication on game theory. The Minimax principle is directly applicable to the decision-making approach used here and cost-benefit analyses. See text reference.
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Reviewer: Ms N. Motebe – NM.				
x	Executive summary: Desktop-Rapid Reserve Results map	Note made-with regards to Desktop-Rapid Reserve quaternary catchments (3%) that have zero recharge stated in table as erroneous. [NM5]	No	These are catchments that have zero recharge indicated in the GRDM (2013) database. Software version 2.3.2.0. The zero recharge is understandable given some quats have a MAP of 170mm/a and the Woodford trend line (DWAF, 2006) has cut-off on rainfall, but under thunderstorm conditions and significant amounts of rainfall within a short time, there is however still groundwater recharge from rainfall (episodic recharge). The recharge will be very low, but not zero.
xii	An assumption was made that 10-15% of all irrigation comes from groundwater.	?? [NM7]	No	Should however be verified in the review in the initial stage of the Gouritz classification stage. When a water use is calculated assumptions will be made somewhere along the line, whether it is for the irrigation schedule, the type of crop on each farm, amount of water used, etc. It is impractical and outside the scope of such a study to visit each farm in the WMA to determine each crop type and from where their irrigation water comes. Thus an assumption was made regarding irrigation water use.
2-2	Section 2.1.3: The EWR was assumed to be 40% of the quaternary baseflow estimate…	Why? [NM11]	Yes	This assumption has been updated and removed for the intermediate Reserve.
2-3	Section 2.1.4.2: The study primarily focuses on shallow aquifers as these are the predominant aquifers from which current groundwater use is taking place…	?? But did refer to deep/DAGEOS aquifers at the end [NM12]	No	Noted.
2-6	Groundwater in the remaining 102 catchments	Desktop-Rapid did take this into cognisance [NM13]	No	Noted comment on groundwater potential and lower risk 102

Page	Report Statement	Comments	Addressed in Report?	Author Comment
	can be allocated at a lower risk to the water use licence applicant and the regulator due to the conservative nature of the desktop-rapid Reserve determination			catchments in the WMA.
2-24	Sec. 2.2.9. Draft fracking regulations (No 102 of 2013)	DEA [NM14]	Yes	Have updated this paragraph with the official fracking regulations released June 2015.
2-27	Figure 2.12: Regional south-north hydrogeological cross-section of the CFB and the Karoo Formations (Rosewarne *et al*., 2013)	Comments on incorrect items in Legend of Rosewarne *et al.* conceptual model [NM15]	No	Unfortunately not much we can do about the incorrect keys in the legend since we did not create this conceptual model.
2-55	Rainfall data was obtained from the WR2005 dataset and were statistically analysed to calculate the 95% and 98% assurance of supply rainfall.	WR2012? Reasons for not using WR2012?	No	The truth is the WR2012 study is not yet fully completed and the spreadsheets containing the WR2012 data per WMA were not available yet at the time of this publication, so it could not be used. Data available on the WR2012 website do not include the spreadsheets yet, checked 26/11/2015.
2-61	Sec. 2.7.3 Dam seepage	Except this dam seepage has previously been a bone of contention considering its lifespan, etc.? [NM21]	Yes	Dam seepage has been changed in the GYMR balance for drought conditions to not be active, as these dams are expected to be dry in drought conditions.
3-3	Spatial impacts on environmental groundwater components such as surface water streams, riparian vegetation and wetlands are important.	As in negative impacts on these must be evaluated again? [NM23]	No	It was outside the scope of this project to perform an environmental impact assessments on the drainages on each of the GRUs selected for the intermediate Reserve determination. For such an environmental impact assessment a comprehensive Reserve is required for each.
	An option for long-term sustainable use of the deep confined aquifer is to utilise storage which can be replenished via surface water artificial recharge during flood peaks	RO DWS need to verify if this is possible? [NM23]	No	If this is considered as a long-term option and the decision is made to evaluate it as a long-term option, then yes, a feasibility study would be a good way to investigate the possibility of using such a strategy.