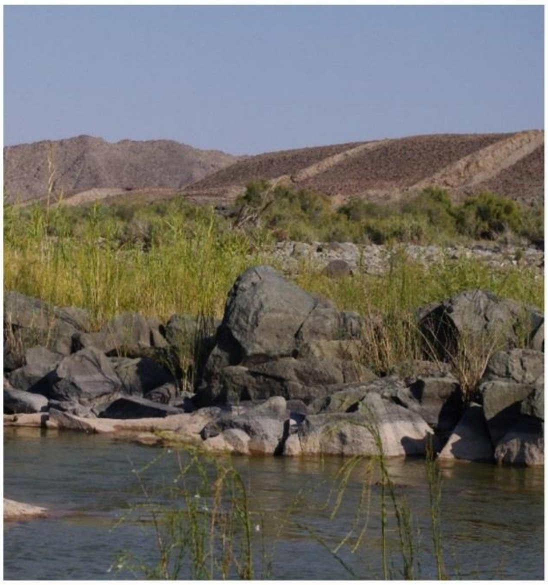
REPORT NUMBER: RDM/WMA06/00/CON/COMP/0317



PROJECT NUMBER: WP 10974

DETERMINATION OF ECOLOGICAL WATER REQUIREMENTS FOR SURFACE WATER (RIVER, ESTUARIES AND WETLANDS) AND GROUNDWATER IN THE LOWER ORANGE WMA

MAIN SUMMARY REPORT

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

AUGUST 2017

DETERMINATION OF ECOLOGICAL WATER REQUIREMENTS FOR SURFACE WATER (RIVER, ESTUARIES AND WETLANDS) AND GROUNDWATER IN THE LOWER ORANGE WMA

MAIN SUMMARY REPORT

Report Number: RDM/WMA06/00/CON/COMP/0317

JULY 2017

REFERENCE

This report is to be referred to in bibliographies as:

Department of Water and Sanitation, South Africa, July 2017. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Main Summary Report. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. DWS Report No: RDM/WMA06/00/CON/COMP/0317.

DOCUMENT INDEX

Index Number	DWS Report Number	Report Title
1	RDM/WMA06/00/CON/COMP/0115	Inception report
2	RDM/WMA06/00/CON/COMP/0116	Resource Unit report
3	RDM/WMA06/00/CON/COMP/0216	River EWR report
4	RDM/WMA06/00/CON/COMP/0316	Buffels, Sout, Swartlintjies, Spoeg, Groen Estuary EWR report
5	RDM/WMA06/00/CON/COMP/0416	Groundwater EWR report
6	RDM/WMA06/00/CON/COMP/0516	BHNR report
7	RDM/WMA06/00/CON/COMP/0616	Wetland EWR report
8	RDM/WMA06/00/CON/COMP/0117	Report on consequences of scenarios
9	RDM/WMA06/00/CON/COMP/0217	Ecological specifications and monitoring report
10	**RDM/WMA06/00/CON/COMP/0317**	**Main Summary report**
11	RDM/WMA06/00/CON/COMP/0417	Close-out report
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DEPARTMENT OF WATER AND SANITATION
CHIEF DIRECTORATE: WATER ECOSYSTEMS

DETERMINATION OF ECOLOGICAL WATER REQUIREMENTS FOR SURFACE WATER (RIVER, ESTUARIES AND WETLANDS) AND GROUNDWATER IN THE LOWER ORANGE WMA

MAIN SUMMARY REPORT

Approved for RFA by:

……………………………………..
Delana Louw
Project Manager

……………………………………..
Date

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ACKNOWLEDGEMENTS

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REPORT SCHEDULE

Version	Date
First draft	August 2017
Final	30 September 2017

EXECUTIVE SUMMARY

BACKGROUND

The Chief Directorate: Water Ecosystems (CD: WE) of the Department of Water and Sanitation (DWS) initiated a study for the provision of professional services to undertake the 'Determination of Ecological Water Requirements for Surface Water (Rivers, Estuaries and wetlands) and Groundwater in the Lower Orange Water Management Area (WMA). Rivers for Africa was appointed as the Professional Service Provider (PSP) to undertake this study.

PURPOSE OF REPORT

The purpose of this report is to summarise all the results and outputs of the range of reports produced during the course of this study. As such, the report summarises and focusses on the technical results of the study.

RESOURCE UNITS

Resource Units (RUs) are required as it may not be appropriate to set the same numerical Reserve for the headwaters of a river as for the lowland reaches. Different sections of a river frequently have different natural flow patterns, react differently to stress according to their sensitivity, and require individual specifications of the Reserve appropriate for that reach. The approach adopted was to consider both Natural Resource Units (NRUs) and Management Resource Units (MRUs) and to take account of the following aspects:

- EcoRegion classification of the river system.
- Geomorphological zonation in which channel gradient has been found to be a dominant factor.
- Land cover.
- Management and operation of the river system; and
- Local knowledge.

The MRUs selected are summarised below:

MRU summary table

MRU	Rationale
MRU Orange A	Gariep Dam wall to Vanderkloof Dam: This section is an isolated section with Vanderkloof Dam being a logical operational endpoint, due to the operation and the barrier effect of the Dam. This RU falls outside of the study area.
MRU Orange B	Vanderkloof Dam wall to Prieska: Prieska town forms a logical endpoint as the water level fluctuation is less significant at this point and irrigation decreases downstream. As the Vaal River is operated to not contribute significantly to the Orange River, it was not selected as an endpoint. An EWR site was problematic in this reach due to the constraint of ESKOM operational rules.
MRU Orange C	Prieska to Boegoeberg Dam: The dam forms a logical endpoint to this reach due to the barrier effect, the similar operation upstream of Boegoeberg and the increase in irrigation downstream of the dam. As most of this reach is influenced by backup from Boegoeberg or is inaccessible, an EWR site was not advised.
MRU Orange D	Boegoeberg Dam to Augrabies Falls: Land use is similar upstream of the Augrabies National Park. The Augrabies Falls was selected as the end of the MRU due to its role as a natural barrier. An EWR site was selected downstream of Boegoeberg Dam
MRU Orange E	Augrabies Falls to Vioolsdrift Weir: The same delineation applies as for the natural RU. Irrigation is limited and constrained by accessibility. An EWR site preferably in an undisturbed section, but must be accessible and was selected just downstream of the Augrabies Falls National Park.

MRU	Rationale
MRU Orange F	Vioolsdrift Weir to the Fish River confluence. The Fish River forms a logical endpoint as the only large tributary entering the Orange at this point. An EWR site was selected downstream of Vioolsdrift Weir.
MRU Orange G	Fish confluence to the start of the estuary: Although the landuse is vastly different, the operation is the same for this area i.e. a conduit for water through to the downstream mining areas that include irrigation and towns. It was decided therefore, that one MRU was relevant. However, for EWR determination, this section includes a critical area. This area is within the Transfrontier Park and as it is less disturbed than the downstream reaches, will include a greater variety of indicators for EWR assessment. An EWR site was therefore selected within this section.
MRU Orange H (estuary)	As an estuary often has a different EWR than a river, this fact warrants a separate MRU from the upstream river section. The upstream border was set by the estuarine specialists as the area which, under current conditions is the section that should be managed as the estuary. It is possible that under natural conditions (with a frequently closed mouth), the estuary border could have been further upstream.

ECOLOGICAL WATER REQUIREMENT SITES

Well established criteria and processes (Louw *et al*., 1999) were adopted to select Ecological Water Requirement (EWR) sites for further analysis. A table with the EWR sites and summarised criteria is provided below.

EWR site number	EWR site name	River	Latitude	Longitude	EcoRegion (Level II)	Geozone	Altitude (m)	MRU	Quaternary catchment	Gauge
EWR O2	Boegoeberg	Orange	-29.0055	22.16225	26.05	Lowland	871	MRU Orange D, RAU D.1	D73C	D7H008
EWR O3	Augrabies	Orange	-28.4287	19.9983	28.01	Lowland	433	MRU Orange E	D81B	D7H014
EWR O4	Vioolsdrift	Orange	-28.7553	17.71696	28.01	Lowland	167	MRU Orange F	D82F	D8H003 D8H013
EWR O5	Sendelingsdrift	Orange	-28.0718	16.95951		Lowland	47	MRU Orange G	D82L	D8H015

ESTUARINE DELINEATION RESULTS

The Lower Orange WMA include six estuaries of national importance namely the Orange, Buffels, Sout, Swartlintjies, Spoeg and Groen. These estuaries each represent a RU and were delineated according to the accepted approach. The geographical boundaries of the estuaries are defined as follows:

Orange Estuary	
Downstream boundary	28°37'58.91"S; 16°27'16.02"E (Estuary mouth)
Upstream boundary	28°33'43.63"S; 16°31'23.02"E
Lateral boundaries	5 m contour above Mean Sea Level (MSL) along each bank
Buffels Estuary	
Downstream boundary	29°40'37.01"S; 17° 3'4.41"E (Estuary mouth)
Upstream boundary	29°40'18.21"S; 17° 4'3.30"E
Lateral boundaries	5 m contour above MSL along each bank
Swartlintjies Estuary	

Downstream boundary	30°15'44.33"; S 17°15'36.39"E (Estuary mouth)
Upstream boundary	30°15'45.73"; S 17°17'8.36"E
Lateral boundaries	5 m contour above MSL along each bank
Spoeg Estuary	
Downstream boundary	30°28'20.54"S; 17°21'34.07"E (Estuary mouth)
Upstream boundary	30°28'17.92"; S 17°22'32.83"E
Lateral boundaries	5 m contour above MSL along each bank
Groen Estuary	
Downstream boundary	30°50'49.05"S; 17°34'35.72"E (Estuary mouth)
Upstream boundary	30°49'38.26"S; 17°34'40.18"E
Lateral boundaries	5 m contour above MSL along each bank
Sout Estuary	
Downstream boundary	31°14'37.66"S; 17°50'52.55"E (Estuary mouth)
Upstream boundary	31°12'38.88"S; 17°53'24.41"E
Lateral boundaries	5 m contour above MSL along each bank

SYSTEMS HYDROLOGY

Results from the Gap analysis recommended the use of the following hydrology datasets to provide the natural and present day flows required for this study:

- ORASECOM Integrated Water Resources Management Plan (IWRMP) Phase 2 study (ORASECOM, 2014) Pitman Model setup for natural and current day flows per quaternary for the Lower Orange excluding the Molopo River and the small coastal rivers.
- The Water Resource Yield Model setup as prepared for the ORASECOM IWRMP Phase 2 study (ORASECOM, 2014) for Molopo River catchment, as this network detail was at a quaternary level.
- Pitman Model Setup and data from the WR2012 Study recently completed, for the Small West Coast Rivers.

ECOCLASSIFICATION OF ORANGE RIVER EWR SITES AND ESTUARY

The results from Louw and Koekemoer (2010) and Louw *et al*. (2013) are summarised below.

EcoClassification result summary of EWR sites located in the Orange River

EWR site	PES[1]	EIS[2]	REC[3]	Comment
EWR O2	**C**	High	**C**	The PES is a result of the loss of frequency of large floods, agricultural return flows, higher low flows than natural in the dry season (droughts and dry periods), decreased low flows in other times, release of sediments and presence of alien fish species and the barrier effect of the dam. As the EIS is High, the REC should be an improvement of the EIS. Due to the constraints of the dam, it is however not possible to achieve the REC.
EWR O3	**C**	High	**B**	The PES is a result of the same impacts listed above. As the EIS is High, the REC should be an improvement of the EIS. To achieve this, it will be required to reinstate droughts (i.e., lower flows than present during the dry season, to improve (increase) the wet season base flows and to clear alien vegetation and improve agricultural practices.
EWR O4	**C**	High	**B/C**	The PES is a result of the same activities as above and mining activities also play a role in this area. As the EIS is High, the REC should be an improvement of the EIS. To achieve the improved REC, wet season base flows must be increased, alien vegetation must be cleared and grazing and trampling must be controlled.

EWR site	PES[1]	EIS[2]	REC[3]	Comment
EWR O5	**B/C**	High	**B**	The PES is again the result of the same issues as listed for EFR O2. As the EIS is High, the REC should be an improvement of the EIS. To achieve the improved REC, wet season base flows must be increased and dry season droughts must be reinstated.
Estuary	**D**	Very High	**C**	The PES is a result of the following: Flow-related impacts: Decreased frequency of small and moderate floods. Higher low flows than natural in the dry season preventing mouth closure and related back flooding. Agricultural return flows cause water quality problems. Non-flow-related impacts: Road infrastructure (crossing salt marsh) and levees. Recreational fishing (specifically, uncontrolled catches a few orders of magnitude greater than legal bag limits) and gill netting. Mining activities. Grazing and hunting on the flood plain. Improvement requires decreased (from present) dry season base flows and droughts to be reinstated, i.e. decreased flow at times during the dry season to facilitate mouth closure two to four times in 10 years. Institute non-flow-related measures (e.g. remove causeway, reduce nutrient input and fishing pressure).

1 Present Ecological State 2 Ecological Importance and Sensitivity 3 Recommended Ecological Category

SUMMARY OF ORANGE RIVER EWR RESULTS: DISCHARGE RECOMMENDATIONS

The results for the EWR sites located in the Orange River are provided below (Louw and Koekemoer, 2010; Louw *et al*., 2013) are summarised below. The final flow requirements, expressed as a percentage of the natural MAR (nMAR).

Summary of EWR results as a percentage of the natural MAR

Site	EC	Maintenance low flows		Drought low flows		High flows		Long-term mean	
		(%nMAR)	Mm^3	(%nMAR)	Mm^3	(%nMAR)	Mm^3	(% nMAR)	Mm^3
EWR O2	PES/REC	11.6	1226.55	4.4	465.24	5.4	570.98	15.2	1607.20
EWR O3	PES: C	8.4	883.10	2.6	273.34	4.7	494.12	11.9	1251.06
	REC: B	17.6	1850.31	3.4	157.37	4.7	494.12	19.2	2018.52
EWR O4	PES: C	6.3	651.11	0.9	35.16	4.2	434.07	8.9	919.82
	REC: B/C	10.1	1043.85	1.3	134.36	4.2	434.07	12.2	1260.88
EWR O5	PES: B/C	6.35	721.63	0.96	109.42	4.51	512.85	10.85	1234.48
	REC: B	10.15	1154.46	1.32	149.64	4.51	512.85	14.66	1667.32

DESKTOP BIOPHYSICAL NODES: EWR ASSESSMENT

Desktop EWRs are provided for 91 of the 99 desktop nodes identified. None of the desktop biophysical nodes have an improved REC relative to the PES, and thus requirements are constrained to Present Day (PD) flows (i.e. there is no improvement in the PES through hydrology).

Summary of Desktop EWRs for the biophysical nodes in the lower Orange River

Node	River name	Annual Runoff (10^6 m^3)				REC	Long-term EWR requirements			
		Mean		Median			(10^6 m^3)		% Natural	
		Natural	PD	Natural	PD		Mean	Median	Mean	Median
Small Orange River tributary										
D71B-03620		9.862	9.862	3.650	3.650	B	1.540	0.963	15.6	26.4
Brak/Ongers River systems										
D61A-06062	Laken	3.430	3.224	1.280	1.190	C	0.364	0.183	10.6	14.3
D61B-05841	Laken tributary	2.688	2.688	0.980	0.980	C	0.286	0.143	10.6	14.6
D61C-05866	Laken	7.634	7.145	2.800	2.610	C	0.811	0.408	10.6	14.6
D61D-06156	Brakpoort	0.920	0.920	0.310	0.310	B	0.138	0.068	15.0	21.9
D61E-06164	Brak	1.961	1.285	0.430	0.250	C	0.206	0.081	10.5	18.8
D61G-06223	Klein Brak	0.966	0.484	0.180	0.060	C	0.087	0.029	9.0	16.1
D61H-05865	Brak	6.829	5.483	1.670	1.310	B/C	0.893	0.371	13.1	22.2
D61H-05960	Klein Brak	1.996	1.326	0.400	0.220	C	0.208	0.077	10.4	19.3
D61J-05654	Groen	2.122	2.122	0.430	0.430	B	0.324	0.127	15.2	29.5
D61K-05388	Groen	4.826	4.826	1.010	1.010	B	0.736	0.290	15.3	28.7
D61L-05453	Perdepoortsleegte	0.474	0.474	0.170	0.170	B	0.070	0.033	14.8	19.4
D61M-05343	Ongers	22.124	5.015	6.690	0.000	C	0.297	0.000	1.3	na
D62A-05078	Ongers	22.904	5.795	7.180	0.310	C	0.810	0.260	3.5	3.6
D62B-04701	Ongers	23.529	6.420	7.690	0.520	B/C	1.249	0.494	5.3	6.4
D62C-05303	Elandsfontein	4.529	4.529	1.840	1.840	B/C	0.609	0.339	13.5	18.4
D62D-05183	Brak	7.544	7.399	3.190	2.920	B/C	1.013	0.569	13.4	17.8
D62G-04703	Brak	17.366	17.22	7.210	6.850	A/B	3.352	1.959	19.3	27.2
D62G-04755	Brak	16.132	15.98	6.660	6.300	B	2.579	1.452	16.0	21.8
D62J-04231	Ongers	42.331	25.07	17.140	8.050	B	6.225	3.077	14.7	18.0
Vis River system										
D51B-06782	Renoster	13.403	12.62	2.690	2.520	B/C	1.384	0.826	10.3	30.7
D51B-07208	Renoster	6.397	6.025	1.284	1.203	B/C	0.661	0.395	10.3	30.8
D51C-06594	Renoster	14.033	13.25	2.820	2.650	B/C	1.447	0.865	10.3	30.7
D52A-07274	Vis	2.933	2.633	0.435	0.397	D	0.168	0.113	5.7	26.0
D52C-06920	Vis	8.054	7.312	1.195	1.092	C/D	0.547	0.362	6.8	30.3
D52D-06761	Muiskraal	2.655	2.356	0.393	0.343	C	0.195	0.130	7.3	33.1
D52E-06758	Vis	11.662	10.58	1.730	1.580	C/D	0.791	0.524	6.8	30.3
D52F-06306	Vis	17.337	15.60	2.661	2.409	C	1.387	0.909	8.0	34.2
D52F-06591	Vis	16.852	15.19	2.500	2.250	D	0.940	0.632	5.6	25.3
D56A-07453	Portugals	1.639	1.586	0.314	0.317	B/C	0.178	0.079	10.9	25.2
D56D-06822	Portugals	8.257	7.994	1.585	1.595	B	1.049	0.476	12.7	30.0
D56D-07091	Portugals	6.262	6.062	1.201	1.206	B	0.794	0.360	12.7	30.0
D56G-06753	Klein Riet	3.544	3.432	0.880	0.840	B	0.516	0.297	14.6	33.7
D56G-06932	Klein Riet	2.564	2.483	0.636	0.608	B	0.373	0.214	14.6	33.6
D56J-06522	Riet	13.932	13.33	3.130	3.030	B/C	1.597	0.865	11.5	27.6
D56J-06649	Riet	13.237	12.81	2.950	2.910	B	1.772	0.984	13.4	33.4
D58A-06302	Vis	28.190	21.52	6.450	0.640	C	1.893	0.382	6.7	5.9
D58C-05390	Vis	46.373	37.77	10.330	4.190	C	3.768	1.686	8.1	16.3
D58C-05932	Vis	45.943	37.32	10.278	4.051	C	3.699	1.628	8.1	15.8
Sak River system										

Node	River name	Annual Runoff (10^6 m^3)				REC	Long-term EWR requirements			
		Mean		Median			(10^6 m^3)		% Natural	
		Natural	PD	Natural	PD		Mean	Median	Mean	Median
D55B-06615	Sak	4.498	3.357	1.570	1.170	C	0.479	0.235	10.6	15.0
D55B-06707	Sak	2.688	2.007	0.939	0.699	C	0.286	0.141	10.6	15.0
D55D-06429	Brak	1.542	1.317	0.304	0.192	B	0.233	0.095	15.1	31.3
D55D-06524	Brak	5.249	4.482	1.030	0.650	B	0.793	0.325	15.1	31.6
D55E-06496	Brak	11.352	8.892	3.320	2.220	B/C	1.507	0.674	13.3	20.3
D55F-06209	Gansvlei	3.135	3.134	0.552	0.553	C	0.341	0.139	10.9	25.2
D55G-06308	Gansvlei	4.661	3.427	0.820	0.190	C	0.421	0.063	9.0	7.7
D55J-06180	Sak	18.928	15.10	5.140	3.070	B/C	2.479	1.192	13.1	23.2
D55J-06243	Sak	17.079	13.33	4.350	2.637	B	2.621	1.204	15.3	27.7
D55K-06347	Klein Sak	1.100	1.100	0.240	0.240	B	0.159	0.057	14.5	23.7
D55L-06115	Sak	20.876	16.99	5.354	3.184	C	2.258	1.046	10.8	19.5
D55M-05697	Sak	22.115	18.14	5.420	3.410	B/C	2.874	1.300	13.0	24.0
D57A-05387	Sak	68.804	56.07	20.742	13.199	C	6.648	3.567	9.7	17.2
D57B-05325	Soutloot	0.886	0.456	0.174	0.093	B/C	0.101	0.037	11.3	21.3
D57C-05254	Sak	69.813	56.59	20.790	13.230	C	6.775	3.604	9.7	17.3
D57E-04374	Sak	72.377	47.13	21.850	16.440	B	9.793	6.069	13.5	27.8
D57E-04534	Sak	70.972	57.69	21.002	13.429	B	9.588	5.530	13.5	26.3
Hartbees River system										
D53B-04104	Hartbees	84.236	66.80	29.150	20.222	D	5.964	2.764	7.1	9.5
D53C-03807	Hartbees	86.535	68.62	29.648	20.297	B	12.591	6.346	14.6	21.4
D53D-03879	Tuins	2.008	1.906	0.204	0.193	A/B	0.253	0.079	12.6	38.7
D53E-03557	Hartbees	89.543	71.48	30.300	20.879	A/B	15.648	7.803	17.5	25.8
D53H-03564	Sout	1.783	1.783	0.090	0.090	A	0.237	0.050	13.3	55.6
D53J-03408	Hartbees	91.687	69.19	30.660	16.665	B	11.959	5.492	13.0	17.9
D54B-05160	Holsloot	2.790	1.194	0.553	0.225	B	0.363	0.130	13.0	23.5
D54D-04630	Carnaveronleegte	10.060	5.250	1.981	0.992	C	1.020	0.454	10.1	22.9
D54D-04896	Carnaveronleegte	8.335	3.567	1.653	0.670	C	0.826	0.341	9.9	20.6
D54F-04645	Verneukpan	6.342	4.703	1.229	0.895	B	0.919	0.404	14.5	32.9
D54F-05004	Botterslaagte	2.713	1.161	0.538	0.218	B	0.353	0.126	13.0	23.4
D54G-04407	Hartbeespoort	21.295	14.72	4.141	2.798	B	3.061	1.346	14.4	32.5
Small West Coast Rivers										
F10B-03391		0.064	0.064	0.000	0.000	B	0.006	0.000	8.8	na
F20E-04290		0.738	0.738	0.140	0.140	B	0.090	0.057	12.2	40.7
F30A-04782		2.313	2.313	0.737	0.737	B	0.345	0.225	14.9	30.5
F30B-04742		1.731	1.731	0.553	0.553	B	0.258	0.168	14.9	30.4
F30C-04823		6.003	6.003	1.914	1.914	B	0.896	0.585	14.9	30.6
F30D-04598		7.158	7.158	2.282	2.282	B	1.068	0.697	14.9	30.5
F30E-04444		1.492	1.492	0.476	0.476	B	0.222	0.145	14.9	30.5
F30G-04539		11.199	11.19	3.570	3.570	B/C	1.407	0.909	12.6	25.5
F40B-04917		0.345	0.345	0.178	0.178	B	0.047	0.034	13.8	19.1
F40C-05007		0.519	0.519	0.268	0.268	B	0.072	0.052	14.0	19.4
F40D-04789		1.215	1.215	0.629	0.629	B	0.172	0.125	14.2	19.9
F40F-05159		1.282	1.282	0.664	0.664	B	0.181	0.132	14.2	19.9
F40G-05320		0.297	0.297	0.154	0.154	B	0.041	0.030	13.7	19.5

Node	River name	Annual Runoff (10^6 m^3)				REC	Long-term EWR requirements			
		Mean		Median			(10^6 m^3)		% Natural	
		Natural	PD	Natural	PD		Mean	Median	Mean	Median
F40H-05480		0.630	0.630	0.326	0.326	D	0.041	0.027	6.5	8.3
F50A-05626		1.546	1.546	0.779	0.779	C	0.164	0.116	10.6	14.9
F50B-05636		0.715	0.715	0.360	0.360	B	0.107	0.077	15.0	21.4
F50C-05764		2.782	2.782	1.402	1.402	B	0.424	0.313	15.2	22.3
F50D-05726		3.597	3.597	1.813	1.813	B	0.550	0.405	15.3	22.3
F50F-05560		1.260	1.260	0.635	0.635	B/C	0.162	0.117	12.8	18.4
F50G-05620		5.458	5.458	2.750	2.750	B	0.835	0.615	15.3	22.4
F60A-05886		0.177	0.177	0.064	0.064	B	0.027	0.017	15.1	26.6
F60C-06147		0.450	0.450	0.161	0.161	B	0.068	0.042	15.2	26.1
F60D-06231		0.675	0.675	0.246	0.246	B	0.106	0.064	15.6	26.0

EWR ASSESSMENT OF THE BUFFELS, SWARTLINTJIES, SPOEG, GROEN ESTUARIES

The assessment of the ecological condition of the Buffels, Swartlintjies, Spoeg, Groen and Sout estuaries reflect the level of resource utilisation in their respective catchments and in their surrounding environs. A summary of some of the key pressures of the estuaries in the study area is provided below.

Summary of the major pressures on the Buffels, Swartlintjies, Spoeg, Groen and Sout estuaries

Pressure	Buffels	Swart-lintjies	Spoeg	Groen	Sout
Groundwater abstraction resulting in loss of freshwater input	●		◖	◖	
Road infrastructure/embankments trapping river inflow/floods	●	●	◖	◖	●
Mining activities (slimes dams, dust, salinization)	●	●	Future	Future	
Roads crossing in the Estuary Functional Zone	●	◖		◖	●
Floodplain development e.g. golf course, houses	●			◖	
Diffuse sewage runoff (e.g. golf course irrigation, ablution)	●			◖	
Grazing in the catchment changing sediment structure	◖	◖	◖	◖	◖
Invasive aliens, e.g. *Acacia cyclops* (rooikrans)	●				
Human disturbance/activities	●			●	●
Saltworks					●
Artificial breaching/mouth manipulation	●				?

MINING ACTIVITIES

A major concern is the planned escalation of mining activities in and around the Namaqualand National Park. Mining in close proximity to the estuaries can hold the following risk for the Swartlintjies, Spoeg and Groen estuaries:

- Disruption of subsurface flow.
- Wind-blown sand that smother estuarine and wetland vegetation.
- Increase sedimentation.
- Loss of salinity gradient in soil and water body (fresh at top and saline in lower reaches).
- Possible leaching of heave metals from mine dumps.

The table below provides an overview of the PES, estuary importance, REC and associated EWR requirements. In all but one system, no additional freshwater water is required to maintain/achieve the REC. In the case of the Spoeg Estuary provisional results indicate that the system require additional groundwater to achieve the REC. This requirement needs to be refined with additional monitoring results (e.g. boreholes, estuary salinity) as very little information is available on the long term trends and responses to groundwater on this coast.

Estuaries EWR and recommendations

Component	Estuary				
	Buffels	**Swartlintjies**	**Spoeg**	**Groen**	**Sout**
Reference MAR (Mm^3/a)	11.2	1.2	1.3	5.5	0.7
Reference groundwater discharge (Mm^3/a)	0.23	0.63	0.36	0.13	1.24
Present groundwater discharge (Mm^3/a)	-0.84	0.59	0.22	0.08	1.13
Present Ecological Status	**↓ D**	**B**	**A/B**	**B**	**E**
Estuarine Importance	Average Importance	Average Importance	Average Importance	Average Importance	Average Importance
Conservation Importance (in Namaqualand National Park)			**High**	**High**	
Recommended Ecological Category	**D**	**B**	**A/B**	**A/B**	**D**
Surface water flow mitigations	↑ floods (road culverts)	↑ floods (road culverts)			↑ floods (weir)
Groundwater mitigations				↑	
Water Quality Mitigations	×			×	
Non-Flow related Mitigations	×			×	×
Potential for further water resource development without impacting on ecology	No	No	No	No	No

GROUNDWATER EWR

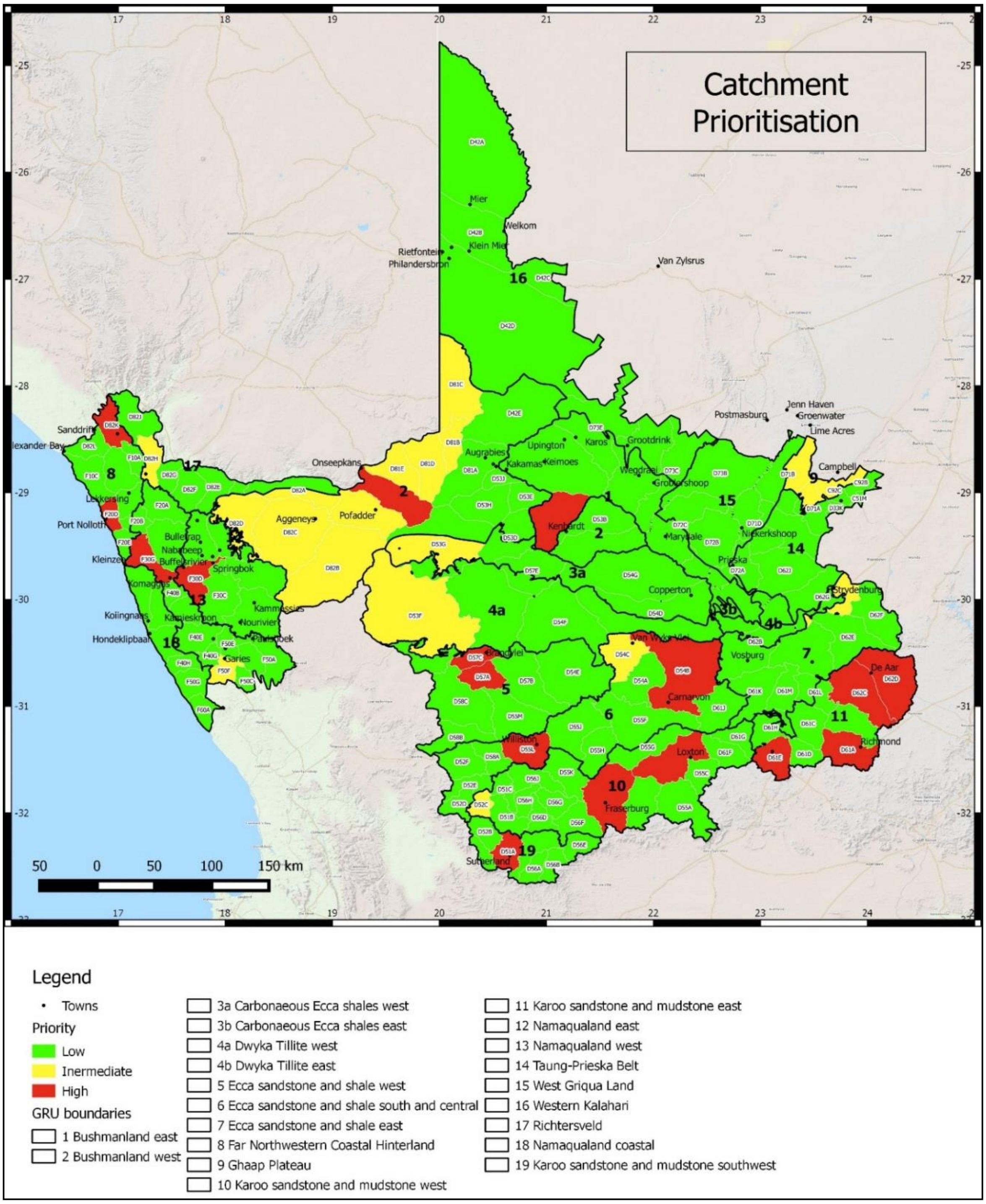
Total groundwater use is 45.36 Mm^3/a, of which 38% is for irrigation. Industry and mining account for 8% of water use, livestock, 22% and domestic water use is 32%.

Several areas are identified as being stressed in terms of high stress indices, declining water levels, and sole source dependency. These are depicted below. Most of the priority catchments are located in the south, the Karoo sandstone and shale GRUs, which are the target areas for potential fracking.

High priority catchments exhibit high stress indices (>0.75) of use relative to recharge, high groundwater dependency (>60%), or significant water level declines.

Intermediately stressed catchments exhibit high stress indices (>0.65), moderate groundwater dependency (<60%), or significant water level declines. Alternatively, they are dolomitic and can potentially be over exploited.

Identified catchment areas in GRUs



BASIC HUMAN NEEDS

The National Water Act (36 of 1998) ensures that everyone has access to sufficient water by setting aside a certain amount of water to meet everyone's basic needs. This amount of water set aside for basic human needs is called the Basic Human Needs Reserve (BHNR). The BHNR is based upon the current and projected population of those either living within the catchment and directly dependant on the catchment or, critically, not being supplied with water from a recognised formal source.

To calculate the BHNR the following steps were specifically undertaken:

- Analysis was based on quaternary division.
- Quaternary catchment boundaries were superimposed upon the smallest aggregations of census data available. The total population for the Lower Orange River WMA, as recorded by the 2011

Census, was 451,620. Extrapolated to 2016 using an average growth rate of 0.25%[1] for the years for 2011 to a current population figure for 2016 of 457,324 is derived.

- Those receiving water from a recognised formal water source and therefore not likely to be dependent on direct abstraction from the rivers were excluded. The remainder are deemed to be part of the "qualifying population".
- For the purposes of the BHNR estimating the population likely to be BHNR dependant were classified as that dependant on boreholes, springs, dams and pools, rivers and streams, water tankers and other means of supply but excluding formal water schemes. The 2016 population in this category was estimated at 95,957[2].
- Those dependant on boreholes were in terms of calculations as these were deemed to be part of the Groundwater Reserve (and schedule 1 users) and covered in report RDM/WMA06/00/CON/COMP/0416.
- The BHN during this step of a Reserve study is calculated for various scenarios that includes 25 and 60 litres and as for the Ecological Reserve, the DWS will then determine which is suitable for the Reserve or Preliminary Reserve to be accepted.

The BHNR for this portion of the population, with models assuming allocations of 25 and 60 litres of water per capita (person) per day (l/c/d) were then calculated and summarised in the tables below.

Summary of BHNR at 25 litres per person per day

Total Population	457,324	**Cubic metres per day**	**Million m³/a**
Population not serviced	95,957		
Population not serviced excluding borehole	55,901		
Population borehole dependant	40,056		
Surface water BHNR 1: @ 25 l/c/d - excluding those on a formal scheme	1,378,947	1,378	0.503
Groundwater BHNR 1@ 25 l/c/d - excluding those on a formal scheme	1,019,980	1,019	0.373
BHNR 1: @ 25 l/c/d including borehole dependant -- excluding those on a formal scheme	2,398,926	2,399	0.876

Summary of BHNR at 60 litres per person per day

Total Population	457,324	**Cubic metres per day**	**Million m³/a**
Population not serviced	95,957		
Population not serviced excluding borehole	55,901		
Population borehole dependant	40,056		
Surface water BHNR 1: @ 25 l/c/d - excluding those on a formal scheme	3,354,059	3,354	1.216
Groundwater BHNR 1@ 25 l/c/d - excluding those on a formal scheme	2,403,363	2,403	0.877
BHNR 1: @ 25 l/c/d including borehole dependant -- excluding those on a formal scheme	5,757,423	5,757	2.101

The BHNR can be split into the surface and groundwater component of the BHNR to avoid double accounting. The Groundwater component of the BHNR utilised in this study was the proportion of people reliant on groundwater without a formal source of supply.

The BHN for the Lower Orange WMA at quaternary level

[1] The population of the WMA is growing at a slower rate than the national average of 1.00% per annum and reflects lack of economic opportunities in the general area and out migration.

[2] The figure for 2016 is virtually identical for 2011 as little no growth is expected in this sector of the population.

Catchment	Population not on formal scheme	Population on bore hole (Schedule 1)	GW dependency % of population	Total BHN (MCM/a @25l/p/d)	GW BHN (MCM/a @25l/p/d)	SW[1] BHN (MCM/a @25l/p/d)
C51M	627	342	53.898	0.006	0.003	0.003
C92B	1641	1106	51.725	0.015	0.010	0.005
C92C	3496	1359	6.180	0.032	0.012	0.019
D33K	157	100	7.564	0.001	0.001	0.001
D42A	365	284	84.533	0.003	0.003	0.001
D42B	425	323	91.938	0.004	0.003	0.001
D42C	3192	1918	72.419	0.029	0.018	0.011
D42D	3356	1622	75.921	0.031	0.015	0.015
D42E	2408	804	27.591	0.022	0.007	0.014
D51A	171	158	99.636	0.002	0.001	0.000
D51B	89	80	92.136	0.001	0.001	0.000
D51C	53	47	92.022	0.000	0.000	0.000
D52A	39	36	92.149	0.000	0.000	0.000
D52B	65	59	92.149	0.001	0.001	0.000
D52C	47	42	92.101	0.000	0.000	0.000
D52D	70	62	91.860	0.001	0.001	0.000
D52E	66	58	91.860	0.001	0.001	0.000
D52F	125	109	91.860	0.001	0.001	0.000
D53A	711	186	34.142	0.006	0.002	0.005
D53B	626	174	55.761	0.006	0.002	0.004
D53C	1522	175	77.491	0.014	0.002	0.012
D53D	1299	142	28.581	0.012	0.001	0.010
D53E	602	64	28.339	0.005	0.001	0.005
D53F	1115	512	51.464	0.010	0.005	0.005
D53G	2984	356	28.942	0.027	0.004	0.024
D53H	1149	121	28.339	0.010	0.001	0.009
D53J	884	76	6.212	0.008	0.001	0.007
D54A	180	155	86.689	0.002	0.001	0.000
D54B	907	715	97.845	0.008	0.007	0.002
D54C	159	137	86.689	0.001	0.001	0.000
D54D	752	522	73.185	0.007	0.005	0.002
D54E	354	316	90.572	0.003	0.003	0.000
D54F	430	373	89.191	0.004	0.003	0.001
D54G	1091	499	48.523	0.010	0.005	0.005
D55A	560	519	94.326	0.005	0.005	0.000
D55B	132	119	91.734	0.001	0.001	0.000
D55C	175	155	92.092	0.002	0.001	0.000
D55D	382	324	96.328	0.003	0.003	0.001
D55E	347	303	98.779	0.003	0.003	0.000
D55F	393	335	87.207	0.004	0.003	0.001
D55G	192	165	88.267	0.002	0.002	0.000
D55H	118	107	92.149	0.001	0.001	0.000
D55J	202	184	92.149	0.002	0.002	0.000
D55K	127	115	92.149	0.001	0.001	0.000
D55L	263	220	98.844	0.002	0.002	0.000
D55M	184	167	92.137	0.002	0.002	0.000
D56A	52	47	92.149	0.000	0.000	0.000
D56B	54	49	92.057	0.000	0.000	0.000

Catchment	Population not on formal scheme	Population on bore hole (Schedule 1)	GW dependency % of population	Total BHN (MCM/a @25l/p/d)	GW BHN (MCM/a @25l/p/d)	SW[1] BHN (MCM/a @25l/p/d)
D56C	95	86	92.149	0.001	0.001	0.000
D56D	62	56	92.149	0.001	0.001	0.000
D56E	69	62	92.149	0.001	0.001	0.000
D56F	105	95	92.149	0.001	0.001	0.000
D56G	65	59	92.149	0.001	0.001	0.000
D56H	46	41	92.149	0.000	0.000	0.000
D56J	95	86	92.149	0.001	0.001	0.000
D57A	91	80	91.975	0.001	0.001	0.000
D57B	232	210	92.149	0.002	0.002	0.000
D57C	126	92	97.943	0.001	0.001	0.000
D57D	770	577	91.996	0.007	0.005	0.002
D57E	1115	178	32.247	0.010	0.002	0.008
D58A	83	73	91.918	0.001	0.001	0.000
D58B	156	133	94.882	0.001	0.001	0.000
D58C	275	242	91.895	0.003	0.002	0.000
D61A	1031	407	89.109	0.009	0.004	0.005
D61B	240	195	85.451	0.002	0.002	0.000
D61C	211	178	86.661	0.002	0.002	0.000
D61D	117	99	86.419	0.001	0.001	0.000
D61E	704	378	96.356	0.006	0.004	0.003
D61F	158	132	86.419	0.001	0.001	0.000
D61G	136	114	86.419	0.001	0.001	0.000
D61H	198	166	86.419	0.002	0.002	0.000
D61J	243	206	86.508	0.002	0.002	0.000
D61K	247	213	87.452	0.002	0.002	0.000
D61L	187	167	90.364	0.002	0.002	0.000
D61M	172	152	89.541	0.002	0.001	0.000
D62A	962	817	97.510	0.009	0.008	0.001
D62B	648	546	94.182	0.006	0.005	0.001
D62C	562	498	96.043	0.005	0.005	0.001
D62D	1269	923	98.969	0.012	0.009	0.003
D62E	357	321	90.759	0.003	0.003	0.000
D62F	350	297	86.279	0.003	0.003	0.000
D62G	2298	2130	95.210	0.021	0.019	0.001
D62H	342	238	70.152	0.003	0.002	0.001
D62J	416	289	70.521	0.004	0.003	0.001
D71A	414	243	61.223	0.004	0.002	0.002
D71B	1396	828	92.625	0.013	0.008	0.005
D71C	432	271	64.613	0.004	0.003	0.001
D71D	645	382	87.249	0.006	0.004	0.002
D72A	464	234	10.324	0.004	0.002	0.002
D72B	1166	580	4.466	0.011	0.005	0.005
D72C	934	564	89.099	0.009	0.005	0.003
D73A	5098	1504	100.000	0.047	0.014	0.033
D73B	1466	807	57.826	0.013	0.008	0.006
D73C	1754	1150	82.721	0.016	0.011	0.005
D73D	3339	713	5.470	0.030	0.007	0.024
D73E	2352	524	2.256	0.021	0.005	0.017

Catchment	Population not on formal scheme	Population on bore hole (Schedule 1)	GW dependency % of population	Total BHN (MCM/a @25l/p/d)	GW BHN (MCM/a @25l/p/d)	SW[1] BHN (MCM/a @25l/p/d)
D73F	9112	1148	1.300	0.083	0.011	0.073
D81A	4225	523	5.770	0.039	0.005	0.034
D81B	501	51	36.847	0.005	0.001	0.004
D81C	1401	211	34.836	0.013	0.002	0.011
D81D	1313	139	28.339	0.012	0.001	0.011
D81E	707	110	9.023	0.006	0.001	0.005
D81F	1143	169	61.055	0.010	0.002	0.009
D81G	560	134	2.505	0.005	0.001	0.004
D82A	411	107	69.435	0.004	0.001	0.003
D82B	556	195	40.139	0.005	0.002	0.003
D82C	774	235	8.514	0.007	0.002	0.005
D82D	635	176	4.062	0.006	0.002	0.004
D82E	126	42	47.288	0.001	0.000	0.001
D82F	184	45	8.094	0.002	0.000	0.001
D82G	199	43	6.294	0.002	0.000	0.001
D82H	37	20	96.873	0.000	0.000	0.000
D82J	8	3	34.831	0.000	0.000	0.000
D82K	296	102	81.849	0.003	0.001	0.002
D82L	439	86	2.637	0.004	0.001	0.003
F10A	7	2	34.831	0.000	0.000	0.000
F10B	17	5	34.831	0.000	0.000	0.000
F10C	19	6	34.831	0.000	0.000	0.000
F20A	54	17	43.407	0.000	0.000	0.000
F20B	29	9	44.291	0.000	0.000	0.000
F20C	168	99	81.666	0.002	0.001	0.001
F20D	112	15	54.956	0.001	0.000	0.001
F20E	14	5	67.545	0.000	0.000	0.000
F30A	401	280	93.266	0.004	0.003	0.001
F30B	207	69	58.267	0.002	0.001	0.001
F30C	330	142	93.525	0.003	0.001	0.002
F30D	457	118	97.249	0.004	0.001	0.003
F30E	543	191	4.411	0.005	0.002	0.003
F30F	151	50	46.628	0.001	0.000	0.001
F30G	290	85	94.227	0.003	0.001	0.002
F40A	134	53	88.891	0.001	0.001	0.001
F40B	48	18	49.539	0.000	0.000	0.000
F40C	155	89	82.120	0.001	0.001	0.001
F40D	56	30	62.303	0.001	0.000	0.000
F40E	250	111	93.373	0.002	0.001	0.001
F40F	494	478	97.311	0.005	0.004	0.000
F40G	40	28	97.782	0.000	0.000	0.000
F40H	25	18	73.684	0.000	0.000	0.000
F50A	729	163	70.911	0.007	0.002	0.005
F50B	30	21	73.684	0.000	0.000	0.000
F50C	125	39	64.672	0.001	0.000	0.001
F50E	106	73	96.703	0.001	0.001	0.000
F50F	128	53	96.375	0.001	0.001	0.001
F50G	38	27	73.684	0.000	0.000	0.000

Catchment	Population not on formal scheme	Population on bore hole (Schedule 1)	GW dependency % of population	Total BHN (MCM/a @25l/p/d)	GW BHN (MCM/a @25l/p/d)	SW[1] BHN (MCM/a @25l/p/d)
F60A	143	47	81.591	0.001	0.000	0.001
TOTAL	**95957**	**40056**		**0.876**	**0.373**	**0.503**

1 Surface water

WETLAND EWR

The assessment of wetland ecoclassification relied on both of the riparian/wetland metrics rated in the national Present Ecological State, Ecological Importance and Ecological Sensitivity (PESEIS) database (DWS, 2014). The underlying assumption is that these two metrics incorporate wetlands within each Sub Quaternary (SQ) (where SQs exist), and as such should provide a useful measure of a more detailed investigation (visual assessment by specialist using satellite imagery) of overall ecological state. Results of the assessment are shown in Figure 10.1.

The desktop EcoClassification of wetlands was summarised at the SQ level and formed the basis of a prioritisation. This prioritisation showed that the ecologically important wetlands were frequently those with low Water Resource Use Importance (WRUI) and vice versa. High and Very High priority wetlands formed three distinct groupings of wetland Hydro-geomorphic (HGM) types (Figure 10.2). These were floodplain wetlands associated with the main stem of the Orange River, depressions (some large but mostly small pans) towards the southern part of the catchment and higher density channelled and unchannelled valley bottom wetlands in quaternary catchments D62C (Elandsfontein), D62D (Brak) and D55E.

Floodplains along the Orange River are mostly in-channel features such as inset benches, flood benches or terraces and are not comparable to meandering floodplains outlined by Rountree *et al*. (DWA, 2012). These floodplains are assessed when the riparian zone is assessed e.g. EWR O3 and O4 at Augrabies and Vioolsdrift respectively. The EWR for floodplain wetlands will therefore be a quantitative flow regime, mostly related to specific flood events that are required for floodplain inundation and sediment and nutrient dynamics.

High priority pans are numerous in the catchment. Some of these pans are extensive e.g. Verneuk Pan, Grootvloer, Boesmankop, Bitterputs and can be in excess of thousands of hectares. It was decided that for each of the large pans a Level 1 WET-Health would be conducted using Google Earth © to assess the vegetation PES (which is based on current land use within each pan) as a measure of the wetland PES (MacFarlane *et al*., 2007). The EWR of high priority pans is expressed through ecological specifications that protect the habitat. To provide these specifications, the EWRs were expressed in terms of a REC (see Table 10.1), which is dependent on the PES, and the ecological importance denotes whether the REC is the same as the PES or an improvement, if at all possible. Where the REC is an improvement of the PES, this will involve management of land use.

Channelled and unchannelled valley bottom wetlands in quaternary catchments D62C (Elandsfontein), D62D (Brak) and D55E (Sak and Sout) were assessed during the PESEIS project (DWS, 2014) as part of the riparian / wetland component assessment. These metrics were used in this study to denote values for the Ecological Importance (EI), Ecological Sensitivity (ES) and PES and verified using Google Earth ©. The EWR of high priority channelled and unchannelled valley bottom wetlands are also expressed through ecological specifications that protect the habitat. To provide these specifications, the EWRs are expressed in terms of a REC (see Table 10.2). This table also outlines the strategy required in order to achieve the REC.

SCENARIO DESCRIPTIONS

The proposed scenarios aim to augment previous work and avoid duplication, while considering more recent information from other water resource planning activities in the Orange River.

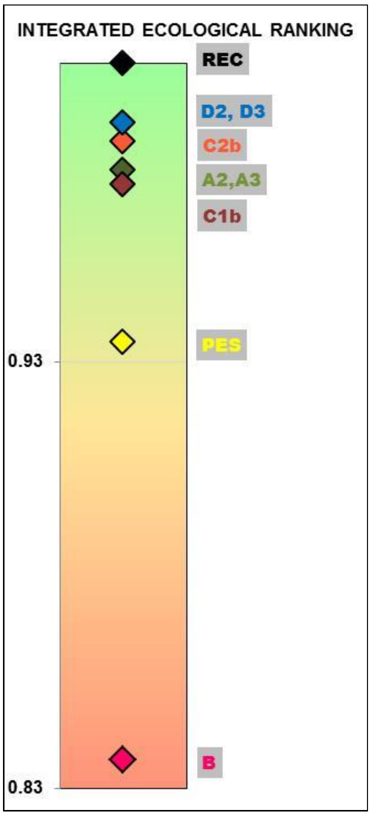
The EWR currently used on the Orange River was originally determined as part of the Orange River Development Project Replanning Study (ORRS), carried out in the middle 1990's based on an outdated environmental requirement methodology. These environmental flow requirements are currently still being released from Vanderkloof Dam and will be replaced once the Reserve was determined and sufficient yield capability created to be able to support the increased environmental requirements. A summary of the scenarios (Sc) are as follows:

- **Scenario A** represents the present day system at 2016 development level.
- **Scenario A2** allowed for improvement to the ORRS environmental requirement in line with the latest REC defined for EWR O5. The purpose of this scenario is to improve the current EWR releases without impacting on the ORP yield (see Appendix A for more detail).
- **Scenario A3** is as Scenario A2 but using the current Namibian water allocations along the Lower Orange which is higher than the current actual water use by Namibia.
- **Scenario B** serves as the base scenario for the 2035 development level when the expected major future water resource development options are in place, but with the ORRS EWR still being released from Vanderkloof and Vioolsdrift dams.
- **Scenario C1b** is as Scenario B, but replaced the ORRS EWR with the "preferred" REC environmental flows as used in the Orange River Reconciliation Strategy Study, which was basically the Recommended EWR "without high flows" for the summer months only at EWR O3. This means that the winter months EWR in the model were set to zero, assuming that the flows released to supply the downstream users during the winter months will be sufficient for environmental purposes at EWR O3.
- **Scenario C2b** is as Scenario C1b but using the Recommended EWR "without high flows" for all the months at EWR O3, thus winter and summer months.
- **Scenario D2** is as Scenario C2b but using a smaller dam at Vioolsdrift.
- **Scenarios D2i and D2ii** are both as Scenario D2 but included slightly higher flows in the months of December and January. These higher flows were based on assessments done for the Estuary by environmental specialists based on the results obtained from Scenario D2.
- **Scenario D3** is as Scenario D2, but with some floods added to EWR O5 requirement.

CONSEQUENCES OF SCENARIOS ON THE RIVER

The first step to determine integrated ranking for the river system is to determine the relative importance of the different EWR sites occurring in the study area. The site weight indicated that EWR O5 carried the highest weight due to the High EIS as EWR O5 is situated in the /Ai-/Ais-Richtersveld Transfrontier Park. This site is also the most downstream site in the Orange River and the accumulated impact of the scenarios will be the highest in spite of the relatively short river reach (141 km).

The results of the weighting and applied to the individual EWR site ranking are plotted on a traffic diagram to illustrate the integrated ecological ranking.

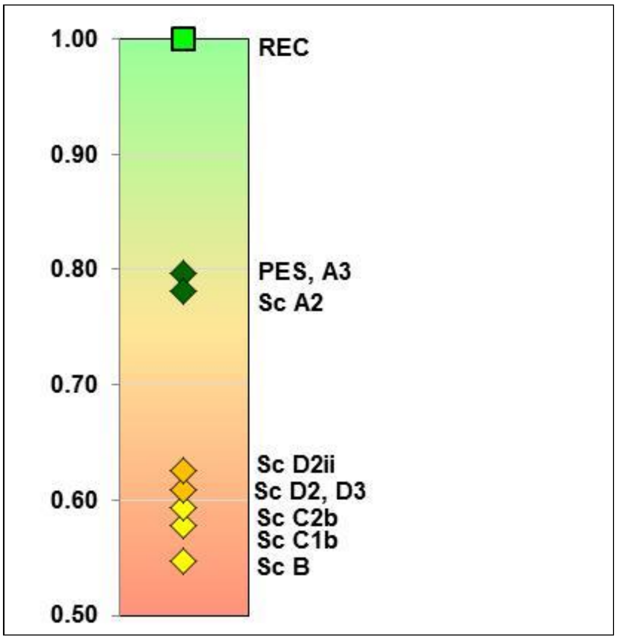


Rivers: Integrated ecological ranking of the scenarios on the Lower Orange River system

Scenarios D2 and D3 are the best option as it is closest to meeting the ecological objectives, with Sc C2b close behind. However, the purpose of setting the preliminary Reserve is to provide management guidance that is legally binding. Therefore, the focus is on the pre-dam situation/pre Classification study (and Reserve determination) as is relevant for a Preliminary Reserve and associated management and immediate implementation. As the recommendations are likely to be set for pre-dam situation, Sc A2/A3 will be the recommended scenario.

CONSEQUENCES OF SCENARIOS ON THE ESTUARY

The ranking of the scenarios is illustrated on the traffic diagram below.



Orange Estuary: Relative ranking of the scenarios versus REC

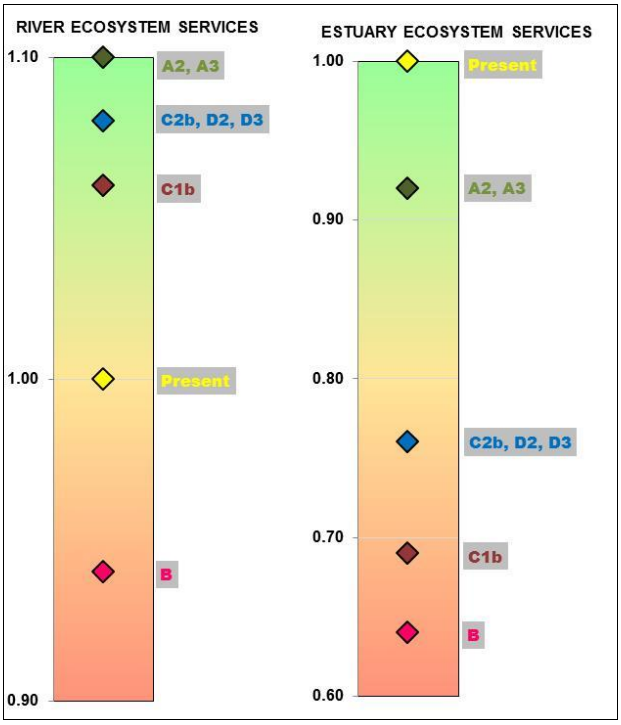
Key findings from this assessment are:

- All the proposed dam development scenarios will reduce the ecological condition of the Orange Estuary from the present state in one or more of the individual abiotic and biotic components significantly. The small dam development (D scenarios) is associated with 12% decline in health (D/E EC), while large dam developments (Sc B and C) are associated with a 13 to 16% decline in health (E EC).
- As with the PES, the ecological condition associated with all proposed scenarios are well below that required for the REC, also for most of the individual abiotic and biotic components.
- Scenario A3 is the operational scenario associated with the least ecological degradation.
- A key flow related requirement to achieve the REC will be to reduce present winter base flows sufficiently to allow for mouth closure and related back-flooding of the saltmarshes with brackish water to reduce soil salinities, but not to the point where the estuary mouth remains closed for longer than 2 to 4 times in 10 years by decreasing river inflow to less than 5 m^3/s. An additional requirement is the need to elevate base flows above 10 m^3/s from December onwards. After long periods of very low flow the instream habitat becomes very reduced and/or shallow.
- As per the 2013 Estuary EWR study (Van Niekerk *et al*., 2013a, b), the REC for the Orange Estuary cannot be achieved through flow interventions only.

The recommendation is defined as the flow scenario (or a slight modification thereof to address low-scoring components) that represents the highest change in river inflow that will still maintain the estuary in the REC. The recommended scenario for the Orange Estuary for the pre-dam situation is the Present or Sc A3 that maintains the D EC.

CONSEQUENCES OF SCENARIOS ON THE ECOSYSTEM SERVICES

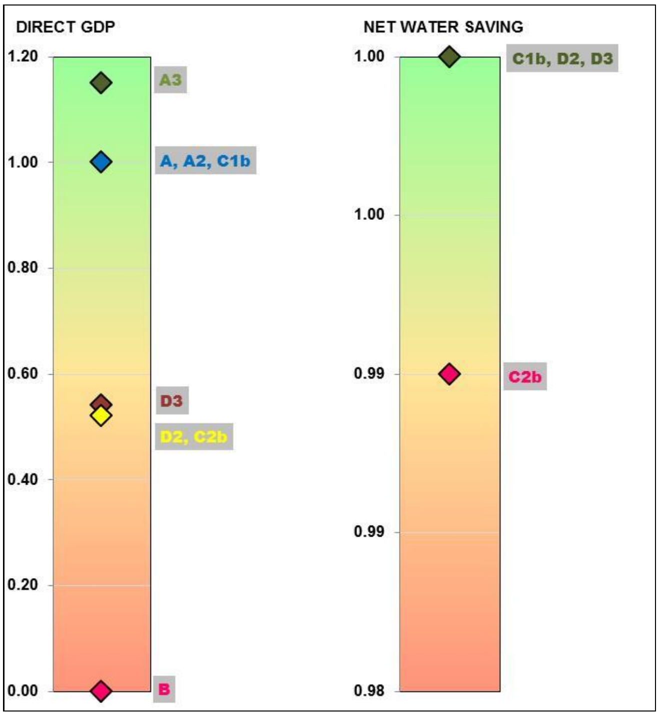
The ranking of the scenarios is illustrated on the traffic diagram below.



Ranking of impact of scenarios on Ecosystem Services in the Orange River system

CONSEQUENCES OF SCENARIOS ON THE ECONOMY

The ranking of the scenarios is illustrated on the traffic diagram below.



Ranking of scenarios in terms of Direct GDP and Net Water Saving benefit

YIELD IMPLICATIONS

For each scenario, the results in the form of a time series of monthly average flows past each site dating from 1920 to 2004 were provided to the study team for further assessment. A summary of those flows is presented in the table below, representing the average annual flow in million m^3/a at the given site and representative scenario. The reduction in yield refers to the decrease in yield of the ORP as result of the different EWRs included for the specific scenario.

Average annual flow (million m^3/a) at the given site and representative scenario

Scenario	EWR O3	Vioolsdrift	EWR O5	Estuary	Yield reduction (million m^3/a)
A	4280.45	3984.34	4430.61	4346.46	Current base
A2	4287.76	3991.62	4437.89	4353.74	0*
A3	4306.79	3925.12	4371.37	4285.71	0*
B	3531.35	2953.75	3183.12	3059.03	2035 Base
C1b	3708.39	3110.33	3298.13	3173.97	425**
C2b	3708.39	3110.33	3375.86	3251.63	825**
D2	3747.05	3205.22	3493.33	3369.03	825**
D2i	3747.05	3205.63	3493.50	3369.19	825**
D2ii	3747.05	3205.76	3493.62	3369.32	825**
D3	3747.15	3206.49	3494.21	3369.90	825**

* Yield reduction relative to Sc A. ** Yield reduction relative to Sc B.

PRELIMINARY RESERVE RECOMMENDATIONS AND ECOLOGICAL SPECIFICATIONS

Ecological Specifications (EcoSpecs) relate to the ecological objectives in terms of the Ecological Category associated with the Preliminary Reserve. It follows therefore that prior to determining EcoSpecs, a decision is required regarding the scenarios to be selected and the Preliminary Reserve and associated Ecological Category. The Ecological Category linked to the Preliminary Reserve is referred to as the Preliminary Ecological Reserve Category (PERC). As the REC cannot always be met, the PERC represents the realistic Ecological Category that will be signed off. The PERC may be the REC, or any other category that is attainable. The PERC is summarised below:

EWR Site	PES	REC	PERC
O3	C	B	B/C
O4	C	B/C	B/C
O5	B/C	B	B
EWR Site	**PES**	**REC**	**PERC**
Estuary	D	C	C/D
Buffels	D	D	D
Swartlintjies	B	B	B
Spoeg	A/B	A/B	A/B
Groen	B	A/B	A/B
Sout	E	D	D/E →D

EcoSpecs are provided for the pre and post dam recommendations for the rivers below.

Driver components	PES	REC	Pre-Dam recommendation PERC (Sc A2; A3)	Post-Dam recommendation D Scenarios*
EWR O3				
Physico chemical	C	C	B/C	B
Fish	C	B	B/C	B
Invertebrates	C	B	B/C	B/C
Riparian vegetation	B/C	B	B/C	B/C
EcoStatus	C	B	B/C	B/C
EWR O4				
Physico chemical	C/D	C/D	C	C
Fish	C	B/C	C	B/C
Invertebrates	C	B/C	B/C	B/C
Riparian vegetation	C	B	B/C	B/C
EcoStatus	C	B/C	B/C	B/C
EWR O5				
Physico chemical	C	C	B/C	B/C
Fish	B/C	B	B	B
Invertebrates	B/C	B/C	B/C	B/C
Riparian vegetation	B/C	B	B	B
EcoStatus	B/C	B	B	B

EcoSpecs are provided for the Orange Estuary below.

Components	PES	PERC	Actions
Hydrology	D	D	Decrease baseflows in winter under current configuration*.
Hydrodynamics	C	C	Increase retention time in winter (this could possibly also facilitate mouth closure under turbulent sea conditions).
Water quality	D	C	Reduce nutrient input in lower Orange River.
Physical habitat alteration	B	B	No improvement required.
Microalgae	E	D	Decrease nutrient input and reduce base flows in winter where possible under current configuration.
Macrophytes	D	C	Reduce nutrient input, remove cause way, control grazing and alien vegetation, reduce soil salinities.
Invertebrates	D	C	Reduce baseflows in winter under current configuration.
Fish	D	C	Reduce baseflows in winter under current configuration, control fishing.
Birds	E	D	Reduce baseflows in winter under current configuration.
EcoStatus	D	C/D	Reduce flows under current configuration, allow for sporadic mouth closure under turbulent sea conditions, and improve vegetation cover and food sources (invertebrates and fish).

* While Scenario A2 and A3 does not show substantial benefits for the estuarine ecology indications are that further refinements can possibly facilitate low enough flows under the present configuration to allow for mouth closure under turbulent sea conditions.

MONITORING PROGRAMME (RIVERS AND ESTUARY)

River monitoring with the emphasis on the biological aspects falls into the DWS monitoring programme, the River Ecosystem Monitoring Programme (REMP) (DWS, 2016a). The driver monitoring (hydrology and water quality) is also part of standard DWS monitoring programmes.

With regards to the estuaries, the emphasis is on the abiotic components being monitored by the DWS Estuary Monitoring Programme. Biotic components such as vegetation and birds should also be included. Fish are being monitored by the Department of Agriculture, Forestry and Fisheries at present. The following detail baseline monitoring activities are recommended:

Salinity - Brine shrimp - Bird Dynamics Monitoring Programme: The Small West Coast estuaries play an important role as bird refuge areas. A critical food source for birds in this region is brine shrimp, which in turn is related to the occurrence of low and high salinities in the small systems, i.e. less than <50 PSU likely to be in very low numbers, >150 PSU likely to be in cyst form. A dedicated study needs to be undertaken that focuses on bird abundance and brine shrimp abundance coupled with in situ salinity observations in these small systems.

The role of ground water in maintaining the salinity gradient of the Buffels, Spoeg and especially the Groen Estuaries: Groundwater plays an important role in maintaining the springs that flow into the middle and upper reaches of the Groen Estuary (situated in the Namaqualand National Park). The springs, in turn, moderate the hyper salinity cycles that naturally occur in this system. The location of the springs needs to be mapped and their groundwater requirements established.

Orange Estuary Nutrient Assessment Programme: In the lower Orange River, a comparison between and the Vioolsdrift (D8H083Q01) and the Sir Ernest Oppenheimer Bridge (D8H012Q01) water quality stations indicate a significant increase in nutrient input below Vioolsdrift. As irrigated agriculture are predominantly concentrated in three areas along this stretch of the river, it is recommended that a few shallow boreholes be installed and monitored in the banks adjacent to these potential hotspots to try and identify the source and/or mechanism of the nutrients. Once the source has been identified, mitigation measures must be developed in consultation with the local famers and an agricultural specialist to reduce the input to the estuary.

Orange Estuary Toxin Verification Programme: No sampling was done for toxic substances (e.g. trace metals, hydrocarbons, herbicides and pesticides) in the Orange Estuary during this study. It is therefore recommended that sediment samples be collected and analysed for toxic substances (i.e. trace metals, petroleum hydrocarbons, herbicides and pesticides). To assist with the interpretation of results, samples should also be analysed for sediment grain size distribution and organic content. A grid of sediment sampling stations should be selected across the estuary, specifically targeting depositional areas (characterised by finer sediment grain sizes and/or higher organic content).

Orange Estuary evaluation of the impact of sustained low flows on water column (in-stream) habitat and fish: Detailed Topographical/Bathymetry surveys of the Orange Estuary at low flows are required to determine at what flow ranges the habitat become unsuitable for fish. The geomorphic survey should be conducted at the same time as biological surveys on fish, inverts and birds.

Nearshore Orange Marine Environment Ecological Water Requirements: The flow requirements of the nearshore Orange Marine Environment - declared an South African Ecologically or Biologically Significant Marine Areas (EBSA) under the Conversion on Biodiversity Conservation - need to be assed to quantify the impact of the proposed Vioolsdrift dam development on the provision of sediments, organics, nutrients and freshwater fronts to the beaches and nearshore marine environment. This aspect needs to be formally addressed as part of the Classification.

GROUNDWATER MONITORING

Several areas have been identified as being stressed in terms of high stress indices, declining water levels, and sole source dependency. By examining trace groundwater quality constituents in the Department of Water and Sanition ZQM database, several chemical parameters which sometimes exceed potable standards were identified, these being Arsenic and Molybdendum. Most of the priority stressed catchments are located in the south, the Karoo sandstone and shale GRUs, which are the target areas for potential fracking.

Sole source aquifers are highly dependent on groundwater, and where they have a high stress index, monitoring of abstraction and water levels is necessary. Contamination or large abstractions from fracking or other activities could cause significant deterioration in water supply to such communities.

The identified high priority stressed catchments include:

- D53C in the vicinity of Kenhardt.
- D57A due to irrigation registration, whose actual use needs to be verified.
- D57C in the vicinity of Brandvlei and where no data is currently available.
- D54B in the vicinity of Carnarvon where insufficient data is available. Monitoring for arsenic is also recommended.
- D55L in the vicinity of Williston due to irrigation registration yet water level data is inadequate and sparse.
- D82K in the vicinity of Kuboes where no data is currently available. Monitoring for arsenic is also recommended.

- F20D in the vicinity of Port Nolloth where insufficient data is available. Monitoring for arsenic is also recommended.
- The dolomites of the Ghaap plateau where water data is available only in the vicinity of Griekwastad. Monitoring for arsenic is also recommended.
- D55D in the vicinity of Loxton where water level declines are evident. Monitoring for arsenic and molybdenum is also recommended.
- D55E in the vicinity of Fraserburg where water level declines are evident. Monitoring for arsenic and molybdenum is also recommended.
- D61A in the vicinity of Richmond where water level declines are evident. Monitoring for arsenic and molybdenum is also recommended.
- D61E in the vicinity of Victoria West Loxton where insufficient data is available. Monitoring for arsenic and molybdenum is also recommended.
- D62C and D where a suitable network exists but monitoring has declined since 2005. Monitoring for arsenic and molybdenum is also recommended.
- F30D in the vicinity of Springbok where water level is available only since 2014, which is of too short a duration. Monitoring for arsenic is also recommended.
- D51A in the vicinity of Sutherland where significant water level declines are evident since 2014.

IMPLEMENTATION

Recommendations are to immediately implement the Preliminary Reserve which requires as a first option the adjustment of the operating rules in terms of the existing environmental allocation released from the Orange River Project (Gariep and Vanderkloof Dams). The major difference in operation will be that the new Preliminary Reserve release will be variable and will be dependent on the upstream catchment conditions in terms of preceding rainfall. A methodology will need to be developed whereby observed rainfall at selected points in the upstream catchment is converted into anticipated streamflow under natural conditions. The required EWR will then be determined based on the natural streamflow, and the required releases will then be calculated in order to allow the water to reach the EWR site. A model will need to be configured to assist with implementation, taking into consideration observed flows (especially from the Vaal) and actual abstractions along the river.

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ABBREVIATIONS

AEC	Alternative Ecological Categories
AOA	Annual Operating Analysis
BHN	Basic Human Needs
BHNR	Basic Human Needs Reserve
BAS	Best Attainable State
BBM	Building Block Methodology
CD: WE	Chief Directorate: Water Ecosystems
CBA	Cost-Benefit Analysis
DWS	Department of Water and Sanitation
DWA	Department Water Affairs
DWAF	Department Water Affairs and Forestry
DRM	Desktop Reserve Model
DRIFT	Downstream Response to Imposed Flow Transformation
EC	Ecological Category
EI	Ecological Importance
EIS	Ecological Importance and Sensitivity
ES	Ecological Sensitivity
EcoSpecs	Ecological Specifications
EWR	Ecological Water Requirements
EBSA	Ecologically or Biologically Significant Marine Areas
EHI	Estuarine Health Index
EPA	Estuarine Protected Area
FRAI	Fish Response Assessment Index
FDI	Flow dependent macroinvertebrates
GIS	Geographical Information System
GAI	Geomorphology Assessment Index
GDP	Gross Domestic Product
GW	Groundwater
GRA II	Groundwater Resource Assessment Phase II
GRU	Groundwater Resource Unit
HFSR	Habitat Flow Stressor Response
HGM	Hydro-geomorphic
HPLC	High-performance liquid chromatography
HF	Hydraulic fracturing
IHI	Index of Habitat Integrity
IWRMP	Integrated Water Resources Management Plan
LSR	Large semi-rheophilic fish guild
LHWP	Lesotho Highlands Water Project
MIRAI	Macroinvertebrate Response Assessment Index
MRU	Management Resource Unit
MRU	Management Resource Unit
MVI	Marginal vegetation macroinvertebrates
MAR	Mean Annual Runoff
MSL	Mean Sea Level
mbgl	metres below ground level
mm/a	Millimetres per annum
MOL	Minimum Operating Level

NBA	National Biodiversity Assessment
NEMP	National Estuarine Management Protocol
NFEPA	National Freshwater Ecosystem Priority Area
NWRCS	National Water Resource Classification System
nMAR	Natural Mean Annual Runoff
NRU	Natural Resource Unit
NPV	Net Present Value
NGO	Non-governmental organisation
ORP	Orange River Project
ORRS	Orange River Replanning Study
ORASECOM	Orange-Senqu River Commission
PAI	Physico-chemical Driver Assessment Index
PERC	Preliminary Ecological Reserve Category
PD	Present Day
PES	Present Ecological State
PESEIS	Present Ecological State, Ecological Importance and Ecological Sensitivity
PSP	Professional Service Provider
REC	Recommended Ecological Category
RSA	Republic of South Africa
RU	Resource Unit
RDRM	Revised Desktop Reserve Model
VEGRAI	Riparian Vegetation Response Assessment Index
REMP	River Ecosystem Monitoring Programme
SC	Scenario
SPATSIM	Spatial and Time Series Modelling
STAS	Stampriet Transboundary Aquifer System
SQ	Sub Quaternary
TEC	Target Ecological Category
TOR	Terms of Reference
TPC	Threshold of Potential Concern
WC/WDM	Water Conservation/Water Demand Management
WMA	Water Management Area
WRPM	Water Resource Planning Model
WRYM	Water Resource Yield Model
WR2012	Water Resources of South Africa, 2012
WARMS	Water Use Authorisation and Registration Management System
WRUI	Water Resource Use Importance

1 INTRODUCTION

1.1 BACKGROUND

The Chief Directorate: Water Ecosystems (CD: WE) of the Department of Water and Sanitation (DWS) initiated a study for the provision of professional services to undertake the 'Determination of Ecological Water Requirements for Surface Water (Rivers, Estuaries, and Wetlands) and Groundwater in the Lower Orange Water Management Area (WMA). The appointed Professional Service Provider (PSP) to undertake this study was Rivers for Africa.

As per the Terms of Reference (TOR), there is a need to undertake detailed Ecological Water Requirement (EWR) and Basic Human Needs (BHN) studies for various water resource components due to mainly:

- Planned hydraulic fracturing (HF) undertaken in the WMA.
- Various water use licence applications.
- The conservation status of various Resources in this catchment; and
- The associated impacts of proposed developments will have on the availability of water.

1.2 STUDY AREA

As indicated in the TOR, the study area is the Lower Orange River WMA (the old WMA 14). It is the largest WMA in the country and covers almost the entire Northern Cape Province. This core area forms part of the Orange-Senqu River Basin, which straddles four International Basin States with the Senqu River originating in the highlands of Lesotho, Botswana in the north-eastern part of the Basin, the Fish River in Namibia and the largest area situated in South Africa. The focus area of the study comprises only the South African portion of the Lower Orange River Catchment. The Eastern Boundary starts where the Vaal River Tributary enters the Orange River, and the Western Boundary is the Atlantic Ocean. The study area is downstream of the Upper Orange, Senqu, and the Integrated Vaal River System and as such, affected by the upstream activities in the highly developed river basin. The Orange River forms the border between the Republic of South Africa (RSA) and Namibia to the west of the 20 degrees longitude over a distance of approximately 550 km.

1.3 PURPOSE OF THIS REPORT

The purpose of this report is to summarise the results and outputs of all the reports produced during this study. Detailed methods will not be included in this summary report.

1.4 PROJECT PLAN

The project plan for the technical tasks are summarised as chronological steps as follows:

- Task 1: Step 1 Project Inception: Step one of the Reserve process basically describes the inception phase during which project planning and process integration takes place. The objective of this task is to produce a concise, clear and unambiguous Inception Report.
- Task 2: Step 2 - Define Resource Units: The task will consist of the following:
  - Rivers: Resource Units determined for the main river during previous studies will be accepted. For the rest of the study areas, the main rivers in quaternary catchments will be accepted as the Resource Units.
  - Estuaries: Delineation of the Orange Estuary has taken place. Five additional estuaries, namely the Buffels, Sout, Swartlintjies, Spoeg and Groen will be delineated.
  - Wetlands: a review of literature and spatial data (such as International / National importance [such as RAMSAR] status, National Freshwater Ecosystem Priority Area (NFEPA), SANBI

Critical Biodiversity Areas (CBAs), ORASECOM) will be conducted in order to prioritise and rank wetlands, and determine which ones will be included in subsequent EWR and BHN assessments.
  - Groundwater: A map of significant Groundwater Resource Units (GRUs) will be compiled.
- Task 3: Step 3 EcoClassification: The task will consist of the following:
  - Rivers: Level IV EcoClassification and the Socio-Cultural Importance have been undertaken at the EWR sites in the Orange River. A Desktop EcoClassification assessment has been undertaken for the rest of the catchment.
  - Estuary: Detailed EcoClassification for the Orange Estuary has been undertaken during the 2013 EWR study and will be accepted as is. A field survey will be undertaken for the additional 5 estuaries and the EcoClassification will be applied during a specialist meeting.
  - Wetlands: Previous data for high priority wetlands will be reviewed and refined where necessary.
- Task 4: Step 4 Quantify EWRs: The task will consist of the following:
  - Rivers: A comprehensive EWR assessment has been undertaken at 4 EWR sites in the Orange River. A desktop model will be applied to address nodes in the rest of the catchment.
  - Basic Human Needs Reserve: The Basic Human Needs Reserve will be determined for surface and groundwater for communities that has no access to formal water schemes.
  - Estuaries: All past assessments have resulted in the most recent assessment of the Orange Estuary EWR being at comprehensive level. The results will be used as is. For the additional 5 estuaries, different inflow regimes (including groundwater) will be investigated in order to estimate sensitivity of ecological processes to modification in freshwater input, and subsequently to inform the recommended EWRs
  - Wetlands: Priority wetlands that have not been catered for during previous studies and where a specified flow regime is not applicable (such as pans or hillslope seeps) will be addressed by quantifying (using best available data or satellite data at least) internal and surrounding landuse and scoring habitat intactness as well as buffer zone integrity.
  - Groundwater: The EWR will be determined as follows: The catchments with baseflow will be identified and baseflow quantified. Baseflow is only relevant in 2 quaternary catchments, where it is minor. The quaternary catchments are to be treated separately in delineation. Large areas of ephemeral groundwater seepage to pans, and groundwater evaporation will be identified and treated as distinct GRUs. Hydraulic fracturing requires large volumes of water and the assessment will take account of this and expand on the fracking issues. The relevance of groundwater to wetlands will also be addressed in the study by delineating RUs based on where significant tracts of wetlands exist. Such regions may require a Reserve in more detail. Estuaries are also supported by groundwater. It is planned to utilise a lakes module to determine the role of ground water that was written as an add-on to WRSM2000 for the WA10 studies in the KZN coastal lakes, which can be calibrated against water quality data from the the estuarine team.
- Task 5: Step 5 Ecological Consequences of operational Scenarios: During this task operational scenarios will be identified and modelled to provide flow scenarios at various points in the study area. The consequences of these scenarios on the status quo of the ecology and socio-economics as well as water balance will be assessed. Based on this, recommendations will be made on future operational scenarios which will maintain either the status quo or will achieve improved future conditions.
- Task 6: Step 7 and 8: EcoSpecs and monitoring: This step refers to the final results and format in which EWR should be provided (EWR rule = Reserve definition), the definition of the EcoSpecs, a monitoring programme and implementation methods specifically linked to the operating of dams.

- Task 7: Study Closure: The study culminates in the final results to be provided in a Main Summary report. A close-out report is also provided and all data on electronically on a flashdrive (10 flashdrives to be provided to DWS).

1.5 OUTLINE OF THIS REPORT

The report outline is provided below.

Chapter 1: Introduction
This Chapter provides a general background to the project, study area and purpose of the report.

Chapter 2: Resource Units
The delineation of Riverine Resource Units (RUs), Groundwater Resource Units (GRUs) are provided. Also included is the delineation of estuaries that are of national importance and priority wetland are identified.
Determine and identify priority wetlands in the study area.

Chapter 3: Systems Hydrology
Chapter 3 provides an overview of the hydrology of the study area. The hydrological datasets used to determine the natural and present day flows for the biophysical nodes in the study area are also discussed.

Chapter 4: Ecoclassification of Orange River EWR Sites
The EcoClassification results re summarised in this chapter.

Chapter 5: Summary of Orange River EWR Results: Discharge Recommendations
The EWR results are summarised in this chapter and provides an explanation and discussion of the approach applied during these studies. The final flow requirements for the PES and REC are provided as an EWR table that shows the results for each month for high flows and low flows separately and an EWR rule table that provides the recommended EWR flows as a duration table, linked to a natural trigger (natural modelled hydrology in this case).

Chapter 6: Desktop Biophysical Nodes: EWR Assessment
Desktop biophysical nodes are listed and a summary of EcoClassification results and estimated EWRs for the desktop biophysical nodes are provided.

Chapter 7: EWR assessment of the Buffels, Swarlintjies, Spoeg, Groen Estuaries
This chapter summarises the EcoClassification and EWR determination of the Buffels, Swartlintjies, Spoeg, Groen and Sout estuaries.

Chapter 8: Groundwater EWR
An overview of the GRUs description is provided as well as prioritised GRUs, calculations of the groundwater component of the Reserve at a quaternary or Sub-quaternary level and quantification of the groundwater component of the EWR.

Chapter 9: Basic Human Needs
This chapter provides an overview of the results of the analysis of the population within the study area with respect to the BHN.

Chapter 10: Wetland EWR

This chapter summarises the desktop EcoClassification, Refinement of priority wetlands and quantification of the Wetland EWR for high priority wetlands.

Chapter 11: Scenario descriptions

This Chapter provides a summary of the different scenarios assessed.

Chapter 12: Consequences of Scenarios

A summary of the consequences of the operational scenarios on the Ecology, Ecosystem and Economic Services and the yield is provided.

Chapter 13: Preliminary Reserve Recommendations

Recommendations are provided for the implementation and monitoring of the suggested operating rule.

Chapater 14: EcoSpecs

A summary of the EcoSpecs and TPCs for EWR O3 – O5, the Orange Estuary and the small West Coast estuaries are provided.

Chapter 15: Estuary Monitoring Programme

This section summarises the remedial actions required to improve the condition of the Orange Estuary and the small West Coast estuaries as well the monitoring requirements to improve confidence in future studies.

Chapter 16: Groundwater Monitoring

A suggested monitoring programme for groundwater resources is provided.

Chapter 17: Implementation

Recommendations are provided for the implementation and monitoring of the suggested operating rule.

Chapter 18: References

Appendix A: Comments Register

Comments from the Client are provided.

2 RESOURCE UNITS

This chapter is an extract from the following report: (DWS, 2016a)
Department of Water and Sanitation, South Africa, March 2016. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Resource Unit report. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. Authored by Louw D, Mackenzie J, Sami K, Van Niekerk L. DWS Report No: RDM/WMA06/00/CON/COMP/0116.

The chapter focusses on the following:

- Delineation of Riverine RUs as well as Groundwater Resource Units (GRUs).
- Delineation of estuaries of national importance occurring in the study area; and
- Determination and identification of priority wetlands in the study area.

2.1 RIVERINE DELINEATION RESULTS

Resource Units (RUs) are required as it may not be appropriate to set the same numerical Reserve for the headwaters of a river as for the lowland reaches. Different sections of a river frequently have different natural flow patterns, react differently to stress according to their sensitivity, and require individual specifications of the Reserve appropriate for that reach. The approach adopted was to consider both Natural Resource Units (NRUs) and Management Resource Units (MRUs) and to take account of the following aspects:

- EcoRegion classification of the river system.
- Geomorphological zonation in which channel gradient has been found to be a dominant factor.
- Land cover.
- Management and operation of the river system; and
- Local knowledge.

The MRUs selected are summarised in Table 2.1 and illustrated in Figure 2.1.

Table 2.1 MRU summary table

MRU	Rationale
MRU Orange A	Gariep Dam wall to Vanderkloof Dam: This section is an isolated section with Vanderkloof Dam being a logical operational endpoint, due to the operation and the barrier effect of the Dam. This RU falls outside of the study area.
MRU Orange B	Vanderkloof Dam wall to Prieska: Prieska town forms a logical endpoint as the water level fluctuation is less significant at this point and irrigation decreases downstream. As the Vaal River is operated to not contribute significantly to the Orange River, it was not selected as an endpoint. An EWR site was problematic in this reach due to the constraint of ESKOM operational rules.
MRU Orange C	Prieska to Boegoeberg Dam: The dam forms a logical endpoint to this reach due to the barrier effect, the similar operation upstream of Boegoeberg and the increase in irrigation downstream of the dam. As most of this reach is influenced by backup from Boegoeberg or is inaccessible, an EWR site was not advised.
MRU Orange D	Boegoeberg Dam to Augrabies Falls: Land use is similar upstream of the Augrabies National Park. The Augrabies Falls was selected as the end of the MRU due to its role as a natural barrier. An EWR site was selected downstream of Boegoeberg Dam
MRU Orange E	Augrabies Falls to Vioolsdrift Weir: The same delineation applies as for the natural RU. Irrigation is limited and constrained by accessibility. An EWR site preferably in an undisturbed section, but must be accessible and was selected just downstream of the Augrabies Falls National Park.

MRU	Rationale
MRU Orange F	Vioolsdrift Weir to the Fish River confluence. The Fish River forms a logical endpoint as the only large tributary entering the Orange at this point. An EWR site was selected downstream of Vioolsdrift Weir.
MRU Orange G	Fish confluence to the start of the estuary: Although the landuse is vastly different, the operation is the same for this area i.e. a conduit for water through to the downstream mining areas that include irrigation and towns. It was decided therefore, that one MRU was relevant. However, for EWR determination, this section includes a critical area. This area is within the Transfrontier Park and as it is less disturbed than the downstream reaches, will include a greater variety of indicators for EWR assessment. An EWR site was therefore selected within this section.
MRU Orange H (estuary)	As an estuary often has a different EWR than a river, this fact warrants a separate MRU from the upstream river section. The upstream border was set by the estuarine specialists as the area which, under current conditions is the section that should be managed as the estuary. It is possible that under natural conditions (with a frequently closed mouth), the estuary border could have been further upstream.

2.2 EWR SITES

Well established criteria and processes (Louw *et al*., 1999) were adopted to select EWR sites for further analysis. A table with the EWR sites and summarised criteria is provided in Table 2.2 and illustrated in Figure 2.1.

Table 2.2 EWR sites

EWR site number	EWR site name	River	Latitude	Longitude	EcoRegion (Level II)	Geozone	Altitude (m)	MRU	Quaternary Catchment	Gauge
EWR O2	Boegoeberg	Orange	-29.0055	22.16225	26.05	Lowland	871	MRU Orange D, RAU D.1	D73C	D7H008
EWR O3	Augrabies	Orange	-28.4287	19.9983	28.01	Lowland	433	MRU Orange E	D81B	D7H014
EWR O4	Vioolsdrift	Orange	-28.7553	17.71696	28.01	Lowland	167	MRU Orange F	D82F	D8H003 D8H013
EWR O5	Sendelingsdrift	Orange	-28.0718	16.95951		Lowland	47	MRU Orange G	D82L	D8H015

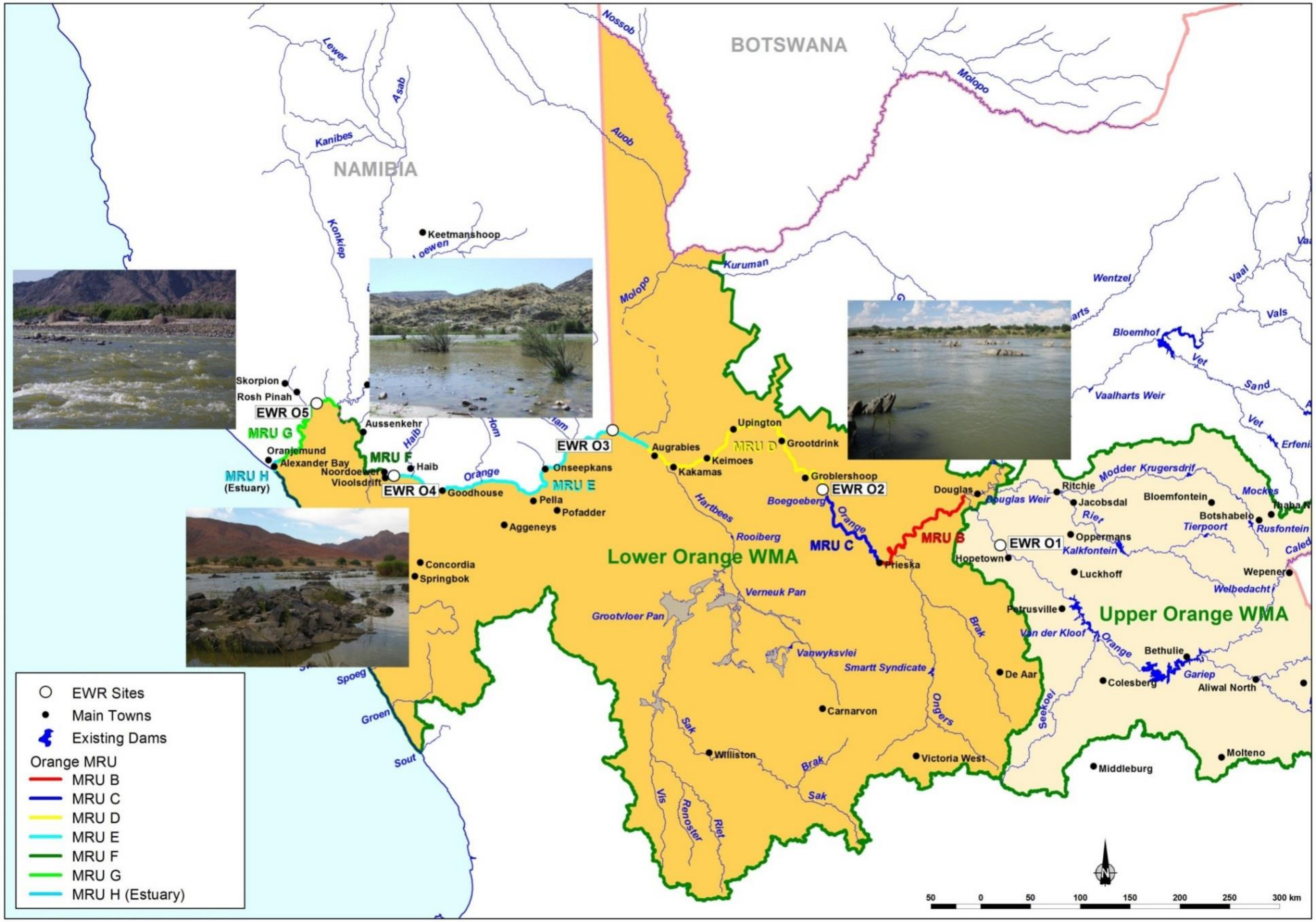


Figure 2.1 MRU delineation and EWR sites

2.3 ESTUARINE DELINEATION RESULTS

The Lower Orange WMA include six estuaries of national importance namely the Orange, Buffels, Sout, Swartlintjies, Spoeg and Groen. These estuaries each represent a RU and were delineated according to the accepted approach. The geographical boundaries of the estuaries are defined in Table 2.3.

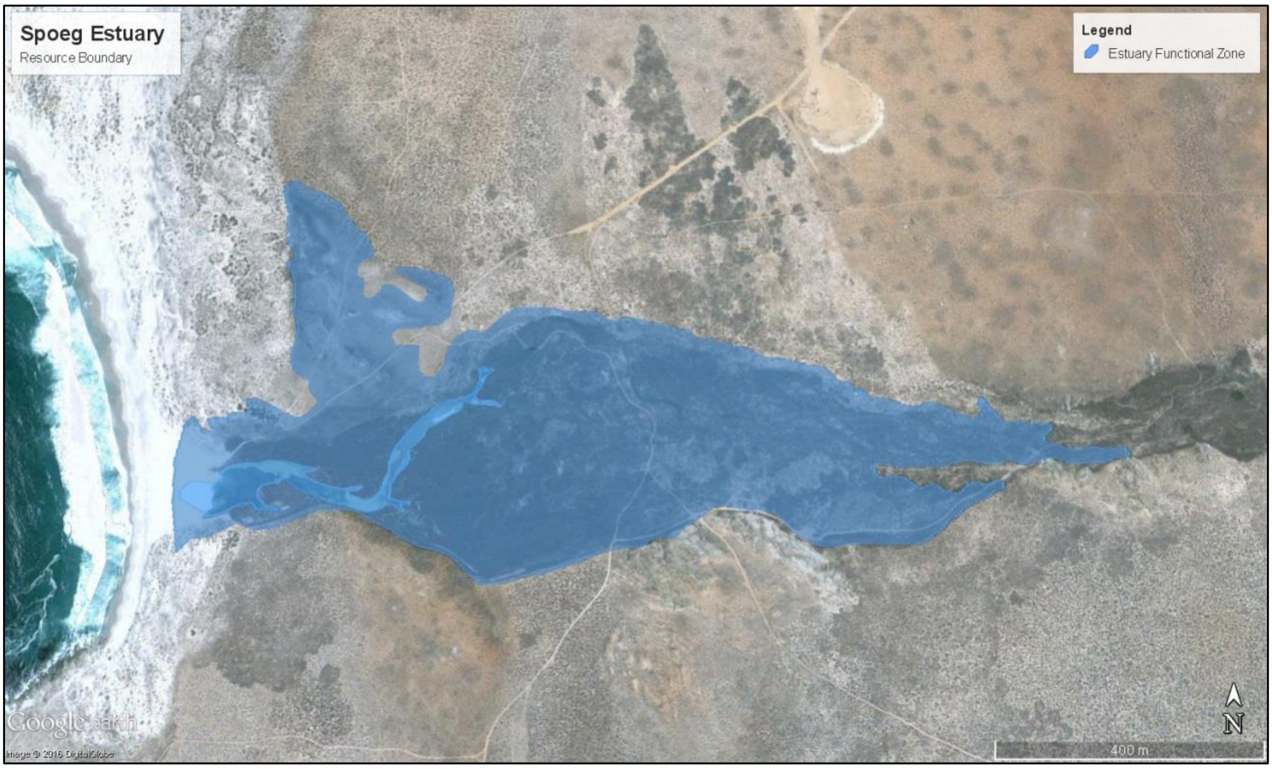
Table 2.3 Geographical boundaries of the estuaries

Orange Estuary	
Downstream boundary	28°37'58.91"S; 16°27'16.02"E (Estuary mouth)
Upstream boundary	28°33'43.63"S; 16°31'23.02"E
Lateral boundaries	5 m contour above Mean Sea Level (MSL) along each bank

Buffels Estuary	
Downstream boundary	29°40'37.01"S; 17° 3'4.41"E (Estuary mouth)
Upstream boundary	29°40'18.21"S; 17° 4'3.30"E
Lateral boundaries	5 m contour above MSL along each bank

Swartlintjies Estuary	
Downstream boundary	30°15'44.33"; S 17°15'36.39"E (Estuary mouth)
Upstream boundary	30°15'45.73"; S 17°17'8.36"E
Lateral boundaries	5 m contour above MSL along each bank

Spoeg Estuary	
Downstream boundary	30°28'20.54"S; 17°21'34.07"E (Estuary mouth)
Upstream boundary	30°28'17.92"; S 17°22'32.83"E
Lateral boundaries	5 m contour above MSL along each bank



Groen Estuary	
Downstream boundary	30°50'49.05"S; 17°34'35.72"E (Estuary mouth)
Upstream boundary	30°49'38.26"S; 17°34'40.18"E
Lateral boundaries	5 m contour above MSL along each bank

Sout Estuary	
Downstream boundary	31°14'37.66"S; 17°50'52.55"E (Estuary mouth)
Upstream boundary	31°12'38.88"S; 17°53'24.41"E
Lateral boundaries	5 m contour above MSL along each bank

2.4 GROUNDWATER RESOURCE UNITS

The objective of this task is to delineate GRUs based on quaternary catchment boundaries, aquifer type, and other physical, management and/or functional criteria. Quaternary catchments form the basic unit of delineation. These can be grouped if geohydrological properties are similar, or further subdivided where significant geohydrological features cut through catchments.

The approach followed in this study for grouping and delineation in hierarchical order is:

- An original primary delineation by quaternary catchment boundary as demarcated in Water Resources South Africa 2012 (WR2012).
- Geological age and lithology based on (GSSA, 2006).
- Identification of ground water regions based on geological considerations.
- Identification of catchments with baseflow to surface water bodies, as listed in Groundwater Resource Assessment Phase II (GRAII) (DWAF, 2006).
- Climate, recharge, and Harvest Potential (DWAF, 2006).
- Groundwater levels from the DWS National groundwater monitoring network.
- Groundwater quality from the DWS National water quality monitoring network.
- Groundwater dependent ecosystems and or wetlands based on Nel *et al*. (2011).
- Groundwater use and stress from the Water Use Authorisation and Registration Management System (WARMS)[3] database.

Nineteen GRUs are described:

[3] Water Resources Simulation Model 2000. The Pitman Model with Sami Model Groundwater interactions.

Bushmanland west: The Bushmanland west GRU is underlain by rocks of the Namaqua-Natal metamorphic Province, which are largely covered by Tertiary cover. Extensive outcrop exists only in the central region from Augrabies to Kenhardt. Recharge is less than 1 mm/a. Mean groundwater level depth per Quaternary catchment increases from less than 20 m near Kenhardt to over 50 m to the west near Aggeneys. Water quality is generally poor and of Class 3 or 4 due to high salinity, with the worst quality water being located in the north from Concordia to Augrabies.

Bushmanland east: The Bushmanland east GRU is underlain by rocks of the Kaaien and Areachap Terranes of the Namaqua-Natal metamorphic Province. Tertiary cover is less extensive than to the west. Recharge is from less than 1 mm/a to over 3 mm/a increasing south-eastward with rainfall. Groundwater levels average 20 - 25 metres below ground level (mbgl). Groundwater quality is less saline than in the western area and is generally of Class 2.

Dwyka Tillite: The Dwyka Tillite GRU is underlain by tillites and largely devoid of sediment cover. Recharge is less than 1 mm/a, except in the eastern pocket where rainfall is higher. Groundwater levels are from 18 - 25 mbgl, but are shallowe than 15 mbgl in the eastern portion. Groundwater is of unacceptable quality due to salinity of Class 4.

Ecca Carbonaceous shale: The Ecca carbonaceous shales overlie Dwyka Tillites and are extensively intruded by dolerite sheets. Recharge is less than 1 mm/a, except in the eastern portion where rainfall is higher. Groundwater levels are from 15 - 25 mbgl. Groundwater quality is poor and of Class 3.

Ecca sandstone and shale west: The Ecca sandstones and shales overlie the carbonaceous shales and have a recharge of 0.5 - 1 mm/a. Groundwater levels are shallow and are 10 - 15 mbgl. Groundwater quality is good to marginal and of Class 1 - 2.

Ecca sandstone and shale central and south west: The Ecca sandstones and shales overlie the carbonaceous shales and have a recharge from 1 - 3.5 mm/a, increasing towards the east. Groundwater levels are shallow and 10 - 15 mbgl. Groundwater quality is highly variable but generally of Class 1 - 2.

Ecca sandstone and shale east: The Ecca sandstones and shales overlie the carbonaceous shales. They have a recharge from 4 - 11 mm/a, increasing from Carnarvon to east of Britstown due to increasing rainfall. Groundwater levels are shallow and 7 - 15 mbgl. Groundwater quality is good and of Class 1.

Far northern Coastal Hinterland: The Gariep belt, extensively covered by Tertiary and Quaternary sediments, underlies the Far Northern Coastal Hinterland. It has recharge of less than 1 mm/a. Groundwater levels are from 25 - 45 mbgl. Groundwater is of poor to unacceptable quality, Class 3 - 4.

Ghaap Plateau: The Ghaap Plateau GRU is underlain by Ghaap Plateau dolomites, which are covered by Kalahari and Tertiary sediments in some. It is the most significant aquifer in the WMA. Recharge is from 7 - 10 mm/a. Groundwater levels are 15 - 20 mbgl. Groundwater quality is of Class 1.

Karoo sandstone and shale west: The Karoo sandstones and shales of the Beaufort Group overlie the Ecca Group. Recharge increases from 1 - 3 mm/a from north to south, being highest in the vicinity of Sutherland. Groundwater levels are from 5 - 15 mbgl. Groundwater quality is of Class 1 - 2.

Karoo sandstone and shale east: The Karoo sandstones and shales of the Beaufort Group overlie the Ecca Group. Recharge increases from 3 mm/a near Loxton, to nearly 12 mm/a around De Aar. Groundwater levels are from 5 - 15 mbgl. Groundwater quality is good to marginal, of Class 1 - 2, with the marginal groundwater found in the South east between Richmond and De Aar.

Namaqualand west: The Namaqualand west GRU is underlain by rocks of the Nama and Vanrhynsdorp groups. Along the coast, they are covered by Tertiary and Quaternary sediments. Recharge is less than than 1 mm/a but can range to over 3 mm/a in the vicinity of Garies due to higher rainfall. Groundwater levels are from 12 to 50 mbgl, being deeper near the coast. Groundwater is of poor to unacceptable quality, Class 3 - 4.

Namaqualand east: The Namaqualand east GRU is underlain by rocks of the Nama and Vanrhynsdorp groups. Recharge is from less than 1 mm/a to 2 mm/a. Groundwater levels are from 12 - 30 mbgl. This GRU was delineated due to a higher water class than the rest of Namaqualand and water quality is of Class 2 - 3 for domestic purposes.

Taung-Prieska belt: The Taung-Prieska Belt is underlain by Dwyka tillite and, Ventersdorp Supergroup rocks, with extensive Tertiary cover. Recharge is from 3.5 mm/a near Prieska up to 9.5 mm/a near Douglas. Groundwater levels are 15 - 20 mbgl. Groundwater quality is of Class 1 - 2.

West Griqualand: The West Griqualand GRU is underlain by the Olifantshoek Supergroup, the Ventersdorp Super Group, some dolomites, and Transvaal Group ironstones. Recharge is from 2 - 6 mm/a and increases to the east. Groundwater levels are 20 - 35 mbgl. Groundwater quality is of Class 1 - 2.

Western Kalahari: The Western Kalahari GRU consists of Quaternary sand cover overlying largely Dwyka Tillite, Koras Group sandstone, or metamorphics of the Kaaien Terrane. Recharge is less than 1 mm/a. Groundwater levels are from 25 to 90 mbgl. Groundwater quality is of class 4 and only improves in the SE around Karos and Grootdrink, where it is of class 2.

Richtersveld: The Richtersveld is underlain by rocks of the Richtersveld Subprovince. Recharge is less than 1 mm/a. Groundwater levels are from 30 - 50 mbgl, being deeper to the east. Groundwater is of marginal to unacceptable quality, Class 2 - 3.

Namaqualand coastal: The Namaqualand west GRU is underlain by rocks of the Nama and Vanrhynsdorp groups, which are covered by Tertiary and Quaternary sediments. Recharge is from less than 1 mm/a to 2 mm/a. Groundwater levels are from 40 - 50 mbgl. Groundwater is of poor to unacceptable quality, Class 3 - 4.

Karoo sandstone and shale southwest: The Karoo sandstones and shales of the Beaufort Group overlie the Ecca Group. Small volumes of baseflow potentially exist in the vicinity of Sutherland due to higher rainfall. Recharge increases from 3 - 8 mm/a from north to south, being highest in the vicinity of Sutherland. Groundwater levels are from 5 - 13 mbgl. Groundwater quality is of Class 1 - 2.

3 SYSTEMS HYDROLOGY

This chapter is summarised from: (DWS, 2016b)
Department of Water and Sanitation, South Africa, August 2016. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. River EWR report. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. Authored by Louw D, Birkhead D, Koekemoer S, Mare M. DWS Report No: RDM/WMA06/00/CON/COMP/0216.

3.1 INTRODUCTION

The flow in the Orange main River is almost entirely dependent on the flows generated in the Upper Orange, Senqu River in Lesotho and the Vaal River along with the related operating rules and system management procedures. The hydrological data, updated and extended as part of the ORASECOM Integrated Water Resources Management Plan (IWRMP) Phase 2 study (ORASECOM, 2014), applied for all the areas upstream of the Orange-Vaal confluence covers an 85-year period from 1920 to 2004 hydrological years. The hydrology information in the upstream catchments is generally of high to very high confidence. The hydrology from the catchments upstream of the Orange-Vaal confluence has a major impact on the flows available along the main Orange River downstream of the confluence and were taken into account when considering flows and related environmental impacts at any of the key points along the lower main Orange River.

Due to the erratic nature of the runoff and very low to zero monthly river flows in the arid tributary catchments within the Lower Orange WMA, several of the quaternary catchments were grouped together to form larger catchments. These quaternary catchment monthly flow records were added together to represent the flows for the related combined catchments, providing flow records at key water resource locations within the Lower Orange WMA as configured in the Water Resource Yield Model (WRYM) and Water Resource Planning Model (WRPM) networks.

Hydrological information is however still available at quaternary catchment scale from the river-runoff modelling and calibration undertaken during the ORASECOM IWRMP Phase 2 study (ORASECOM, 2014). This, in fact, formed the basis of the hydrology used as input to the WRYM and WRPM networks.

The Molopo River hydrological data was obtained from the Feasibility Study of the “Potential for sustainable Water Resources Development in the Molopo-Nossob Water Course” by ORASECOM (ORASECOM, 2009) and is regarded as low confidence due to absence of observed flow data in most of this area and the extremely high losses that occurs naturally, which is difficult to estimate accurately.

3.2 APPROACH

In this study, the latest and best available hydrology datasets were selected. Results from the Gap analysis recommended the use of the following hydrology datasets to provide the natural and present day flows required for this study:

- ORASECOM IWRMP Phase 2 study (ORASECOM, 2014) Pitman Model setup for natural and current day flows per quaternary for the Lower Orange, excluding the Molopo River and the small coastal rivers.
- The WRYM setup as prepared for the ORASECOM IWRMP Phase 2 study (ORASECOM, 2014) for Molopo River catchment, as this network detail was at a quaternary level.

- Pitman Model Setup and data from the WR2012 Study recently completed, to be used for the Small West Coast Rivers.

High losses occur in the Lower Orange along the main Orange, the Molopo River, Sak and Hartbees Rivers and other lower Orange River tributaries that take place under natural and developed conditions. In the preparation of the cumulative natural and present day flows, these losses were taken into account.

Water requirements within the tributary catchments were updated, using the most recent urban/industrial requirements from the All Town Study (DWS, 2015). Irrigation requirements from the tributary catchments were limited, but updated where required by using the latest available data from the WARMS.

The models as listed above and the related system setups were analysed for natural conditions and present day development level. These flow sequences are required as input to the Revised Desktop Reserve Model (RDRM) (Hughes *et al*., 2012; Hughes *et al*., 2014) and/or the original Desktop Reserve Model (DRM) (Hughes and Hannart, 2003).

Biophysical Nodes

The RUs, defined as part of Task 2 of this study, (DWS, 2016a), for the arid sections in the Lower Orange River tributaries, represented by quaternary catchments, and consists of a number of Sub Quaternary (SQ) reaches. This also linked to the groundwater units and the previous assessments undertaken at a quaternary basis. The biophysical nodes represent the outflow point at each of these quaternary catchments in most cases, with some exceptions particularly in the case of endoreic areas. Ninety-nine (99) biophysical nodes were defined within the Lower Orange tributaries including the small coastal rivers along the west coast and are presented in Figure 3.1.

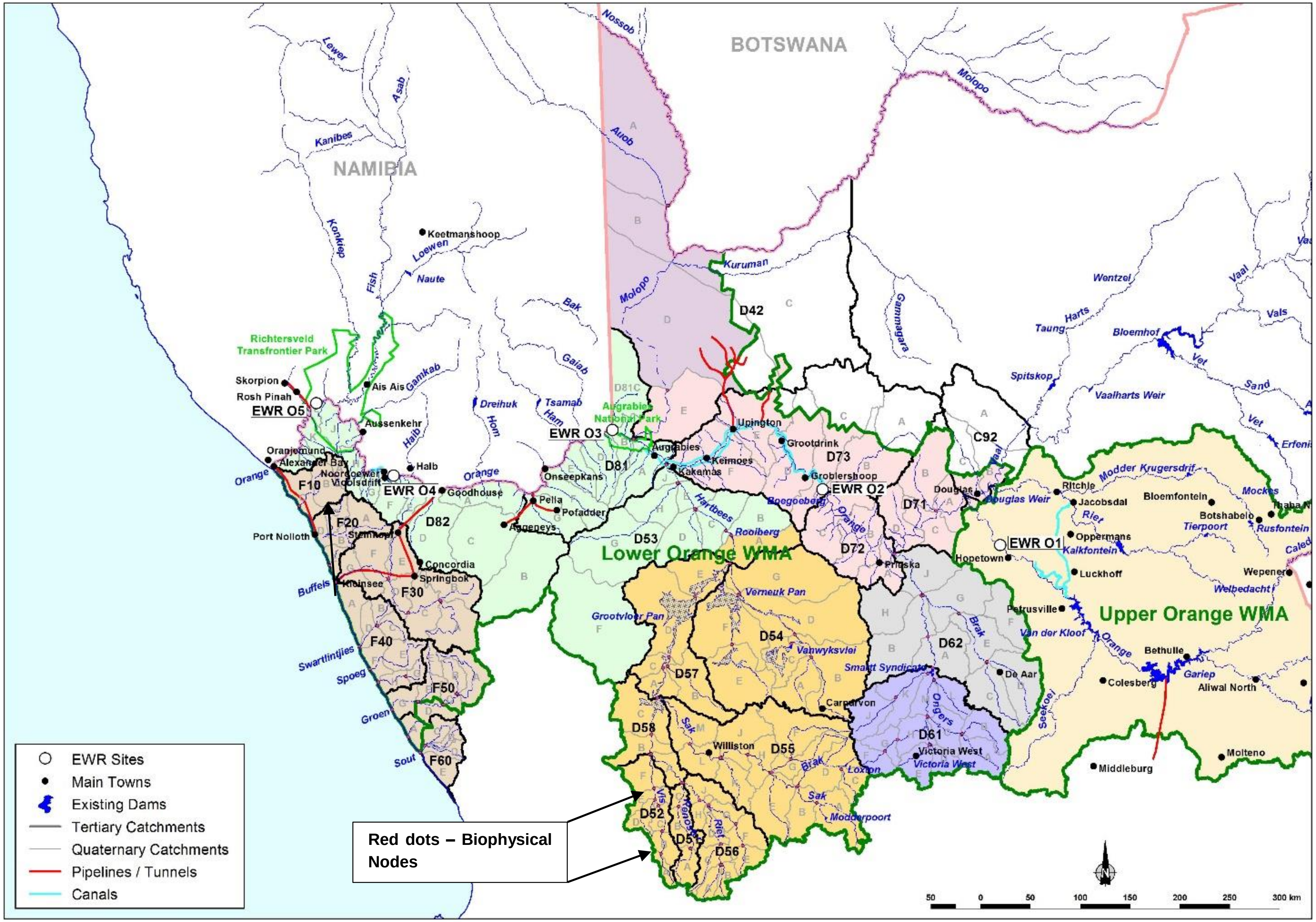


Figure 3.1 Location of Biophysical Nodes in the Lower Orange River

3.3 RESULTS

3.3.1 Natural flows

Under natural conditions, the flows generated within the Lower Orange River are very small in comparison with that entering the Lower Orange River from the Vaal River and the Upper Orange River. The Mean Annual Runoff (MAR) under natural conditions from the Vaal River amounts to 4 024 million m^3/a with 6 695 million m^3/a from the Upper Orange River, in total thus 10 719million m^3/a, with only 198 million m^3/a reaching the Orange River from the natural flow generated in the lower Orange RSA tributaries. These flows are represented in Table 3.1 by the cumulative flows for catchment numbers 20 (Brak River), 72 (Hartbees River) as well as the 50.1 million m^3/a from the small tributaries feeding directly into the main Orange River from D71, D72, D73 and 13.8 million m^3/a from the small tributaries located in D81 and D82. The natural inflow from the RSA Lower Orange tributaries, therefore, represents only about 1.9% of the total natural flow entering the Lower Orange River. Another 21.4 million m^3/a is generated within the small coastal rivers along the west coast (Figure 3.2). Table 3.1 provides a summary of the cumulative natural and present day flows at the selected biophysical nodes per quaternary catchment, as well as the location of each biophysical node. Large volumes of the generated natural flows are lost in the enormous pans/wetlands found in the Sak, Hartbees and Molopo rivers. The volumes lost in the Lower Molopo wetlands and Kalahari sand is so high that none of the Molopo flows reaches the Orange River. Only a small portion of the local runoff generated close to the confluence of the Molopo and Orange rivers physically enters the main Orange River. Figure 3.2 provides an indication of the natural flow generated within the Lower Orange tributaries and small rivers along the West coast.

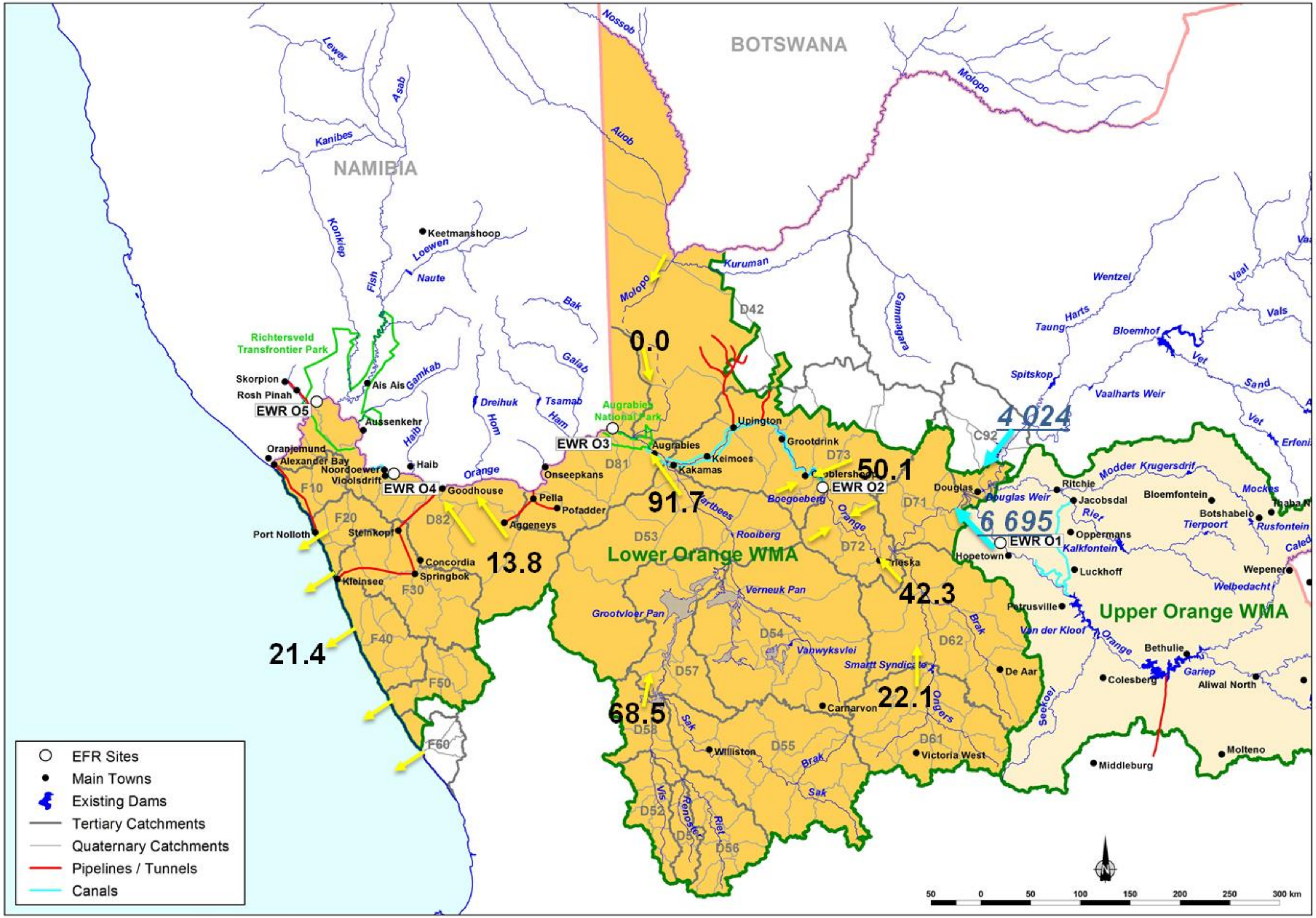


Figure 3.2 Natural flows generated from the Lower Orange

3.3.2 Present day flows

Due to the low rainfall and related runoff within the Lower Orange River tributaries, limited developments exist that utilise surface water as a resource. Ground water resources supply most of the water requirements, in particular, those of the towns. Table 3.1 provides a summary of the present day and natural flows at each of the biophysical nodes.

Table 3.1 Average natural and present day flows at the selected biophysical nodes

No	Quaternary Catchment	Node	Latitude	Longitude	Average annual flow (million m³)			Present Day (% of natural)
					Natural	Present Day	Difference	
Orange Small tributaries								
1	D71B	D71B03620	-29.20724	23.34363	9.862	9.862	0.000	100%
Brak Ongers River								
2	D61A	D61A06062	-31.20947	23.60141	3.430	3.226	0.204	94%
3	D61B	D61B05841	-31.2038	23.60679	2.690	2.690	0.000	100%
4	D61C	D61C05866	-31.05066	23.24582	7.634	7.145	0.489	94%
5	D61D	D61D06156	-31.30007	23.26646	0.920	0.920	0.000	100%
6	D61E	D61E06164	-31.30064	23.25767	1.960	1.285	0.675	66%
7	D61F	D61G06223	-31.35528	22.78456	0.970	0.484	0.486	50%
8	D61G	D61H05960	-31.252603	22.919494	1.996	1.326	0.670	66%
9	D61H	D61H05865	-31.044787	23.240097	6.829	5.483	1.346	80%
10	D61J	D61J05654	-30.87568	22.90351	2.110	2.110	0.000	100%
11	D61K	D61K05388	-30.661076	23.248275	4.826	4.826	0.000	100%
12	D61L	D61L05453	-30.72082	23.30871	0.470	0.470	0.000	100%
13	D61M	D61M05343	-30.61084	23.29821	22.124	5.015	17.109	23%
14	D62A	D62A05078	-30.33245	23.25014	22.904	5.795	17.109	25%
15	D62B	D62B04701	-29.9643	23.18373	23.529	6.420	17.109	27%
16	D62C	D62C05303	-30.56393	23.86438	4.529	4.529	0.000	100%
17	D62D	D62D05183	-30.55835	23.87186	7.544	7.399	0.146	98%
18	D62E	D62G04755	-30.12453	23.57422	16.132	15.986	0.146	99%
19	D62G	D62G04703	-29.9619	23.20277	17.366	17.220	0.146	99%
20	D62J	D62J04231	-29.58993	22.9062	42.331	25.077	17.255	59%
Vis River								
21	D56A	D56A07453	-32.35131	21.00809	1.639	1.586	0.052	97%
22	D56B	D56B07428	-32.34862	21.0213	1.667	1.614	0.053	97%
23	D56C	D56D0791	-32.16351	21.01843	6.262	6.062	0.200	97%
24	D56D	D56D06822	-31.81654	20.89108	8.257	7.994	0.263	97%
25	D56E	D56F07144	-32.18088	21.25144	1.002	0.971	0.032	97%
26	D56F	D56G06932	-31.98243	21.1828	2.564	2.483	0.081	97%
27	D56G	D56G06753	-31.81039	20.90019	3.544	3.432	0.112	97%
28	D56H	D56J06649	-31.76611	20.80411	13.237	12.816	0.421	97%
29	D56J	D56J06522	-31.60344	20.62585	13.932	13.334	0.599	96%
30	D51A	D51B07208	-32.196087	20.690202	6.397	6.025	0.372	94%
31	D51C	D51B06782	-31.81523	20.57795	13.403	12.624	0.779	94%
32	D51C	D51C06594	-31.607192	20.616258	14.033	13.254	0.779	94%
33	D52A	D52A07274	-32.2338	20.3713	2.933	2.633	0.300	90%
34	D52B	D52C06920	-32.034583	20.392677	8.054	7.312	0.743	91%
35	D52C	D52E06758	-31.80475	20.36033	11.662	10.587	1.075	91%
36	D52D	D52D06761	-31.747605	20.329598	2.655	2.356	0.299	89%
37	D52E	D52F06591	-31.64769	20.32002	16.852	15.192	1.660	90%

No	Quaternary Catchment	Node	Latitude	Longitude	Average annual flow (million m³)			Present Day (% of natural)
					Natural	Present Day	Difference	
38	D52F	D52F06306	-31.342123	20.286009	17.337	15.604	1.733	90%
39	D58A	D58A06302	-31.33839	20.30058	28.190	21.528	6.662	76%
40	D58B	D58C05932	-31.16235	20.30892	45.943	37.325	8.618	81%
41	D58C	D58C05390	-30.83714	20.38228	46.373	37.774	8.598	81%
Sak River								
42	D55A	D55B06707	-31.81091	22.05219	2.688	2.007	0.682	75%
43	D55B	D55B06615	-31.6658	21.84276	4.498	3.357	1.141	75%
44	D55C	D55D06429	-31.514518	22.321611	1.542	1.317	0.226	85%
45	D55D	D55D06524	-31.65441	21.85421	5.249	4.482	0.768	85%
46	D55E	D55E06496	-31.53304	21.56503	11.352	8.892	2.460	78%
47	D55F	D55F06209	-31.41459	21.783169	1.950	1.950	0.000	100%
48	D55G	D55G06308	-31.52921	21.57471	4.661	3.427	1.234	74%
49	D55H	D55J06243	-31.365849	21.32659	17.079	13.337	3.742	78%
50	D55J	D55J06180	-31.38729	21.04388	18.928	15.104	3.824	80%
51	D55K	D55K06347	-31.3921	21.03468	1.100	1.100	0.000	100%
52	D55L	D55L06115	-31.25786	20.71239	20.876	16.991	3.885	81%
53	D55M	D55M05697	-30.83767	20.39273	22.115	18.140	3.974	82%
54	D57A	D57A05387	-30.57032	20.45329	68.804	56.077	12.726	82%
55	D57B	D57B05325	-30.55522	20.49942	0.886	0.456	0.430	51%
56	D57C	D57C05254	-30.47333	20.51714	69.813	56.596	13.217	81%
57	D57D	D57E04534	-29.93926	20.81221	70.972	57.696	13.276	81%
58	D57E	D57E04374	-29.65111	21.18345	72.377	47.134	25.243	65%
Hartbees River								
59	D54A	D54B05160	-30.502431	22.014179	2.790	1.194	1.596	43%
60	D54B	D54D04896	-30.2966	21.8473	8.335	3.567	4.769	43%
61	D54C	D54B05129	-30.377384	21.814306	0.000	0.000	0.000	100%
62	D54D	D54D04630	-29.92641	21.2768	10.060	5.250	4.810	52%
63	D54E	D54F05004	-30.37747	21.18407	2.713	1.161	1.552	43%
64	D54F	D54F04645	-29.93643	21.26027	6.342	4.703	1.639	74%
65	D54G	D54G04407	-29.65312	21.18988	21.295	14.729	6.566	69%
66	D53A	D53A04099	-29.39973	21.20478	82.162	64.835	17.327	79%
67	D53B	D53B04104	-29.357025	21.148597	84.236	66.803	17.433	79%
68	D53C	D53C03807	-29.16175	20.84653	86.535	68.628	17.907	79%
69	D53D	D53D03879	-29.15301	20.82764	2.008	1.906	0.103	95%
70	D53E	D53E03557	-28.92011	20.66884	89.543	71.482	18.060	80%
71	D53H	D53H03564	-28.91865	20.65892	1.783	1.783	0.000	100%
72	D53J	D53J03408	-28.752278	20.547549	91.687	69.195	22.492	75%
Molopo River								
73	D42A	D42A01082	-26.435639	20.64088	2.266	2.087	0.178	92%
74	D42D	D42D02283	-28.08516	20.58034	0.000	0.000	0.000	100%
75	D42E	D42E03047	-28.5143	20.21567	0.000	0.000	0.000	100%
Small West Coast rivers								
76	F10A	F10B03391	-28.71823	17.10232	0.022	0.022	0.000	100%
77	F10C	F10B03391(2)	-28.97699	16.72195	0.064	0.064	0.000	100%
78	F20E	F20E04290	-29.52422	17.00079	0.738	0.738	0.000	100%
79	F30A	F30A04782	-29.89982	18.14349	2.313	2.313	0.000	100%
80	F30B	F30B04742	-29.89061	18.13899	1.731	1.731	0.000	100%

No	Quaternary Catchment	Node	Latitude	Longitude	Average annual flow (million m³)			Present Day (% of natural)
					Natural	Present Day	Difference	
81	F30C	F30C04823	-29.98675	17.79761	6.003	6.003	0.000	100%
82	F30D	F30D04598	-29.67807	17.60292	7.158	7.158	0.000	100%
83	F30E	F30E04444	-29.66987	17.60944	1.492	1.492	0.000	100%
84	F30G	F30G04539	-29.67664	17.05329	11.199	11.199	0.000	100%
85	F40B	F40B04916	-30.08611	17.45965	0.345	0.345	0.000	100%
86	F40C	F40C05007	-30.09004	17.46775	0.519	0.519	0.000	100%
87	F40D	F40D04789	-30.264	17.26102	1.215	1.215	0.000	100%
88	F40F	F40F05159	-30.4723	17.36051	1.282	1.282	0.000	100%
89	F40G	F40G05320	-30.55411	17.73929	0.297	0.297	0.000	100%
90	F40H	F40H05480	-30.59577	17.44355	0.630	0.630	0.000	100%
91	F50A	F50A05626	-30.73706	18.27257	1.546	1.546	0.000	100%
92	F50B	F50B05636	-30.7319	18.26622	0.715	0.715	0.000	100%
93	F50C	F50C05764	-30.82303	18.11749	2.782	2.782	0.000	100%
94	F50D	F50D05726	-30.78946	17.85192	3.597	3.597	0.000	100%
95	F50F	F50F05560	-30.78446	17.85221	1.260	1.260	0.000	100%
96	F50G	F50G05620	-30.84514	17.57622	5.458	5.458	0.000	100%
97	F60A	F60A05886	-31.09686	17.72978	0.177	0.177	0.000	100%
98	F60C	F60C06147	-31.17986	17.90619	0.450	0.450	0.000	100%
99	F60D	F60D06231	-31.24218	17.84726	0.675	0.675	0.000	100%

4 ECOCLASSIFICATION OF ORANGE RIVER EWR SITES

This chapter is summarised from: (DWS, 2016b)
Department of Water and Sanitation, South Africa, August 2016. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. River EWR report. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. Authored by Louw D, Birkhead D, Koekemoer S, Mare M. DWS Report No: RDM/WMA06/00/CON/COMP/0216.

4.1 LOCALITY AND DESCRIPTION OF SITES

Table 4.1 provides the locality of the EWR sites nestled within the identified MRUs (Figure 4.1). For additional information regarding EWR sites, please consult DWS (2016a).

Table 4.1 Locality and characteristics of EWR sites

EWR site number	EWR site name	River	Co-ordinates		EcoRegion (Level II)	Geomorphic zone	Altitude (m)	MRU	Quaternary Catchment	Gauge
			Latitude	Longitude						
EWR O2	Boegoeberg	Orange	-29.0055	22.16225	26.05	Lowland	871	MRU Orange D, RAU D.1	D73C	D7H008
EWR O3	Augrabies	Orange	-28.4287	19.9983	28.01	Lowland	433	MRU Orange E	D81B	D7H014
EWR O4	Vioolsdrift	Orange	-28.7553	17.71696	28.01	Lowland	167	MRU Orange F	D82F	D8H003 D8H013
EWR O5	Sendelingsdrift	Orange	-28.0718	16.95951	28.01	Lowland	47	MRU Orange G	D82L	D8H015

Figure 4.1 provides the locality of the EWR sites within the study area.

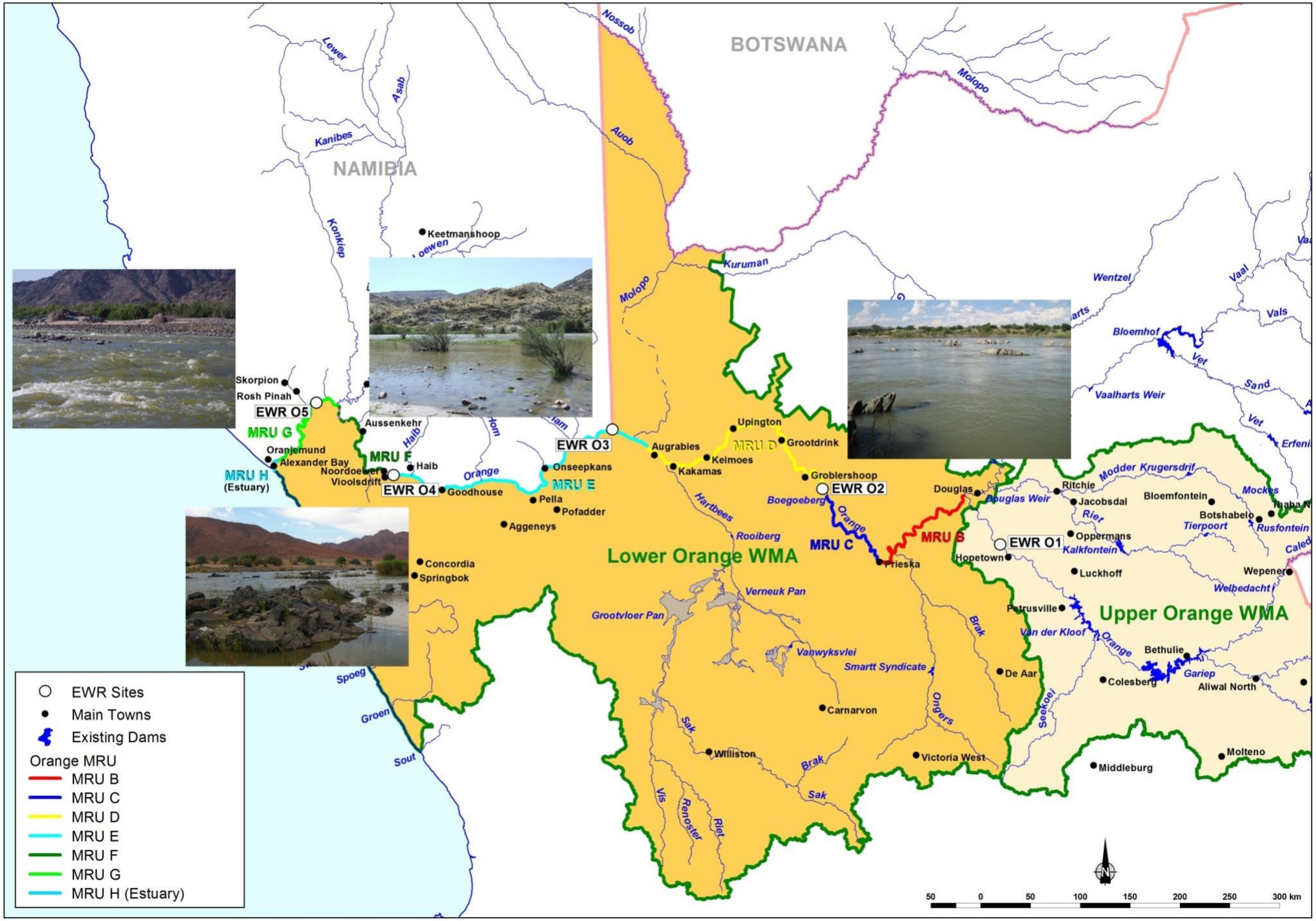


Figure 4.1 Locality and view of EWR sites in context of the MRUs

4.2 ECOCLASSIFICATION LEVEL IV APPROACH

The EcoClassification process followed the methods of Kleynhans and Louw (2007). Information provided in the following sections is a summary of the EcoClassification approach. For additional detailed information on the approach and suite of EcoStatus methods and models, refer to:

- Physico-chemical Driver Assessment Index (PAI): Kleynhans *et al*. (2005); DWAF (2008a).
- Geomorphology Assessment Index (GAI): Rowntree and du Preez (2006 – Draft report).
- Fish Response Assessment Index (FRAI): Kleynhans (2007).
- Macroinvertebrate Response Assessment Index (MIRAI): Thirion (2007).
- Riparian Vegetation Response Assessment Index (VEGRAI): Kleynhans *et al*. (2007).
- Index of Habitat Integrity (IHI): Kleynhans *et al*. (2009).

EcoClassification refers to the determination and categorisation of the Present Ecological State (PES) (health or integrity) of various biophysical attributes of rivers compared to the natural (or close to natural) reference condition. The purpose of EcoClassification is to gain insight into the causes and sources of the deviation of the PES of biophysical attributes from the reference condition. This provides the information needed to derive desirable and attainable future ecological objectives for the river. The EcoClassification process also supports a scenario-based approach where a range of ecological endpoints has to be considered.

The state of the river, expressed in terms of biophysical components is:

- Drivers (physico-chemical, geomorphology, hydrology), which provide a particular habitat template; and
- Biological responses (fish, riparian vegetation, and macroinvertebrates).

Different processes are followed to assign a category (A→F; A = Natural, and F = critically modified) to each component (See box below). Ecological evaluation in terms of expected reference conditions, followed by integration of these components, represents the Ecological Status or EcoStatus of a river. Therefore, the EcoStatus can be defined as the totality of the features and characteristics of the river and its riparian areas that bear upon its ability to support an appropriate natural flora and fauna (modified from Iversen *et al*., 2000). This ability relates directly to the capacity of the system to provide a variety of goods and services.

Ecological Category	Description
A	Unmodified, near natural.
B	Largely natural with few modifications.
C	Moderately modified.
D	Largely modified.
E	Seriously modified.
F	Critically / Extremely modified.

4.2.1 Present Ecological State

The steps followed in the EcoClassification process are as follows:

- Determine reference conditions for each component.
- Determine the PES for each component, as well as for the EcoStatus that represents an integrated PES for all components.
- Determine the trend for each component, as well as for the EcoStatus.

- Determine the reasons for the PES and whether these are flow or non-flow related.
- Determine the EIS for the biota and habitat.
- Considering the PES and the Ecological Importance and Sensitivity (EIS), suggest a realistic Recommended Ecological Category (REC) for each component, as well as for the EcoStatus.

Following standard methods, the Level 4 EcoStatus assessment was applied and Figure 4.2 (modified from Kleynhans and Louw, 2007) shows the minimum required for this assessment.

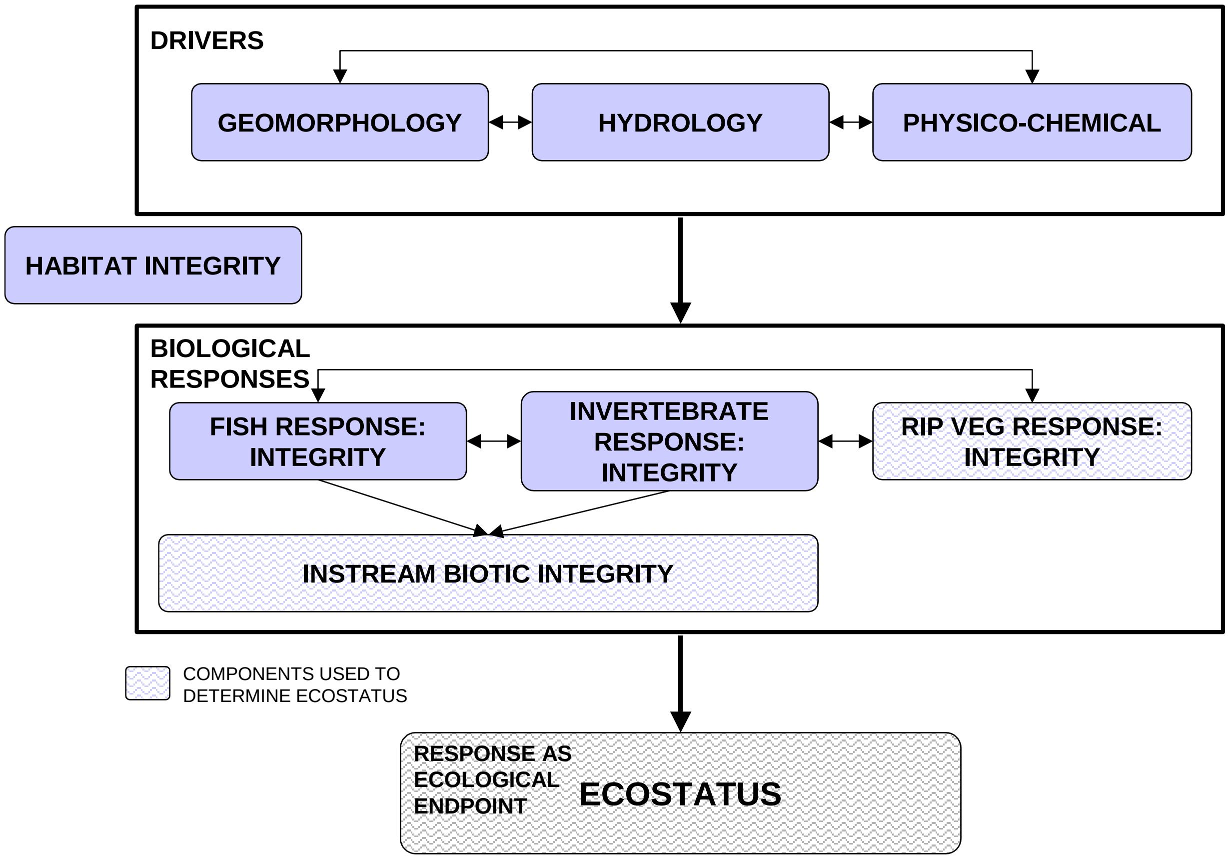


Figure 4.2 EcoStatus Level 4 determination

The role of the EcoClassification process is, amongst others, to define the various Ecological Categories (ECs) for which EWRs will be set. It is, therefore, an essential step in the EWR process. The EWR process is essentially a scenario-based approach and the EWRs are determined for a range of ECs referred to as EWR scenarios. The range of ECs could include the PES, REC (if different from the PES) and the Alternative Ecological Categories (AECs). When designing a scenario that could decrease the PES, flow changes are first to be evaluated. If this, and the response of other drivers, are deemed insufficient on its own to change the category, then the current non-flow related impacts are 'increased', or new non-flow related impacts are included. An attempt is made to create a realistic scenario; however, it must be acknowledged that there are many scenarios that could result in a changed EC.

4.2.2 Ecological Importance and Sensitivity

The EIS was calculated using a refined (from Kleynhans and Louw, 2007 and Louw *et al*., 2010) EIS model, developed during 2010 by Dr. Kleynhans. This approach estimates and classifies the EIS of the streams in a catchment by considering a number of components surmised to be indicative of these characteristics.

As the basis for the estimation of EIS, the following ecological aspects are considered:

- For both the instream and riparian components of the river, the presence of rare and endangered species, unique species (i.e., endemic or isolated populations) and communities, intolerant species and species diversity were taken into account.
- Habitat diversity, which included specific habitat types such as reaches with a high diversity of habitat types, i.e., pools, riffles, runs, rapids, waterfalls, riparian forests, etc.

With reference to the bullets above, biodiversity in its general form (i.e. Noss, 1990) takes into account as far as the available information allows:

- Considering the importance of a particular river or stretch of river in providing connectivity between different sections of the river, i.e., whether it provides a migration route or corridor for species,
- The presence of conservation or relatively natural areas along the river section also served as an indication of ecological importance and sensitivity.
- The sensitivity (or fragility) of the system and its resilience (i.e., the ability to recover, following disturbance) of the system to environmental changes was also considered. Consideration of both the biotic and abiotic components was included here.

This report summarises the EIS results of the study and the models provided electronically. EIS categories are summarised in Table 4.2.

Table 4.2 EIS categories (Modified from DWAF, 1999)

EIS Categories	General Description
Very high	Quaternaries/delineations considered unique on a national or even international level based on unique biodiversity (habitat diversity, species diversity, unique species, rare and endangered species). These rivers (in terms of biota and habitat) are usually very sensitive to flow modifications and have no or only a small capacity for use.
High	Quaternaries/delineations that considered unique on a national scale due to biodiversity (habitat diversity, species diversity, unique species, rare and endangered species). These rivers (in terms of biota and habitat) may be sensitive to flow modifications but in some cases, may have a substantial capacity for use.
Moderate	Quaternaries/delineations considered unique on a provincial or local scale due to biodiversity (habitat diversity, species diversity, unique species, rare and endangered species). These rivers (in terms of biota and habitat) are usually not very sensitive to flow modifications and often have a substantial capacity for use.
Low/Marginal	Quaternaries/delineations not considered unique at any scale. These rivers (in terms of biota and habitat) are generally not very sensitive to flow modifications and usually, have a substantial capacity for use.

4.2.3 Recommended Ecological Category

The REC is a recommendation from an ecological viewpoint, considered within the decision-making process in the National Water Resource Classification System (NWRCS). The recommendation is based on, either maintenance of the PES, or an improvement thereof. An improved REC is considered only if the EIS is HIGH or VERY HIGH. The guidelines to derive the REC based on the level of the PES and the EIS as indicated in Table 4.3. Note that in all cases the restoration potential and practicalities of the ecological attainability of recommendations that require improvements are considered.

Table 4.3 Guideline for REC determination

PES	EIS	REC	Comment
A, A/B, B	High or Very High	A, A/B, B	The PES will be maintained as it is already in a good condition that will support the high EIS.
B/C	High or Very High	B	As this condition is close to a B, marginal improvement may be required as a B is sufficient to support the high EIS.
C	High or Very High	B	Attempts should be made to improve by a Category.
C/D	High or Very High	B/C	Attempts should be made to improve by a Category.
D	High or Very High	C	Attempts should be made to improve by a Category.
D/E, E, E/F, F	n/a	D	Any Category below a D should (if restoration potential still exists) be improved to at least a D to ensure a minimum level of sustainability. This is irrespective of the EIS. It is unlikely though that it would be practical to improve an F river to a D without considerable investment, effort and possibly physical rehabilitation of the river.

4.3 ECOCLASSIFICATION RESULTS (ORANGE RIVER)

The results from Louw and Koekemoer (2010) and Louw *et al*. (2013) are provided as summary tables for each EWR site.

4.3.1 EWR O2 (Boegoeberg): EcoClassification results

Table 4.4 EWR O2: EcoClassification results

EWR O2 (BOEGOEBERG)

EIS: HIGH
Highest scoring metrics are instream and riparian rare /endangered biota, unique riparian biota, instream biota intolerant to flow, taxon richness of riparian biota, diversity of riparian habitat types, critical riparian habitat, refugia, and migration corridor.

PES: C
Loss of large flood frequency, agricultural return flows, higher low flows than natural in the dry season, drought and dry periods, decreased low flows at other times, the release of sediment, presence of alien fish species and barrier effect of dams.

REC: B/C
Instream improvement was not possible due to constraints and no EWR was set for the REC.

Driver Components	PES	TREND	REC
IHI HYDROLOGY	E		
WATER QUALITY	C		C
GEOMORPHOLOGY	C	0	C
INSTREAM IHI	C/D		
RIPARIAN IHI	B/C		
Response Components	**PES**	**TREND**	**REC**
FISH	C	0	C
MACRO INVERTEBRATES	C	0	C
INSTREAM	C	0	C
RIPARIAN VEGETATION	B	0	A/B
RIVERINE FAUNA	C	0	B
ECOSTATUS	C	0	B/C
EIS	HIGH		

4.3.2 EWR O3 (Augrabies)

Table 4.5 EWR O3: EcoClassification results

EWR O3 (AUGRABIES)

EIS: HIGH
Highest scoring metrics are instream and riparian rare /endangered biota, unique instream and riparian biota, taxon richness of riparian biota, diversity of riparian habitat types, critical riparian habitat, refugia, migration corridor, National Park.

PES: C
Decrease in large flood frequency. Agricultural return flows, agricultural activities and associated water quality impacts. Higher low flows than natural in the dry season, drought and dry periods. Decreased low flows at other times. The presence of alien fish and vegetation species. Barrier effect of dams. Decreased sedimentation.

REC: B
Reinstate droughts (i.e., lower flows than present during the drought season).Improve (higher) wet season base flows. Clear alien vegetation. Improve agricultural practices.

Driver Components	PES	TREND	REC
IHI HYDROLOGY	E		
WATER QUALITY	C		C
GEOMORPHOLOGY	C	0	C
INSTREAM IHI	D		
RIPARIAN IHI	C/D		
Response Components	**PES**	**TREND**	**REC**
FISH	C	0	B
MACRO INVERTEBRATES	C	0	B
INSTREAM	C	0	B
RIPARIAN VEGETATION	B/C	-	B
RIVERINE FAUNA	C	0	B
ECOSTATUS	C	0	B
EIS	HIGH		

4.3.3 EWR O4 (Vioolsdrift)

Table 4.6 EWR O4: EcoClassification results

EWR O4 (VIOOLSDRIFT)

EIS: HIGH
Highest scoring metrics are instream and riparian rare /endangered biota, unique instream and riparian biota, migration corridor, Transfrontier Park in the MRU.

PES: B/C
Decreased large flood frequency. Agricultural return flows and mining activities – water quality problems. Higher low flows than natural in the dry season, drought and dry periods. Decreased low flows at other times. The presence of alien fish and vegetation species. Barrier effect of dams. Decreased sedimentation due to upstream dams and lack of large floods.

REC:
Improved (higher) wet season base flows. Clear alien vegetation. Control grazing and trampling.

Driver Components	PES	TREND	REC
IHI HYDROLOGY	D		
WATER QUALITY	C/D		C/D
GEOMORPHOLOGY	C	0	C
INSTREAM IHI	D		
RIPARIAN IHI	D		
Response Components	**PES**	**TREND**	**REC**
FISH	C	0	B/C
MACRO INVERTEBRATES	C	0	B/C
INSTREAM	C	0	B/C
RIPARIAN VEGETATION	C	-	B
RIVERINE FAUNA	C	-	B/C
ECOSTATUS	C	-	B/C
EIS	HIGH		

4.3.4 EWR O5 (Sendelingsdrift)

Table 4.7 EWR O5: EcoClassification results

EWR O5 (SENDLINGSDRIFT)

EIS: HIGH
Highest scoring metrics are rare and endangered instream and riparian species. Unique instream and riparian species. Important migration corridor for various species. The site is situated in the /Ai-/Ais–Richtersveld Transfrontier Park.

PES: B/C
Decreased small and moderate flood frequency. Agricultural return flows and mining activities – water quality problems. Higher low flows than natural in the dry season, drought and dry periods. Decreased low flows at other times. The presence of alien fish and vegetation species. Barrier effect of dams.

REC: B
Increased (from present) wet season base flows. Reinstate dry season droughts.

Driver Components	PES	REC
IHI HYDROLOGY	C	C
WATER QUALITY	C	C
GEOMORPHOLOGY	B/C	B
INSTREAM IHI	C	
RIPARIAN IHI	C	
Response Components	**PES**	**REC**
FISH	B/C	B
MACRO INVERTEBRATES	B/C	B
INSTREAM	B/C	B
RIPARIAN VEGETATION	B/C	B
RIVERINE FAUNA	B	B
ECOSTATUS	B/C	B
EIS	HIGH	

4.4 ECOCLASSIFICATION SUMMARY

The results are summarised for the PES, REC and EIS per site in Table 4.8.

Table 4.8 EcoClassification summary

EWR site	PES	REC	EIS
EWR O2	C	B/C	High
EWR O3	C	B	High
EWR O4	C	B/C	High
EWR O5	B/C	B	High

4.5 ECOCLASSIFICATION CONFIDENCE

Table 4.9 provides the confidence in the EcoClassification process, based on data availability and EcoClassification, where:

- Data availability: Evaluation based on the adequacy of any available data for interpretation of the EC.
- EcoClassification: Evaluation based on the confidence in the accuracy of the EC.

The confidence score is based on a scale of 0 – 5 and colour coded where:
0 – 1.9: Low 2 – 3.4: Moderate 3.5 – 5: High

Table 4.9 Confidence in EcoClassification

EWR site	Data availability									EcoClassification								
	Hydrology	Physico-chemical	Geomorphology	IHI	Fish	Macro-invertebrates	Vegetation	Average	Median	Hydrology	Physico-chemical	Geomorphology	IHI	Fish	Macro-invertebrates	Vegetation	Average	Median
O2	2.5	3.3	4	3.5	3	4	4.5	3.5	3.5	3	3.5	3.5	2.6	3	4	4	3.4	3.5
O3	2	3	3	3.5	3	4	4.5	3.3	3	3	3.5	3	3	3.5	4	3.8	3.4	3.5
O4	2	2.3	3.5	3.5	3	4	4.5	3.3	3.5	3	2.5	3	3	3.5	4	3.8	3.3	3
O5	-	2	3	3.5	3	3	3.5	3	3	-	2.5	3	4.3	3	3	3.7	3.2	3

5 SUMMARY OF ORANGE RIVER EWR RESULTS: DISCHARGE RECOMMENDATIONS

This chapter is summarised from: (DWS, 2016b)
Department of Water and Sanitation, South Africa, August 2016. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. River EWR report. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. Authored by Louw D, Birkhead D, Koekemoer S, Mare M. DWS Report No: RDM/WMA06/00/CON/COMP/0216.

5.1 APPROACH

The Habitat Flow StressorResponse (HFSR) method (Hughes and Louw, 2010), a modification of the Building Block Methodology (BBM; King and Louw, 1998) was used to determine the low (base) flow EWRs. This method is one of the methods used to determine EWRs at the intermediate level.

EWRs were determined, using the following process outlined below:

The basic approach is to compile stress indices for fish and macroinvertebrates. The stress index describes the consequences of flow reduction on flow-dependent biota (or guilds) and is determined by first assessing the response of habitat availability and quality to flow reduction. The habitat flow index describes the instantaneous response of habitat to flow in terms of a 0 – 10 index relevant which is relevant for the specific site and described separately for fish and macroinvertebrates. The zero stress (best habitat) and 10 stress (worst habitat) is fixed to ensure that the range for fish and macroinvertebrates are similar:

- 0 –Optimum habitat represented by the maximum natural base flow. Note that without adequate hydrological data, this is difficult to identify.
- 10 – Zero discharge (Note: Surface water may still be present).
- 2 to 9 - Gradual decrease in habitat suitability because of decreased discharge.

The second step is to determine the biotic stress index that describes the instantaneous response of biota to change in habitat (and therefore flow) in terms of a 0 – 10 stress index. The description of the change in habitat availability at each stress level (as described in the habitat stress index) is then associated with the response of the fish and macroinvertebrate indicators. The biotic stress is, then described separately for fish and macroinvertebrates. The zero stress, representing optimum habitat, therefore, represents a situation of zero stress to biota with the maximum abundance of species present under these conditions.

The stress index, therefore, describes the habitat conditions and biotic response of fish and macroinvertebrates at a range of low flows. The fish and macroinvertebrate stress-flow relationship will not be similar, as the responses to the same flow will/can result in different stress for fish and macroinvertebrates.

Using fish and macroinvertebrate stress indices, natural and present day flow time-series are converted to a stress time-series. The resulting stress time-series is in turn, converted to a stress duration graph for the highest and lowest flow months. This provides the specialist with information on how much the stress has changed, due to changes in flow, from natural under present conditions.

It would follow that if flow has decreased from natural, stress would increase and vice versa. If specialists disagree with the levels of stress under natural conditions based on their knowledge of the species, the stress indices are refined.

The tools used to determine the stress indices include, specialist knowledge and information regarding the indicator species or taxa and associated habitat requirements, hydraulics (required in a specific format), and the natural hydrology.

At this stage, the only assessment undertaken is the instantaneous response of habitat and biota to flow reduction. This means that the actual stress requirements **at specific durations and during specific seasons** to maintain the biota in a certain ecological state still needs assessment. Considering the information used to determine the EC for the instream biota, the stress required to maintain or achieve this ecological state is determined. The stress requirement is set for drought and maintenance conditions. Drought stress is set at 5% exceedance. Depending on the river, the maintenance stress is set at a percentage, which is determined based on the low flow hydrological variability of the assessed river. The more variable the river, the higher the percentage at which maintenance stress is set. Any stress requirements for other percentage points can also be provided.

However, the requirements are still provided in terms of the separate fish and macroinvertebrate indices. Obviously, one can only deal with one stress-flow relationship, and an integrated stress index is required for this. The integrated stress curve comprises the highest stress of either the fish or macroinvertebrate component at any one flow. By converting the results for both fish and macroinvertebrates to integrated stress, the results are comparable.

Figure 5.1 illustrates an example of the interpolated individual component stresses as well as the integrated curve. The black line represents the integrated curve while the other curves represent the stress flow relationships for the various components. The integrated curve, in this case, consists of the flow dependant macroinvertebrates (FDI) (red curve) for the stress range 0 to 5, and fish (blue curve) for the stress range 5 to 10.

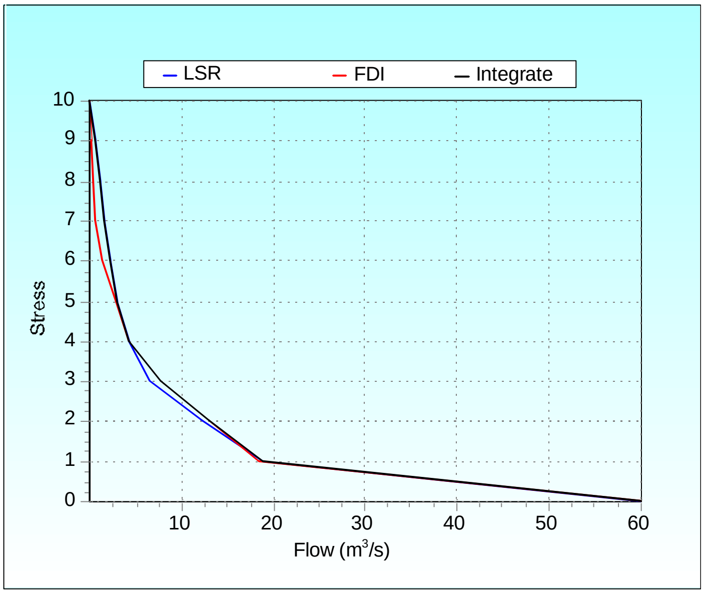


Figure 5.1 Component and integrated stress curves

Specialists determine the required stress (based on the habitat and biotic response) for different durations and for different ECs. The complexity here, as with all flow requirement methods, is to interpret an instantaneous response in terms of duration and seasonal requirements. A graph is produced that reflects the required stress, converted to integrated stress, along with the natural and present day flow that is also converted to integrated stress. This, therefore, supplies the 'hydrological check' to ensure that the requirements are realistic in terms of the natural hydrology and present day hydrology (only used when realistic and of reasonable confidence). The low flow stress requirement for an EC consists of the component with the lowest stress requirement (highest flow requirements). For example, if fish has a stress requirement of 6 at 5% duration to achieve an EC of a C, and similarly macroinvertebrates a stress of 8, the final requirement is a stress of 6. This makes provision for the macroinvertebrates, whereas the 8 stress would not cater for the fish and result in the fish being in a lower EC. These final requirements are therefore connected manually (a 'hand drawn line' as the required stress duration) and illustrated as a stress duration graph.

Figure 5.2 is an example of a stress duration graph and illustrates the stress requirements and stress points required for a D PES and REC (purple arrowed curve), and C AEC (green arrowed curve) during the dry season. The different coloured circles indicate the requirements of the instream biota for the specific EC. Each circle indicates a different biotic component with labels as follows:

- LSR – Large semi-rheophilic fish guild.
- FDI – Flow dependent macroinvertebrates.
- MVI – Marginal vegetation macroinvertebrates.

In the example provided below (Figure 5.2), the drought flows (5%) of the different biotic components are the same for all ECs.

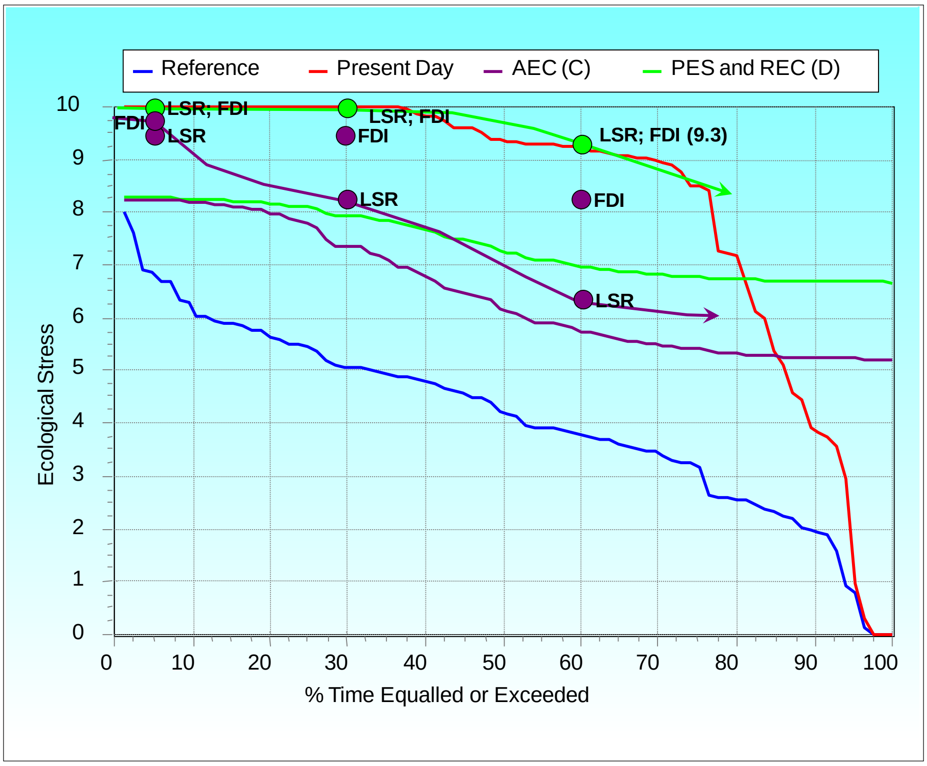


Figure 5.2 **Stress duration curve for a D PES and REC, and C AEC up - DRY season**

The provision of a complete low flow regime entails the manipulation of these stress requirements (provided for two key months or the high and low flow season), outlined below:

- Included in the above graph, Desktop estimates for the same assessed ECs, converted to stress, are included in the graph above.
- The hydrologist then uses the Desktop estimate and modifies it to fit the specialist requirements using the DRM and the Flow Stressor Response model within SPATSIM[4] (Spatial and Time Series Modelling) (Hughes and Forsythe, 2006). The process is specifically designed this way, as the seasonal characteristics of the hydrology and rules of the different ECs are built into the Desktop estimate[5]. This ensures that the requirements set by specialists do not deviate significantly from the natural seasonal variability.
- There is a range of options that one can use to make these modifications to the DRM, such as changing the total volume required for the year, changing specific monthly volumes, changing durations of either drought or maintenance flows, changing the seasonal distribution and changing the category rules and shape factors.
- The DRM extrapolates the requirements to the other months or seasons and specialists can check these other months.
- Document changes made to the DRM in order to fit the specialist requirements.
- Document the graphs for the final low flow stress requirements.

5.1.1 High flows

The approach to set high flows is a combination of the Downstream Response to Imposed Flow Transformation (DRIFT; King *et al*., 2003) approach and BBM (King and Louw, 1998). The high flows are determined as follows:

- Specialists identify and table the flood ranges for each flood class and the associated geomorphology and riparian vegetation functions.
- This information is provided to the instream specialists who indicate:
  - which instream function these floods addresses;
  - whether additional instream functions are required; and
  - whether these require any additional flood classes to the ones already identified.
- Identification of the number of floods for each flood class as well as when (early, mid, late) in the season they should occur.
- Adjustment of the number of identified floods for the different ECs.
- To ensure realistic flooding regimes a hydrologist evaluates the floods. The assessment is undertaken using a nearby gauge with daily data. Without this information, it is difficult to judge whether floods are realistic.
- The hydrologist then determines the daily average and documents the months in which the floods are spaced.
- Floods are then included in the DRM to provide the final .rul and .tab files.

5.1.2 Final flow requirements

After combining low and high flows, the final flow requirements for each EC consist of:

- An EWR table, which shows the results of high flows and low flows for each month separately. Modelled results exclude high frequency floods (higher than 1:1), as they are unmanageable.

[4]SPATSIM is an integrated data management and modelling software package developed in Delphi using the spatial data handling functions of Map Objects. The design allows for the efficient management, processing and modelling of the type of data associated with a range of water resource assessment approaches used in South Africa, including streamflow and other time series data display and analysis, rainfall-runoff models (including the Pitman monthly model) and a variety of Ecological Reserve determination models.

[5]The desktop estimates for specific ECs include rules for these ECs based on long-term data records and expert information.

- An EWR rule table which provides the recommended EWR flows as a duration table, showing flows which should be provided when linked to a natural trigger (natural modelled hydrology in this case). Supplied EWR rules are for total flows as well as for low flows only.

The low flow EWR rule table is useful for operating the system, whereas for the operation of high flows one uses the EWR table.

5.2 RESULTS

5.2.1 EWR O2 (Boegoeberg): EWR results

After combining low- and high flows, the final flow requirements for each EC consist of:

- An EWR table, which shows the results for each month for high flows and low flows separately (Table 5.1). Modelled results exclude high frequency floods, as they are unmanageable.
- An EWR rule table which provides the recommended EWR flows as a duration table, linked to a natural trigger (natural modelled hydrology in this case). Supplied EWR rules are for total flows as well as for low flows only (Table 5.2).

The low flow EWR rule table is used for the operation of low flows, whereas the EWR table is used for the operation of high flows.

Table 5.1 EWR O2: EWR table for PES and REC: C

Desktop version:		**2**	**Virgin Mean Annual Runoff (MAR) (Mm^3)**	**10573.7**
BFI	**0.329**	**Distribution type**		**Vaal**
MONTH	**LOW FLOWS**		**HIGH FLOWS**	
	Maintenance (m^3/s)	**Drought (m^3/s)**	**Daily average (m^3/s) on top of base flow**	**Duration (days)**
October	28.211	0.627		
November	36.708	13.665	150	6
December	39.92	19.512	150	6
January	47.269	21.408	150	6
February	61.393	31.478	350	8
March	60.014	31.051	850	12
April	53.153	11.705		
May	39.716	10.906		
June	30.813	11.3		
July	24.956	10.919		
August	23.653	10.171		
September	24.231	6.115		
Total Mm^3	1226.55	465.24	570.98	
% of natural MAR	11.6	4.4	5.5	
Total EWR	1607.2			
% of natural MAR	15.2			

Table 5.2 EWR O2: Assurance rules for PES and REC: C

Desktop Version 2, Printed on 2010/11/03
Summary of EWR rule curves for: EWRO2 Natural Flows
Determination based on defined BBM Table with site-specific assurance rules.
Regional Type: Vaal PES and REC = C

Data are given in m^3/s mean monthly flow

Reserve flows

Month	% Points 10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	41.794	41.290	40.355	38.693	35.879	31.408	24.876	16.404	7.318	0.886
Nov	78.886	73.772	68.755	63.201	53.796	46.506	37.174	27.231	19.120	15.301
Dec	81.831	76.003	70.433	64.246	54.201	46.139	36.811	28.390	22.927	21.077
Jan	86.915	81.014	75.267	68.727	58.092	49.246	39.134	30.201	24.623	22.993
Feb	167.673	147.682	130.734	114.213	88.708	72.594	55.999	43.593	37.338	35.992
Mar	212.180	209.565	202.463	186.957	160.086	123.942	87.367	60.804	48.008	41.514
Apr	61.872	61.103	59.035	54.536	46.721	36.114	25.189	17.023	12.905	12.019
May	48.843	48.166	46.652	43.699	38.752	31.794	23.840	16.814	12.427	11.144
Jun	40.975	40.456	39.304	37.064	33.308	27.997	21.852	16.304	12.705	11.486
Jul	34.839	34.425	33.615	32.153	29.748	26.210	21.682	16.858	12.923	11.070
Aug	35.162	34.856	34.289	33.280	31.571	28.857	24.892	19.749	14.233	10.328
Sep	37.215	36.958	36.513	35.750	34.456	32.304	28.403	21.748	13.353	7.494

Reserve flows without High Flows

Oct	41.794	41.290	40.355	38.693	35.879	31.408	24.876	16.404	7.318	0.886
Nov	51.211	50.561	49.289	46.994	43.219	37.667	30.560	22.988	16.810	13.902
Dec	53.136	52.548	51.243	48.705	44.449	38.431	31.468	25.182	21.104	19.723
Jan	58.221	57.564	56.095	53.229	48.428	41.677	33.959	27.141	22.883	21.639
Feb	71.576	70.962	69.309	65.713	59.466	50.988	42.256	35.728	32.437	31.729
Mar	67.585	67.014	65.465	62.082	56.221	48.336	40.357	34.563	31.771	31.280
Apr	61.872	61.103	59.035	54.536	46.721	36.114	25.189	17.023	12.905	12.019
May	48.843	48.166	46.652	43.699	38.752	31.794	23.840	16.814	12.427	11.144
Jun	40.975	40.456	39.304	37.064	33.308	27.997	21.852	16.304	12.705	11.486
Jul	34.839	34.425	33.615	32.153	29.748	26.210	21.682	16.858	12.923	11.070
Aug	35.162	34.856	34.289	33.280	31.571	28.857	24.892	19.749	14.233	10.328
Sep	37.215	36.958	36.513	35.750	34.456	32.304	28.403	21.748	13.353	7.494

Natural Duration curves

Oct	631.571	345.904	243.160	171.151	109.282	82.788	63.762	40.931	25.336	5.780
Nov	918.985	673.117	500.725	372.319	254.479	224.730	170.517	136.802	59.047	17.191
Dec	1020.120	723.973	540.834	415.502	339.382	299.522	213.527	114.475	82.269	33.774
Jan	1270.557	903.875	638.303	521.184	395.508	298.484	227.173	172.547	96.210	43.003
Feb	2052.472	1278.741	891.353	538.802	436.872	319.498	273.276	229.588	135.235	45.705
Mar	1562.280	1034.289	698.014	607.411	468.765	335.738	252.647	200.396	126.176	41.514
Apr	899.541	636.867	406.590	319.606	288.630	238.515	170.093	119.487	75.598	29.344
May	353.271	265.091	197.431	133.277	106.732	82.154	72.353	47.551	34.606	11.470
Jun	192.647	140.895	91.454	71.937	60.683	56.296	43.534	33.029	22.477	11.617
Jul	149.578	100.896	84.569	67.040	47.525	39.221	32.818	26.329	19.108	15.084
Aug	152.337	106.582	83.796	60.140	50.881	34.069	27.770	23.466	18.246	14.445
Sep	229.946	126.123	86.844	65.251	48.935	39.734	28.403	21.748	13.353	8.333

5.2.2 EWR O3 (Augrabies): EWR results

After combining low- and high flows, the final flow requirements for each EC consist of:

- An EWR table, which shows the results for each month for high flows and low flows separately (Table 5.3 – 5.4). Modelled results exclude high frequency floods, as they are unmanageable.
- An EWR rule table which provides the recommended EWR flows as a duration table, linked to a natural trigger (natural modelled hydrology in this case). Supplied EWR rules are for total flows as well as for low flows only (Table 5.5 – 5.6).

The low flow EWR rule table is used for the operation of low flows, whereas the EWR table is used for the operation of high flows.

Table 5.3 EWR O3: EWR table for PES: C

Desktop version:		2	Virgin MAR (Mm^3)	10513.1
BFI	0.321	Distribution type		Vaal
MONTH	LOW FLOWS		HIGH FLOWS	
	Maintenance (m^3/s)	Drought (m^3/s)	Daily average (m^3/s) on top of base flow	Duration (days)
October	21.303	0		
November	26.529	4.996	150	6
December	28.289	11.503	150	6
January	32.818	12.649	150	6
February	41.932	18.259	350	8
March	40.759	17.993	680	12
April	36.835	8.171		
May	28.578	8.255		
June	23.44	8.872		
July	19.734	7.051		
August	18.906	6.62		
September	19.174	0.98		
Total Mm^3	883.1	273.34	494.12	
% of natural MAR	8.4	2.6	4.7	
Total EWR	1251.06			
% of natural MAR	11.9			

Table 5.4 EWR O3: EWR table for REC: B

Desktop version:		2	Virgin MAR (Mm^3)	10513.1
BFI	0.321	Distribution type		Vaal
MONTH	LOW FLOWS		HIGH FLOWS	
	Maintenance (m^3/s)	Drought (m^3/s)	Daily average (m^3/s) on top of base flow	Duration (days)
October	30.573	0		
November	50.997	4.996	150	6
December	60.593	15.102	150	6
January	80.058	12.649	150	6
February	112.695	29.315	350	8
March	114.188	30.552	680	12
April	95.29	8.171		
May	61.835	8.255		
June	37.721	9.622		
July	23.829	9.491		
August	20.268	9.14		
September	19.389	0.98		
Total Mm^3	1850.31	157.37	494.12	
% of natural MAR	17.6	3.4	4.7	
Total EWR	2018.52			
% of natural MAR	19.2			

Table 5.5 EWR O3: Assurance rules for PES: C

Desktop Version 2, Printed on 2010/11/04
Summary of EWR rule curves for: EWR O3 Natural Flows
Determination based on defined BBM Table with site-specific assurance rules.
Regional Type: Vaal PES = C

Data are given in m^3/s mean monthly flow

Reserve flows

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
	% Points									
Oct	31.557	31.178	30.480	29.242	27.155	23.841	18.990	12.651	5.723	0.000
Nov	65.933	60.925	56.132	50.999	42.292	36.002	27.841	18.899	11.195	6.982
Dec	68.900	62.971	57.368	51.403	42.074	35.325	27.632	20.516	15.497	13.222
Jan	76.372	69.112	62.097	54.413	43.272	34.906	26.535	19.904	15.927	14.331
Feb	159.208	134.641	113.429	93.237	66.395	51.557	38.472	29.439	24.667	22.895
Mar	184.526	177.511	162.886	139.020	108.533	78.046	54.180	39.555	32.540	30.055
Apr	51.049	49.491	46.254	40.754	33.170	24.759	17.341	12.220	9.515	8.510
May	39.997	39.086	37.217	33.943	29.104	23.159	17.211	12.499	9.673	8.539
Jun	33.355	32.813	31.727	29.787	26.745	22.627	17.932	13.590	10.527	9.138
Jul	28.504	28.148	27.459	26.223	24.194	21.196	17.307	13.045	9.374	7.366
Aug	28.089	27.831	27.356	26.514	25.094	22.840	19.539	15.227	10.513	7.115
Sep	23.717	23.529	23.203	22.645	21.700	20.127	17.579	13.631	7.996	1.988

Reserve flows without High Flows

Oct	31.557	31.178	30.480	29.242	27.155	23.841	18.990	12.651	5.723	0.000
Nov	38.256	37.703	36.635	34.718	31.573	26.926	20.896	14.289	8.597	5.484
Dec	40.268	39.631	38.355	36.076	32.502	27.663	22.148	17.046	13.447	11.816
Jan	45.989	45.032	43.069	39.630	34.547	28.303	22.056	17.107	14.138	12.948
Feb	58.295	56.840	53.818	48.682	41.601	33.747	26.821	22.040	19.514	18.576
Mar	56.174	54.453	50.864	45.008	37.528	30.047	24.192	20.603	18.882	18.272
Apr	51.049	49.491	46.254	40.754	33.170	24.759	17.341	12.220	9.515	8.510
May	39.997	39.086	37.217	33.943	29.104	23.159	17.211	12.499	9.673	8.539
Jun	33.355	32.813	31.727	29.787	26.745	22.627	17.932	13.590	10.527	9.138
Jul	28.504	28.148	27.459	26.223	24.194	21.196	17.307	13.045	9.374	7.366
Aug	28.089	27.831	27.356	26.514	25.094	22.840	19.539	15.227	10.513	7.115
Sep	23.717	23.529	23.203	22.645	21.700	20.127	17.579	13.631	7.996	1.988

Natural Duration curves

Oct	625.022	339.729	238.616	164.643	103.756	76.240	57.239	34.909	18.821	0.000
Nov	914.267	664.780	492.404	364.016	246.127	219.066	162.211	129.147	50.710	8.954
Dec	1012.929	715.192	532.706	406.933	331.291	290.737	204.794	105.802	74.175	24.985
Jan	1262.321	923.439	638.792	513.740	386.914	298.574	219.079	163.956	87.623	34.476
Feb	2068.130	1297.202	903.282	548.251	432.614	313.600	268.556	222.359	128.001	38.447
Mar	1579.234	1029.312	705.279	602.210	475.821	337.481	248.693	196.181	122.525	38.041
Apr	909.772	633.503	413.584	324.093	285.313	244.904	175.428	122.145	72.234	25.667
May	355.152	262.418	195.744	130.589	107.056	81.851	69.739	45.669	32.053	8.793
Jun	190.698	138.897	89.664	74.742	60.035	54.333	41.539	33.013	20.652	11.323
Jul	147.345	99.836	89.595	65.315	45.613	36.989	31.127	24.709	17.085	12.851
Aug	149.029	112.541	83.065	62.724	48.092	34.629	25.291	20.535	14.938	11.137
Sep	224.877	120.988	81.709	60.116	44.159	34.688	26.505	16.725	8.252	3.221

Table 5.6 EWR O3: Assurance rules for REC: B

Desktop Version 2, Printed on 2010/11/04
Summary of EWR rule curves for:EWRO3 Natural Flows
Determination based on defined BBM Table with site-specific assurance rules.
Regional Type: Vaal REC = B

Data are given in m^3/s mean monthly flow

	% Points									
Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	45.572	45.145	44.182	42.204	38.529	32.471	23.869	13.822	4.967	0.000
Nov	98.751	93.748	88.716	82.693	71.750	61.056	45.959	28.578	13.718	6.808
Dec	112.793	106.347	99.404	90.547	76.024	61.632	44.979	29.944	20.193	16.890
Jan	131.804	124.946	117.059	106.342	88.710	70.025	48.667	29.796	18.015	14.571
Feb	239.908	216.227	192.258	164.745	125.280	94.919	66.705	46.745	36.637	34.307
Mar	269.643	262.286	246.887	219.882	180.747	134.750	92.006	61.765	46.452	38.041
Apr	121.675	118.015	110.355	96.921	77.453	54.571	33.308	18.264	10.647	8.890
May	79.624	78.350	75.503	69.947	60.639	47.550	32.588	19.369	11.116	8.703
Jun	52.356	51.609	49.950	46.724	41.316	33.667	24.818	16.828	11.646	9.891
Jul	33.211	32.985	32.471	31.410	29.431	26.171	21.571	16.274	11.745	9.639
Aug	30.269	30.071	29.624	28.707	27.003	24.195	20.207	15.549	11.443	9.272
Sep	30.834	30.741	30.397	29.686	28.290	25.729	21.438	15.107	7.476	1.735
Reserve flows without High Flows										
Oct	45.572	45.145	44.182	42.204	38.529	32.471	23.869	13.822	4.967	0.000
Nov	70.979	70.350	68.922	65.968	60.464	51.397	38.599	23.865	11.267	5.409
Dec	84.098	82.892	80.214	75.005	66.273	53.924	39.637	26.736	18.370	15.536
Jan	103.110	101.496	97.887	90.845	79.047	62.456	43.491	26.736	16.275	13.217
Feb	144.274	140.567	132.809	119.202	99.485	76.310	54.774	39.537	31.822	30.044
Mar	146.201	142.472	134.667	120.979	101.143	77.829	56.164	40.836	33.074	31.285
Apr	121.675	118.015	110.355	96.921	77.453	54.571	33.308	18.264	10.647	8.890
May	79.624	78.350	75.503	69.947	60.639	47.550	32.588	19.369	11.116	8.703
Jun	52.356	51.609	49.950	46.724	41.316	33.667	24.818	16.828	11.646	9.891
Jul	33.211	32.985	32.471	31.410	29.431	26.171	21.571	16.274	11.745	9.639
Aug	30.269	30.071	29.624	28.707	27.003	24.195	20.207	15.549	11.443	9.272
Sep	30.834	30.741	30.397	29.686	28.290	25.729	21.438	15.107	7.476	1.735
Natural Duration curves										
Oct	625.022	339.729	238.616	164.643	103.756	76.240	57.239	34.909	18.821	0.000
Nov	914.267	664.780	492.404	364.016	246.127	219.066	162.211	129.147	50.710	8.954
Dec	1012.929	715.192	532.706	406.933	331.291	290.737	204.794	105.802	74.175	24.985
Jan	1262.321	923.439	638.792	513.740	386.914	298.574	219.079	163.956	87.623	34.476
Feb	2068.130	1297.202	903.282	548.251	432.614	313.600	268.556	222.359	128.001	38.447
Mar	1579.234	1029.312	705.279	602.210	475.821	337.481	248.693	196.181	122.525	38.041
Apr	909.772	633.503	413.584	324.093	285.313	244.904	175.428	122.145	72.234	25.667
May	355.152	262.418	195.744	130.589	107.056	81.851	69.739	45.669	32.053	8.793
Jun	190.698	138.897	89.664	74.742	60.035	54.333	41.539	33.013	20.652	11.323
Jul	147.345	99.836	89.595	65.315	45.613	36.989	31.127	24.709	17.085	12.851
Aug	149.029	112.541	83.065	62.724	48.092	34.629	25.291	20.535	14.938	11.137
Sep	224.877	120.988	81.709	60.116	44.159	34.688	26.505	16.725	8.252	3.221

5.2.3 EWR O4 (Vioolsdrift): EWR results

After combining low- and high flows, the final flow requirements for each EC consist of:

- An EWR table, which shows the results for each month for high flows and low flows separately (Table 5.7 – 5.8). Modelled results exclude high frequency floods, as they are unmanageable.
- An EWR rule table which provides the recommended EWR flows as a duration table, linked to a natural trigger (natural modelled hydrology in this case). Supplied EWR rules are for total flows as well as for low flows only (Table 5.9 – 5.10).

The low flow EWR rule table is used for the operation of low flows, whereas the EWR table is used for the operation of high flows.

Table 5.7 EWR O4: EWR table for PES: C

Desktop version:		2	Virgin MAR (Mm^3)	10335.01
BFI	0.312	Distribution type		Vaal
MONTH	LOW FLOWS		HIGH FLOWS	
	Maintenance (m^3/s)	Drought (m^3/s)	Daily average (m^3/s) on top of base flow	Duration (days)
October	12.783	0		
November	18.34	0	170	6
December	20.708	2.233	60 170	5 6
January	25.928	2.319	170	6
February	35.255	7.875	340	8
March	35.235	7.856	500	12
April	30.393	3.854		
May	21.409	4.829		
June	15.308	3.498		
July	11.408	2.639		
August	10.311	2.356		
September	10.034	0		
Total Mm^3	651.11	35.16	434.07	
% of natural MAR	6.3	0.9	4.2	
Total EWR	919.82			
% of natural MAR	8.9			

Table 5.8 EWR O4: EWR table for REC: B/C

Desktop version:		2	Virgin MAR (Mm^3)	10335.01
BFI	0.312	Distribution type		Vaal
MONTH	LOW FLOWS		HIGH FLOWS	
	Maintenance (m^3/s)	Drought (m^3/s)	Daily average (m^3/s) on top of base flow	Duration (days)
October	22.199	0		
November	30.049	0	170	6
December	33.18	2.233	60 170	5 6
January	40.414	2.319	170	6
February	53.819	12.333	340	8
March	53.311	12.303	500	12
April	46.751	3.854		
May	34.152	5.081		
June	25.848	5.478		
July	20.294	4.133		
August	18.773	2.356		
September	18.54	0		
Total Mm^3	1043.85	134.36	434.07	
% of natural MAR	10.1	1.3	4.2	
Total EWR	1260.88			
% of natural MAR	12.2			

Table 5.9 EWR O4: Assurance rules for PES: C

Desktop Version 2, Printed on 2010/11/05
Summary of EWR rule curves for: EWRO4 Natural Flows
Determination based on defined BBM Table with site-specific assurance rules.
Regional Type: Vaal PES = C

Data are given in m^3/s mean monthly flow

Reserve flows

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	18.927	18.675	18.198	17.333	15.852	13.492	10.084	5.827	1.688	0.000
Nov	57.741	52.179	46.926	41.387	31.962	25.570	17.583	9.487	3.514	0.000
Dec	72.078	63.462	55.516	47.320	34.552	26.293	17.409	9.971	5.545	4.425
Jan	70.583	62.303	54.184	45.173	32.261	22.852	14.108	7.922	4.790	4.068
Feb	146.798	122.512	100.934	79.747	51.969	36.569	24.104	16.465	13.024	12.277
Mar	143.662	138.431	127.394	108.778	83.896	57.826	36.723	23.790	17.966	16.700
Apr	42.016	40.453	37.157	31.597	24.165	16.379	10.077	6.214	4.475	4.096
May	29.914	29.105	27.412	24.443	20.141	15.084	10.384	7.060	5.376	4.988
Jun	21.732	21.280	20.353	18.682	16.081	12.663	8.987	5.908	4.077	3.613
Jul	16.449	16.194	15.686	14.760	13.236	11.012	8.233	5.417	3.339	2.726
Aug	15.297	15.125	14.799	14.207	13.195	11.581	9.251	6.340	3.510	2.438
Sep	12.402	12.289	12.088	11.734	11.119	10.076	8.364	5.720	2.113	0.000

Reserve flows without High Flows

Oct	18.927	18.675	18.198	17.333	15.852	13.492	10.084	5.827	1.688	0.000
Nov	26.382	25.894	24.924	23.156	20.243	15.995	10.687	5.307	1.337	0.000
Dec	29.357	28.684	27.304	24.819	20.951	15.867	10.397	5.819	3.094	2.405
Jan	36.161	35.070	32.786	28.781	22.976	16.154	9.814	5.328	3.057	2.533
Feb	48.810	47.134	43.598	37.634	29.663	21.311	14.550	10.406	8.541	8.135
Mar	48.782	47.107	43.571	37.609	29.639	21.289	14.529	10.387	8.521	8.116
Apr	42.016	40.453	37.157	31.597	24.165	16.379	10.077	6.214	4.475	4.096
May	29.914	29.105	27.412	24.443	20.141	15.084	10.384	7.060	5.376	4.988
Jun	21.732	21.280	20.353	18.682	16.081	12.663	8.987	5.908	4.077	3.613
Jul	16.449	16.194	15.686	14.760	13.236	11.012	8.233	5.417	3.339	2.726
Aug	15.297	15.125	14.799	14.207	13.195	11.581	9.251	6.340	3.510	2.438
Sep	12.402	12.289	12.088	11.734	11.119	10.076	8.364	5.720	2.113	0.000

Natural Duration curves

Oct	617.290	332.064	230.880	156.915	96.778	68.504	49.507	27.274	11.092	0.000
Nov	905.096	654.931	482.554	354.171	236.273	209.336	152.365	119.425	40.860	0.000
Dec	1002.860	704.824	522.461	396.565	321.263	280.369	194.437	95.456	63.937	4.734
Jan	1252.087	913.206	628.491	503.655	376.613	288.986	208.748	153.655	77.326	24.190
Feb	2063.864	1293.461	898.313	539.790	424.611	305.035	260.007	213.802	119.444	29.882
Mar	1577.203	1023.167	701.430	596.027	472.200	331.343	242.742	190.181	116.629	31.851
Apr	906.879	629.217	411.092	322.631	281.034	241.238	171.188	117.909	67.948	21.323
May	352.830	259.244	192.753	127.412	104.600	78.995	66.577	42.641	28.902	5.619
Jun	188.345	136.535	87.346	72.380	58.627	51.979	39.182	30.687	18.326	9.340
Jul	144.710	97.420	86.962	63.045	43.037	34.353	28.491	22.073	14.490	10.215
Aug	145.128	108.639	79.648	58.830	44.194	30.727	21.408	16.637	11.036	5.238
Sep	218.835	114.934	75.656	54.063	38.171	28.546	20.455	10.683	2.218	0.000

Table 5.10 EWR O4: Assurance rules for REC: B/C

Desktop Version 2, Printed on 2010/11/05
Summary of EWR rule curves for: EWRO4 Natural Flows
Determination based on defined BBM Table with site specific assurance rules.
Regional Type: Vaal REC = B/C

Data are given in m^3/s mean monthly flow

% Points

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	31.766	31.447	30.704	29.141	26.200	21.373	14.701	7.399	1.800	0.000
Nov	74.473	69.078	63.966	58.310	48.043	39.468	27.617	14.645	4.699	0.000
Dec	86.512	77.922	69.818	60.962	46.615	35.624	23.222	12.514	6.096	4.514
Jan	85.724	78.848	71.898	63.615	50.112	38.119	24.586	12.902	5.899	4.173
Feb	163.354	142.077	122.406	102.019	72.867	54.170	36.795	24.502	18.278	16.843
Mar	161.737	157.177	147.634	130.898	106.645	78.140	51.650	32.909	23.419	21.231
Apr	61.069	59.224	55.363	48.591	38.778	27.243	16.525	8.942	5.102	4.217
May	44.994	44.266	42.629	39.424	34.059	26.559	18.097	10.790	6.411	5.332
Jun	34.071	33.550	32.377	30.081	26.237	20.865	14.802	9.568	6.431	5.658
Jul	29.066	28.816	28.233	27.005	24.697	20.908	15.672	9.940	5.546	4.289
Aug	26.878	26.632	26.059	24.852	22.582	18.855	13.705	8.068	3.746	2.509
Sep	26.715	26.506	26.061	25.162	23.454	20.449	15.694	9.267	2.218	0.000

Reserve flows without High Flows

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	31.766	31.447	30.704	29.141	26.200	21.373	14.701	7.399	1.800	0.000
Nov	42.999	42.567	41.562	39.445	35.465	28.930	19.900	10.015	2.437	0.000
Dec	43.684	42.929	41.228	37.900	32.328	24.540	15.750	8.162	3.614	2.493
Jan	53.204	52.277	50.189	46.103	39.263	29.702	18.913	9.597	4.015	2.639
Feb	70.452	68.578	64.656	57.777	47.808	36.092	25.204	17.501	13.601	12.701
Mar	69.789	67.935	64.055	57.251	47.392	35.803	25.034	17.415	13.557	12.667
Apr	61.069	59.224	55.363	48.591	38.778	27.243	16.525	8.942	5.102	4.217
May	44.994	44.266	42.629	39.424	34.059	26.559	18.097	10.790	6.411	5.332
Jun	34.071	33.550	32.377	30.081	26.237	20.865	14.802	9.568	6.431	5.658
Jul	29.066	28.816	28.233	27.005	24.697	20.908	15.672	9.940	5.546	4.289
Aug	26.878	26.632	26.059	24.852	22.582	18.855	13.705	8.068	3.746	2.509
Sep	26.715	26.506	26.061	25.162	23.454	20.449	15.694	9.267	2.218	0.000

Natural Duration curves

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	617.290	332.064	230.880	156.915	96.778	68.504	49.507	27.274	11.092	0.000
Nov	905.096	654.931	482.554	354.171	236.273	209.336	152.365	119.425	40.860	0.000
Dec	1002.860	704.824	522.461	396.565	321.263	280.369	194.437	95.456	63.937	4.734
Jan	1252.087	913.206	628.491	503.655	376.613	288.986	208.748	153.655	77.326	24.190
Feb	2063.864	1293.461	898.313	539.790	424.611	305.035	260.007	213.802	119.444	29.882
Mar	1577.203	1023.167	701.430	596.027	472.200	331.343	242.742	190.181	116.629	31.851
Apr	906.879	629.217	411.092	322.631	281.034	241.238	171.188	117.909	67.948	21.323
May	352.830	259.244	192.753	127.412	104.600	78.995	66.577	42.641	28.902	5.619
Jun	188.345	136.535	87.346	72.380	58.627	51.979	39.182	30.687	18.326	9.340
Jul	144.710	97.420	86.962	63.045	43.037	34.353	28.491	22.073	14.490	10.215
Aug	145.128	108.639	79.648	58.830	44.194	30.727	21.408	16.637	11.036	5.238
Sep	218.835	114.934	75.656	54.063	38.171	28.546	20.455	10.683	2.218	0.000

5.2.4 EWR O5 (Sendelingsdrift): EWR results

After combining low and high flows, the final flow requirements for each EC consist of:

- An EWR table, which shows the results for each month for high flows and low flows separately (Table 5.11 – 5.12). Modelled results exclude high frequency floods, as they are unmanageable.
- An EWR rule table which provides the recommended EWR flows as a duration table, linked to a natural trigger (natural modelled hydrology in this case). Supplied EWR rules are for total flows as well as for low flows only (Table 5.13 – 5.14).

The low flow EWR rule table is used for the operation of low flows, whereas the EWR table is used for the operation of high flows.

Table 5.11 EWR O5: EWR table for PES: B/C

Desktop version:		2	Virgin MAR (Mm³)	11 373
BFI	0.301	Distribution type		Vaal
MONTH	LOW FLOWS		HIGH FLOWS	
	Maintenance (m³/s)	Drought (m³/s)	Daily average (m³/s) on top of base flow	Duration (days)
October	13.1	2.1		
November	18.4	2.9	190	7
December	21.5	3.4	60 190	5 7
January	29.4	4.6	60 190	5 7
February	43.0	6.7	60 300	5 10
March	40.4	6.3	60 500	5 12
April	35.8	5.6		
May	25.08	3.9		
June	16.8	2.7		
July	12.1	1.9		
August	10.6	1.7		
September	10.1	0		
Total Mm³	721.63	109.42	512.85	
% of natural MAR	6.35	0.96	4.51	
Total EWR	1234.48			
% of natural MAR	10.85			

Table 5.12 EWR O5: EWR table for REC: B

Desktop version:		2	Virgin MAR (Mm³)	11373
BFI	0.301	Distribution type		Vaal
MONTH	LOW FLOWS		HIGH FLOWS	
	Maintenance (m³/s)	Drought (m³/s)	Daily average (m³/s) on top of base flow	Duration (days)
October	22.9	2.6		
November	30.5	3.3	190	7
December	34.5	4.5	60 190	5 7
January	45.7	5.9	60 190	5 7
February	65.1	10.0	60 300	5 10
March	61.0	9.4	60 500	5 12
April	54.6	6.2		
May	39.5	5.9		
June	28.2	4.0		
July	21.4	2.9		
August	19.3	2.6		
September	18.8	0		
Total Mm³	1154.46	149.64	512.85	
% of natural MAR	10.15	1.32	4.51	
Total EWR	1667.32			

Desktop version:		2	Virgin MAR (Mm^3)	11373
BFI	0.301	Distribution type		Vaal
MONTH	LOW FLOWS		HIGH FLOWS	
	Maintenance (m^3/s)	Drought (m^3/s)	Daily average (m^3/s) on top of base flow	Duration (days)
% of natural MAR	14.66			

Table 5.13 EWR O5: Assurance rules for PES: B/C

Desktop Version 2, Printed on 2013/02/05 Regional Type: Vaal PES = B/C
Data are given in m3/s mean monthly flow

Reserve flows

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	19.455	19.247	18.863	18.183	17.035	15.214	12.547	9.063	5.254	2.508
Nov	65.21	58.599	52.641	46.787	36.789	31.191	23.927	15.97	9.113	3.306
Dec	80.362	70.539	61.798	53.229	39.833	31.95	22.964	14.652	8.788	6.131
Jan	94.095	82.061	71.105	59.937	43.81	33.27	22.723	14.369	9.357	7.347
Feb	178.144	149.066	123.701	99.227	66.656	48.078	31.695	20.386	14.41	12.192
Mar	156.519	150.135	136.824	115.102	87.354	59.606	37.884	24.573	18.189	15.927
Apr	49.497	47.902	44.586	38.953	31.184	22.568	14.97	9.725	6.954	5.924
May	34.954	34.064	32.237	29.037	24.307	18.497	12.683	8.078	5.316	4.208
Jun	23.824	23.355	22.416	20.741	18.113	14.555	10.5	6.749	4.102	2.903
Jul	17.399	17.143	16.646	15.756	14.295	12.136	9.334	6.265	3.621	2.175
Aug	15.684	15.516	15.207	14.659	13.735	12.269	10.123	7.317	4.251	2.041
Sep	12.512	12.409	12.23	11.922	11.402	10.536	9.134	5.883	2.188	0.555

Reserve flows without High Flows

Oct	19.455	19.247	18.863	18.183	17.035	15.214	12.547	9.063	5.254	2.508
Nov	26.58	26.188	25.428	24.065	21.828	18.522	14.234	9.536	5.487	3.273
Dec	30.461	29.861	28.659	26.515	23.151	18.597	13.405	8.603	5.216	3.68
Jan	41.14	40.092	37.941	34.172	28.603	21.761	14.916	9.493	6.24	4.935
Feb	59.566	57.645	53.654	46.873	37.522	27.15	18.004	11.691	8.355	7.116
Mar	55.434	53.218	48.599	41.062	31.433	21.804	14.267	9.648	7.432	6.648
Apr	49.497	47.902	44.586	38.953	31.184	22.568	14.97	9.725	6.954	5.924
May	34.954	34.064	32.237	29.037	24.307	18.497	12.683	8.078	5.316	4.208
Jun	23.824	23.355	22.416	20.741	18.113	14.555	10.5	6.749	4.102	2.903
Jul	17.399	17.143	16.646	15.756	14.295	12.136	9.334	6.265	3.621	2.175
Aug	15.684	15.516	15.207	14.659	13.735	12.269	10.123	7.317	4.251	2.041
Sep	12.512	12.409	12.23	11.922	11.402	10.536	9.134	5.883	2.188	0.555

Natural Duration curves

Oct	706.187	309.569	217.611	156.519	98.212	64.191	44.605	22.252	10.749	2.595
Nov	805.208	601.728	474.263	354.198	245.224	191.331	158.225	114.363	37.176	3.306
Dec	994.388	659.939	506.724	396.744	317.003	284.468	223.029	87.582	49.231	21.001
Jan	1403.872	1016.473	786.376	510.682	382.09	257.68	208.964	130.974	72.405	28.129
Feb	2300.566	1709.974	1229.638	824.417	482.684	362.913	285.189	211.959	132.593	25.765
Mar	1869.067	1069.474	744.004	656.25	538.777	350.317	277.666	203.409	148.309	42.832
Apr	962.813	876.034	474.672	353.646	302.431	247.5	193.769	146.231	100.536	26.424
May	367.182	276.96	220.154	157.672	118.492	107.116	79.025	48.596	30.597	6.803
Jun	186.485	141.049	92.886	72.184	57.681	54.414	45.71	30.077	17.662	7.928
Jul	147.991	100.553	80.276	59.054	41.237	33.819	28.342	21.39	14.639	10.055
Aug	158.065	112.351	82.131	53.566	34.476	24.739	20.845	17.365	12.227	7.781
Sep	213.492	130.305	73.453	52.558	37.681	24.41	14.892	5.883	2.188	2.033

Table 5.14 EWR O5: Assurance rules for REC: B

Desktop Version 2, Printed on 2013/02/05 Regional Type: Vaal REC = B
Data are given in m3/s mean monthly flow

%Points

Reserve flows

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	35.029	34.703	33.945	32.348	29.346	24.417	17.605	10.149	4.433	2.595
Nov	82.375	75.887	69.985	63.895	52.943	45.132	34.106	21.411	10.558	3.306
Dec	98.92	89.011	79.852	70.14	54.426	42.912	29.59	17.562	9.761	7.119
Jan	110.193	100.083	90.458	79.82	62.561	48.939	33.367	19.61	11.021	8.511
Feb	197.552	171.659	147.54	122.307	86.217	62.628	40.706	25.197	17.344	15.534
Mar	161.171	153.882	138.537	113.892	83.701	55.485	35.368	24.428	19.891	18.947
Apr	71.412	69.309	64.908	57.189	46.005	32.858	20.642	11.999	7.622	6.613
May	52.044	51.22	49.379	45.787	39.768	31.305	21.63	13.082	7.746	6.186
Jun	39.877	39.25	37.858	35.15	30.611	24.191	16.764	10.058	5.709	4.235
Jul	30.665	30.401	29.8	28.559	26.244	22.432	17.051	10.856	5.559	3.096
Aug	29.593	29.322	28.69	27.36	24.859	20.754	15.08	8.87	4.109	2.747
Sep	30.715	30.575	29.966	28.505	25.455	20.092	12.551	4.848	0.192	0.192

Reserve flows without High Flows

Oct	35.029	34.703	33.945	32.348	29.346	24.417	17.605	10.149	4.433	2.595
Nov	43.614	43.229	42.357	40.553	37.19	31.651	23.833	14.832	7.137	3.306
Dec	48.908	48.131	46.407	43.053	37.43	29.478	20.278	11.972	6.584	4.759
Jan	60.182	59.212	57.043	52.81	45.719	35.746	24.347	14.276	7.988	6.151
Feb	85.176	82.754	77.684	68.791	55.906	40.76	26.686	16.729	11.687	10.524
Mar	69.877	66.8	60.319	49.912	37.162	25.247	16.752	12.132	10.216	9.817
Apr	71.412	69.309	64.908	57.189	46.005	32.858	20.642	11.999	7.622	6.613
May	52.044	51.22	49.379	45.787	39.768	31.305	21.63	13.082	7.746	6.186
Jun	39.877	39.25	37.858	35.15	30.611	24.191	16.764	10.058	5.709	4.235
Jul	30.665	30.401	29.8	28.559	26.244	22.432	17.051	10.856	5.559	3.096
Aug	29.593	29.322	28.69	27.36	24.859	20.754	15.08	8.87	4.109	2.747
Sep	30.715	30.575	29.966	28.505	25.455	20.092	12.551	4.848	0.192	0.192

Natural Duration curves

Oct	706.187	309.569	217.611	156.519	98.212	64.191	44.605	22.252	10.749	2.595
Nov	805.208	601.728	474.263	354.198	245.224	191.331	158.225	114.363	37.176	3.306
Dec	994.388	659.939	506.724	396.744	317.003	284.468	223.029	87.582	49.231	21.001
Jan	403.872	16.473	786.376	510.682	382.09	257.68	208.964	130.974	72.405	28.129
Feb	300.566	709.974	229.638	824.417	482.684	362.913	285.189	211.959	132.593	25.765
Mar	869.067	69.474	744.004	656.25	538.777	350.317	277.666	203.409	148.309	42.832
Apr	962.813	876.034	474.672	353.646	302.431	247.5	193.769	146.231	100.536	26.424
May	367.182	276.96	220.154	157.672	118.492	107.116	79.025	48.596	30.597	6.803
Jun	186.485	141.049	92.886	72.184	57.681	54.414	45.71	30.077	17.662	7.928
Jul	147.991	100.553	80.276	59.054	41.237	33.819	28.342	21.39	14.639	10.055
Aug	158.065	112.351	82.131	53.566	34.476	24.739	20.845	17.365	12.227	7.781
Sep	213.492	130.305	73.453	52.558	37.681	24.41	14.892	5.883	2.188	2.033

5.3 EWR RESULT SUMMARY

Table 5.15 provides the final flow requirements, expressed as a percentage of the natural MAR (nMAR).

Table 5.15 Summary of EWR results as a percentage of the natural MAR

Site	EC	Maintenance low flows		Drought low flows		High flows		Long-term mean	
		(%nMAR)	Mm^3	(%nMAR)	Mm^3	(%nMAR)	Mm^3	(% nMAR)	Mm^3
EWR O2	PES/REC	11.6	1226.55	4.4	465.24	5.4	570.98	15.2	1607.20
EWR O3	PES: C	8.4	883.10	2.6	273.34	4.7	494.12	11.9	1251.06
	REC: B	17.6	1850.31	3.4	157.37	4.7	494.12	19.2	2018.52
EWR O4	PES: C	6.3	651.11	0.9	35.16	4.2	434.07	8.9	919.82
	REC: B/C	10.1	1043.85	1.3	134.36	4.2	434.07	12.2	1260.88
EWR O5	PES: B/C	6.35	721.63	0.96	109.42	4.51	512.85	10.85	1234.48
	REC: B	10.15	1154.46	1.32	149.64	4.51	512.85	14.66	1667.32

5.4 CONFIDENCE IN THE EWR RESULTS

The overall confidence in the results is linked to the confidence in the hydrology and hydraulics as the hydrology provides the check and balance of the results and the hydraulics convert the requirements in terms of hydraulic parameters to flow. Therefore, the following rationale is applied when determining the overall confidence:

- If the hydraulics confidence is lower than the biological responses column, the hydraulics confidence becomes the overall confidence. Hydrology confidence is considered, especially if used to guide the requirements.
- If the biological confidence is lower than the hydraulics confidence, the biological confidence becomes the overall confidence. Hydrology confidence is also considered. If the hydrology guided requirements, then this confidence will be overriding.

The confidence score is based on a scale of 0 - 5 and colour coded where:

0–1.9: Low 2–3.4: Moderate 3.5–5: High

Table 5.16 Overall Confidence in EWR results

Site	Hydrology	Biological responses: Low flows	Hydraulic: Low flows	OVERALL: LOW FLOWS	Comment	Biophysical responses: High flows	Hydraulics: High flows	OVERALL: HIGH FLOWS	Comment
EWR O2	3.5	2.7	2.5	**2.5**	Hydraulic confidence is not high as the measured flows were all higher than the flows required.	3.3	5	**3.3**	Even though the hydraulics confidence was high, the biophysical response was moderate and that became the overall confidence.
EWR O3	2	3	2	**2**	See above for hydraulic confidence. As the hydraulic confidence was lower than the biological responses, this became the overall confidence.	3.5	5	**3.5**	Even though the hydraulics confidence was high, the biophysical response was lower (although still high) and that became the overall confidence.
EWR O4	2.6	3	2.5	**2.5**	See above.	2.8	5	**2.8**	Even though the hydraulics confidence was high, the biophysical responses were moderate and that became the overall confidence.

Site	Hydrology	Biological responses: Low flows	Hydraulic: Low flows	OVERALL: LOW FLOWS	Comment	Biophysical responses: High flows	Hydraulics: High flows	OVERALL: HIGH FLOWS	Comment
EWR O5	2.8	3.5	3	**3**	The hydraulic and biological confidences are both high.	3.5	3	**3**	The hydraulic and biophysical confidences are both moderate.

6 DESKTOP BIOPHYSICAL NODES: EWR ASSESSMENT

This chapter is summarised from: (DWS, 2016b)
Department of Water and Sanitation, South Africa, August 2016. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. River EWR report. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. Authored by Louw D, Birkhead D, Koekemoer S, Mare M. DWS Report No: RDM/WMA06/00/CON/COMP/0216

6.1 SCALE

The SQs river reaches as indicated in http://www.dwa.gov.za/iwqs/gis_data/river/rivs500k.html and http://www.dwa.gov.za/iwqs/gis_data/river/River_Report_01.pdf, forms the basis of the national PESEIS study (DWS, 2014a). A SQ changes when a significant tributary joins it. This means that a SQ may potentially be subdivided into various EcoRegions, geomorphic zones (slope zones) resource units (natural or management), etc. Such subdivisions are not addressed at desktop level, and may be required when higher confidence assessments are done. The version of the 1:500 000 coverage that was used for the PESEIS 2012 study (DWS, 2014b), was a version used by the National Freshwater Ecosystem Priority Areas (NFEPA) project in 2009 (Nel *et al*., 2011).

Desktop EWRs are usually assessed at SQ scale and for purposes of the Reserve study, the EWRs are assessed at the end of the quaternary catchment in the main river of the quaternary catchment. The reason for this is the following:

- During the PESEIS 2012 study (DWS, 2014b), many SQs were not assessed.
- Due to these gaps, reliance was placed on the 2010 EWR study (Louw and Koekemoer, 2010) that was undertaken at a quaternary catchment scale.
- The SQs other than the main river in the quaternary catchment are even more likely to be ephemeral in nature and results in the increasing problematic application of the EWR desktop models.

The node names correspond to the SQ in which they occur (see Table 6.1).

6.2 DESKTOP BIOPHYSICAL NODES

A desktop biophysical node represents a point at the end of the SQ or in this case, the SQ in the main river at the end of the quaternary catchment. These desktop biophysical nodes are represented in Figures 6.1 to 6.3 and also include the PES results. Note that the names of the desktop biophysical nodes relate to the SQ name in which they are situated. The EWRs provided are for the node and represents all the SQs in the main river of the quaternary catchment.

6.3 DESKTOP ECOCLASSIFICATION

The PES of the 2010 EWR study (Louw and Koekemoer, 2010) was used as a starting point for the quaternary catchments and compared to the PESEIS 2012 study (DWS, 2014b) (specifically the SQ in the main river at the end of the quaternary catchment). Where there were differences, a Google Earth assessment was undertaken, and the PES of SQs located upstream of the biophysical node in the main river considered and motivated decision made. Results for the nodes within the F primary catchment were only available from the PESEIS 2012 study (DWS, 2014b). As these results were at SQ level, all SQ results of the main river in the quaternary catchments were considered during the determination of the PES.

The Ecological Importance (EI) component of the national PESEIS study (DWS, 2014a) was used[6] to assess whether the REC should be improved. In cases where the importance (EI) is high or very high, an improved REC is recommended. The estimated EWR is linked to the REC and these results are provided in the following chapter. It must, however, be noted that if the REC is not based on an improved flow regime, the EWR for the PES is used. Information on the requirements needed to achieve the REC and the attainability there-of is supplied in Table 6.1.

Table 6.1 summarises the EcoClassification results used in this study, based on both the 2010 EWR (Louw and Koekemoer, 2010) and the PESEIS 2012 (DWS, 2014b) assessment and forms the basis for the EWR estimation. Table 6.2 lists the nodes that require improvement and the associated issues that will have to be addressed. For additional information, please refer to Appendix A (DWS, 2016b), which provides the same information as Table 6.1. but includes the coordinates of the nodes and a comment on the summary comparison between the results of the 2010 EWR study (Louw and Koekemoer, 2010) and the national PESEIS study (DWS, 2014b).

The columns of Table 6.1 refer to:

- Column 1: SQ number (Biophysical node name).
- Column 2: 2010 node name (quaternary catchment). Note these names are not included for the F catchments as this did not form part of the PESEIS 2010 assessment. The associated quats can be seen in Appendix A.
- Column 3: River name where available.
- Column 4: PES according to the results of the 2010 EWR study (Louw and Koekemoer, 2010) compared to the national PESEIS study (DWS, 2014a). As the 2010 EWR study excluded the F catchment, results were taken from the PESEIS 2012 study (DWS, 2014b).
- Column 5: EI according to the results of the national PESEIS study (DWS, 2014a). Only High or Very High evaluation is indicated as it is immaterial whether it is Low or Moderate.
- Column 6: REC generated during this study and documented in this report. If the RDRM (Hughes *et al*., 2012; Hughes *et al*., 2014) results are different from the REC (i.e. improvements required to achieve the REC other than increased flows), the RDRM EC is provided in brackets.

Table 6.1 Desktop biophysical nodes: EcoClassification summary results (PESEIS 2012 - DWS, 2014b)

1	2	3	4	5	6
Biophysical Node name	**2010 place name**	**River**	**PES**	**EI**	**REC (RDRM)**
Molopo River					
D42A-01082	D42A (910)	Nossob	**B**	**High**	**B**
D42D-02283	D42D	Molopo River	**B/C**		**B/C**
D42E-03047	D42D	Molopo River	**C**		**C**
Vis, Sak and Hartbees Rivers					
D51B-07208	D51B	Renoster River: Onderplaas to Sterkfontein	**B/C**		**B/C**
D51B-06782	D51C	Renoster River	**B/C**		**B/C**
D51C-06594	D51C	Renoster River	**B/C**		**B/C**
D52A-07274	D52A	Vis	**D**		**D**
D52C-06920	D52C	Vis	**C/D**		**C/D**

[6] The Ecological Sensitivity component was not used as it is only an indication of sensitivity to biota to flow and water quality changes. Sensitivity to flow changes may not require improved flows. Furthermore, species sensitive to flow cannot be a motivation for non-flow related changes. Discussion with DWS: RQIS, supported this approach.

1	2	3	4	5	6
Biophysical Node name	**2010 place name**	**River**	**PES**	**EI**	**REC (RDRM)**
D52E-06758	D52C/E	Vis	C/D		C/D
D52D-06761	D52D	Muiskraal	C		C
D52F-06591	D52E	Vis	D		D
D52F-06306	D52F	Vis	C		C
D53A-04197	D53A	Hartbees[7]	B		B
D53B-04104	D53B	Hartbees	D		D
D53C-03807	D53C	Hartbees: Kenhardt to Tuins River confluence	B		B
D53D-03879	D53D	Tuins	A/B		A/B
D53E-03557	D53E	Hartbees: Tuins to Sout River confluence	A/B		A/B
D53H-03564	D53H	Sout	A		A
D53J-03408	D53J	Hartbees	B		B
D54B-05160	D54A	Holsloot	B		B
D54D-04896	D54B	Carnaveronleegte	C		C
D54D-04630	D54D	Carnaveronleegte	C		C
D54F-05004	D54E	Botterslaagte	B		B
D54F-04645	D54F	Verneukpan	B		B
D54G-04407	D54G	Hartbeespoort	B		B
D55B-06707	D55A	Sak River	C		C
D55B-06615	D55B	Sak River	C		C
D55D-06429	D55C	Brak River	B		B
D55D-06524	D55D	Brak River	B		B
D55E-06496	D55E	Brak River	B/C		B/C
D55F-06209	D55F	Gansvlei River	C		C
D55G-06308	D55G	Gansvlei River	C		C
D55J-06243	D55H	Sak River	B		B
D55J-06180	D55J	Sak River	B/C		B/C
D55K-06347	D55K	Klein Sak	B		B
D55L-06115	D55L	Sak River	C		C
D55M-05697	D55M	Sak River	B/C		B/C
D56A-07453	D56A	Portugals R	B/C		B/C
D56B-07428	D56B	Riet River	B		B
D56D-07091	D56C	Portugals R	B		B
D56D-06822	D56D	Portugals R	B		B
D56F-07144	D56E	Klein Riet	B		
D56G-06932	D56F	Klein Riet	B		B
D56G-06753	D56G	Klein Riet	B		B
D56J-06649	D56H	Riet	B		B
D56J-06522	D56J	Riet	B/C		B/C
D57A-05387	D57A	Sak River	C		C
D57B-05325	D57B	Soutloot	B/C		B/C
D57C-05254	D57C	Sak	C		C
D57E-04534	D57D	Sak	B		B

[7]No EWR to be estimated for this node as it is situated immediately DS of a large dam with no outlet capacities.

1	2	3	4	5	6
Biophysical Node name	**2010 place name**	**River**	**PES**	**EI**	**REC (RDRM)**
D57E-04374	D57E	Sak	B		B
D58A-06302	D58A	Vis	C		C
D58C-05932	D58B	Vis	C		C
D58C-05390	D58C	Vis	C		C
Brak Ongers River					
D61A-06062	D61A	Laken	C		C
D61B-05841	D61B	Laken tributary	C		C
D61C-05866	D61C	Laken	C		C
D61D-06156	D61D	Brakpoort	B		B
D61E-06164	D61E	Brak	C		C
D61G-06223	D61F	Klein Brak	C		C
D61H-05960	D61G	Klein Brak	C		C
D61H-05865	D61H	Brak	B/C		B/C
D61J-05654	D61J	Groen	B		B
D61K-05388	D61K	Groen	B		B
D61L-05453	D61L	Perdepoortsleegte	B		B
D61M-05343	D61M	Ongers	C		C
D62A-05078	D62A	Ongers	C		C
D62B-04701	D62B	Ongers	B/C		B/C
D62C-05303	D62C	Elandsfontein	B/C		B/C
D62D-05183	D62D	Brak	B/C		B/C
D62G-04755	D62E	Brak	B		B
D62G-04703	D62G	Brak	A/B		A/B
D62J-04231	D62J	Ongers	B/C	High	B (B/C)
D71B-03620	D71B	Orange tributary	B		B
Small West coast rivers					
F10B-03391		Holgat	B	High	B
F20E-04290		Kwaganap	C	High	B (C)
F30A-04782		Buffels	B		B
F30B-04742		Brak	B		B
F30C-04823		Buffels	B		B
F30D-04598		Buffels	B		B
F30E-04444		Skaap	B		B
F30G-04539		Buffles	B/C		B/C
F40B-04917		WildeperdehoekseBrak	B		B
F40C-05007		Swartlintjies	B		B
F40D-04789		Swartlintjies	B		B
F40F-05159		Spoeg	B		B
F40G-05320		Bitter	C	High	B (C)
F40H-05480		Bitter	D		D
F50A-05626		Hartbees	C		C
F50B-05636		Swart-Doring	B		B
F50C-05764		Swart-Doring	B		B

1	2	3	4	5	6
Biophysical Node name	**2010 place name**	**River**	**PES**	**EI**	**REC (RDRM)**
F50D-05726		Swart-Doring	B		B
F50F-05560		Groen	B/C		B/C
F50G-05620		Groen	B		B
F60A-05886		Brak	B		B
F60C-06147		Sout	B		B
F60D-06231		Sout	B		B

Table 6.2 Aspects to be addressed to achieve the REC improvement

Biophysical Node name	River	PES	EI	REC	Improvements
D42A-01082	Nossob	B	High	B	None required as the PES already a B state.
D62J-04231	Ongers	B/C	High	B	Livestock, roads and crossings, irrigation in lower reach - from Orange River.
F10B-03391	Holgat	B	High	B	None required as the PES already a B state.
F20E-04290	Kwaganap	B/C	High	B	Roads and crossings, livestock, lower reach rivers do not exist due to mining activities, estuary.
F40G-05320	Bitter	C	High	B	Roads and crossings, dryland agriculture.

Desktop EcoClassification results are presented in Figures 6.1 to 6.3.

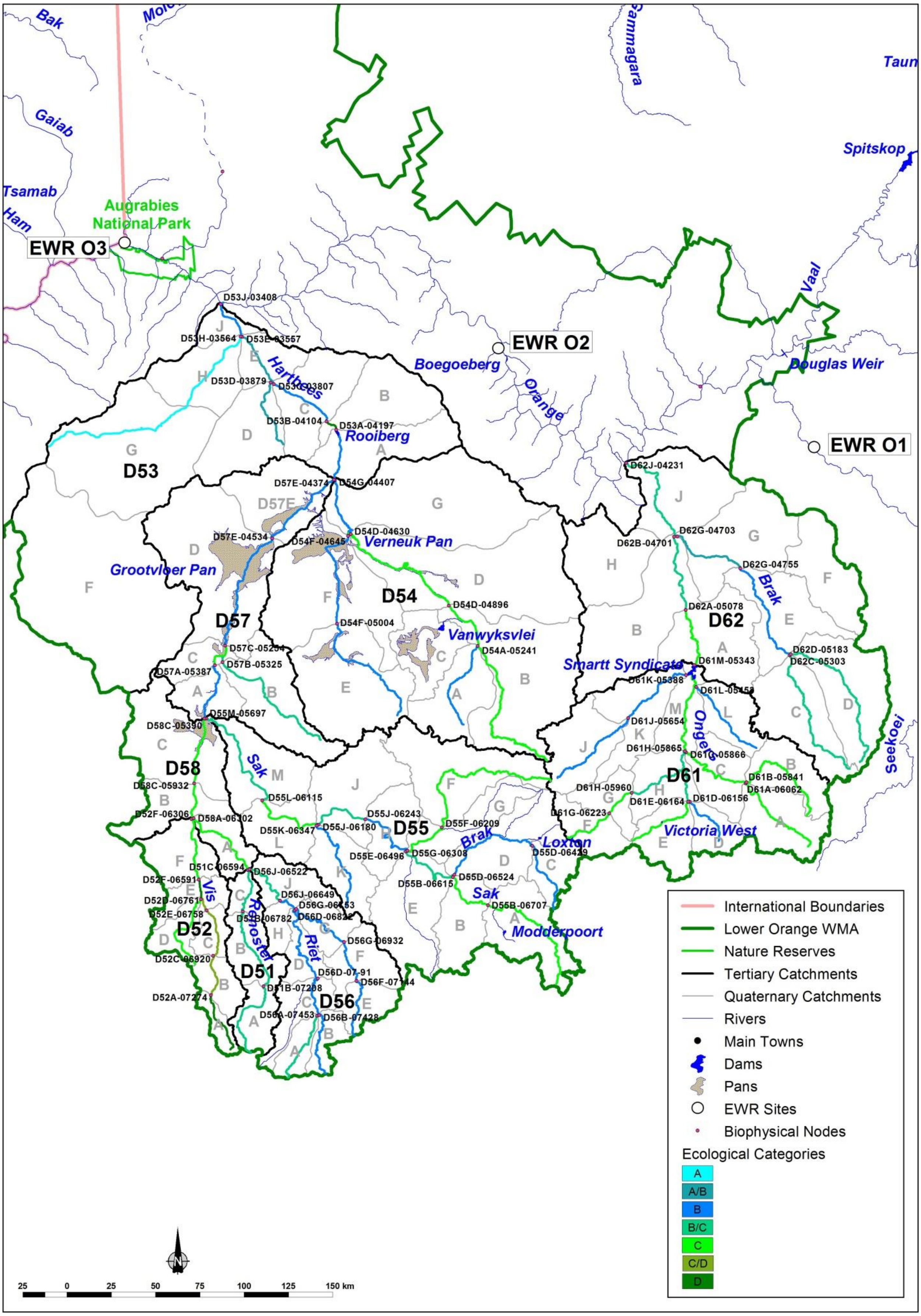


Figure 6.1 The location of the desktop biophysical nodes located in tertiary catchments D5 and D6, and the associated EcoClassification results

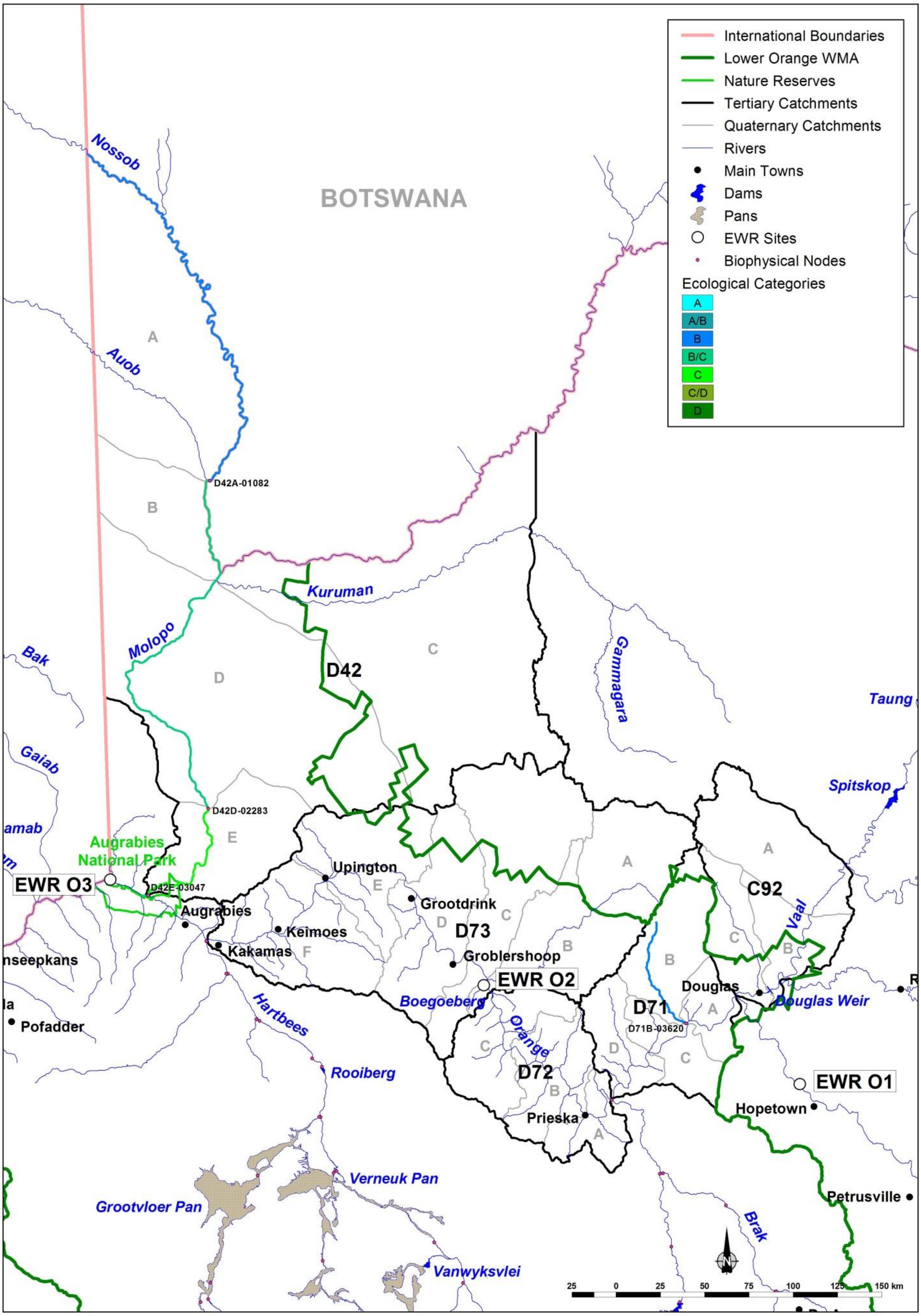


Figure 6.2 The location of the desktop biophysical nodes located in tertiary catchments D7 and D42, and the associated EcoClassification results

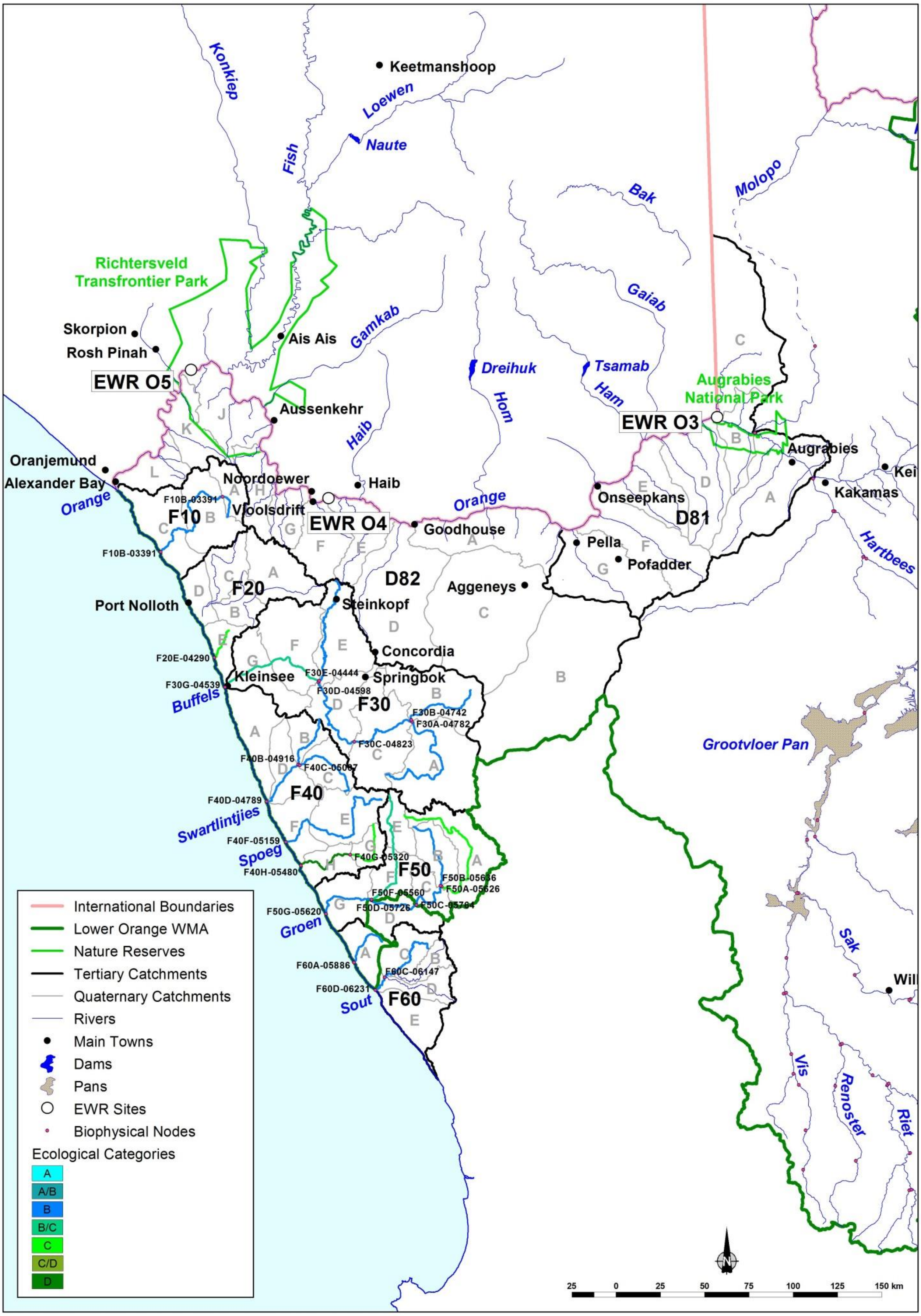


Figure 6.3 The location of the desktop biophysical nodes located in tertiary catchments F and D8, and the associated EcoClassification results

6.4 EWR ESTIMATION BACKGROUND

The DRM of Hughes and Hannart (2003) has been extensively used over the last decade for estimating EWRs in this and other countries. The DRM is used in this study, rather than the RDRM version (refer to Hughes *et al*., 2012; Hughes *et al*., 2014) for the following reason: The "lower Orange" hydrology is largely characterised by high flows with very little base flow contribution. The RDRM's high flow component is considered insufficiently developed and tested for these types of systems, as is its functionality when there is no ecologically-based low flow requirement. These, and other considerations, are being addressed in an existing Water Research Commission (WRC)/DWS project. Therefore, the stand-alone version of the DRM was used for this study.

6.5 APPROACH

The quaternary catchments requiring Desktop EWR assessments were provided by Rivers for Africa, together with the PES and REC. So-called 'nodes' were located at the quaternary catchment outlets and are labelled using SQ NFEPA[8] codes. WRP Consulting Engineers provided Naturalised and Present Day (PD) monthly hydrological time-series for the period 1920 - 2004.

Desktop EWRs are provided for 91 of the 99 desktop nodes identified. None of the desktop biophysical nodes have an improved REC relative to the PES, and thus requirements are constrained to PD flows (i.e. there is no improvement in the PES through hydrology).

6.6 RESULTS

The EWR results are provided in the following formats as text files named according to the biophysical node:

- Time-series of average monthly EWR flow requirements (in 10^6 m^3) for the period 1920 to 2004.
- Assurance rules for EWR total flows (in 10^6 m^3).

A summary of the total flow requirements, including naturalised and PD runoff is provided in Table 6.3. As mentioned previously, these catchments have highly variable temporal flow distributions, largely characterised by high flows with low baseflow contributions. Consequently, the use of MAR is somewhat misleading, as all flows contribute to MAR, but extreme floods occur infrequently and cannot be deemed to be part of an "average (or mean) year". For this reason, the results are also presented in terms of median annual runoff, which is the annual runoff at the 50th percentile (i.e. half of the annual runoffs are less, and half are higher). Note that when considered in terms of median runoff, the EWR requirements can be substantially higher[9], reflecting the distribution of annual volumes. A further point worth mentioning is that the default DRM high flow rule curve does not increase substantially below the 10th percentile. For these systems, however, a substantial proportion of the high flow volume (naturalised and PD) may occur below at low percentiles[10]. Although these volumes may not be part of the EWR high flow requirement, in the absence of very large storage reservoirs, these large floods are not essentially "manageable", and would occur anyway.

A few results in Table 6.3 require discussion:

- Requirements are not provided for the nodes in the Molopo River system, including the Nossob. The nodes in the Molopo (D42D-02283 and D42E-03047) essentially have no surface flow; the

[8]National Freshwater Ecosystem Priority Areas Project (http://bgis.sanbi.org/nfepa/project.asp). The numerical NFEPA codes are unique to each SQ at a national level.
[9]Up to 40% for certain catchments.
[10]Infrequent high floods.

Nossob (D42A-01082) flows very infrequently under naturalised and PD conditions - only 3.7% of the months have (surface) flows under PD conditions.

- Five nodes (Ongers River: D61M-05343; D62A-05078; D62B-04701; Gansvlei: D55G-06308; and Vis: D58A-06302) have low EWR results. These are due to requirements being constrained to PD hydrology which indicates substantially reduced flows from naturalised conditions for these catchments. By comparison, the unconstrained requirements are: Ongers between 15.3 and 16.7%; Gansvlei 25.0%; and Vis 25.9%, of median naturalised runoffs. There are no justifications for increasing flows above PD conditions.
- Other nodes that have seemingly low requirements are:
  - F10B-03391, which has a very low runoff (mean of 0.064 million m^3 and median of zero) with 66% of the (85-year) volume occurring less than 10% of the time. This implies a strongly ephemeral hydrology, that in the absence of large storage reservoir/s, should remain essentially unchanged;
  - F40H-05480 (8.3% of median) and D53B-04104 Hartbees River, 9.5% of median) which both have a D Category REC.

Table 6.3 Summary of Desktop EWRs for the biophysical nodes in the lower Orange River

Node	River name	Annual Runoff (10^6 m^3)				REC	Long-term EWR requirements			
		Mean		Median			(10^6 m^3)		% Natural	
		Natural	PD	Natural	PD		Mean	Median	Mean	Median
Small Orange River tributary										
D71B-03620		9.862	9.862	3.650	3.650	B	1.540	0.963	15.6	26.4
Brak/Ongers River systems										
D61A-06062	Laken	3.430	3.224	1.280	1.190	C	0.364	0.183	10.6	14.3
D61B-05841	Laken tributary	2.688	2.688	0.980	0.980	C	0.286	0.143	10.6	14.6
D61C-05866	Laken	7.634	7.145	2.800	2.610	C	0.811	0.408	10.6	14.6
D61D-06156	Brakpoort	0.920	0.920	0.310	0.310	B	0.138	0.068	15.0	21.9
D61E-06164	Brak	1.961	1.285	0.430	0.250	C	0.206	0.081	10.5	18.8
D61G-06223	Klein Brak	0.966	0.484	0.180	0.060	C	0.087	0.029	9.0	16.1
D61H-05865	Brak	6.829	5.483	1.670	1.310	B/C	0.893	0.371	13.1	22.2
D61H-05960	Klein Brak	1.996	1.326	0.400	0.220	C	0.208	0.077	10.4	19.3
D61J-05654	Groen	2.122	2.122	0.430	0.430	B	0.324	0.127	15.2	29.5
D61K-05388	Groen	4.826	4.826	1.010	1.010	B	0.736	0.290	15.3	28.7
D61L-05453	Perdepoortsleegte	0.474	0.474	0.170	0.170	B	0.070	0.033	14.8	19.4
D61M-05343	Ongers	22.124	5.015	6.690	0.000	C	0.297	0.000	1.3	na
D62A-05078	Ongers	22.904	5.795	7.180	0.310	C	0.810	0.260	3.5	3.6
D62B-04701	Ongers	23.529	6.420	7.690	0.520	B/C	1.249	0.494	5.3	6.4
D62C-05303	Elandsfontein	4.529	4.529	1.840	1.840	B/C	0.609	0.339	13.5	18.4
D62D-05183	Brak	7.544	7.399	3.190	2.920	B/C	1.013	0.569	13.4	17.8
D62G-04703	Brak	17.366	17.22	7.210	6.850	A/B	3.352	1.959	19.3	27.2
D62G-04755	Brak	16.132	15.98	6.660	6.300	B	2.579	1.452	16.0	21.8
D62J-04231	Ongers	42.331	25.07	17.140	8.050	B	6.225	3.077	14.7	18.0
Vis River system										
D51B-06782	Renoster	13.403	12.62	2.690	2.520	B/C	1.384	0.826	10.3	30.7
D51B-07208	Renoster	6.397	6.025	1.284	1.203	B/C	0.661	0.395	10.3	30.8
D51C-06594	Renoster	14.033	13.25	2.820	2.650	B/C	1.447	0.865	10.3	30.7
D52A-07274	Vis	2.933	2.633	0.435	0.397	D	0.168	0.113	5.7	26.0

Node	River name	Annual Runoff (10^6 m^3)				REC	Long-term EWR requirements			
		Mean		Median			(10^6 m^3)		% Natural	
		Natural	PD	Natural	PD		Mean	Median	Mean	Median
D52C-06920	Vis	8.054	7.312	1.195	1.092	C/D	0.547	0.362	6.8	30.3
D52D-06761	Muiskraal	2.655	2.356	0.393	0.343	C	0.195	0.130	7.3	33.1
D52E-06758	Vis	11.662	10.58	1.730	1.580	C/D	0.791	0.524	6.8	30.3
D52F-06306	Vis	17.337	15.60	2.661	2.409	C	1.387	0.909	8.0	34.2
D52F-06591	Vis	16.852	15.19	2.500	2.250	D	0.940	0.632	5.6	25.3
D56A-07453	Portugals	1.639	1.586	0.314	0.317	B/C	0.178	0.079	10.9	25.2
D56D-06822	Portugals	8.257	7.994	1.585	1.595	B	1.049	0.476	12.7	30.0
D56D-07091	Portugals	6.262	6.062	1.201	1.206	B	0.794	0.360	12.7	30.0
D56G-06753	Klein Riet	3.544	3.432	0.880	0.840	B	0.516	0.297	14.6	33.7
D56G-06932	Klein Riet	2.564	2.483	0.636	0.608	B	0.373	0.214	14.6	33.6
D56J-06522	Riet	13.932	13.33	3.130	3.030	B/C	1.597	0.865	11.5	27.6
D56J-06649	Riet	13.237	12.81	2.950	2.910	B	1.772	0.984	13.4	33.4
D58A-06302	Vis	28.190	21.52	6.450	0.640	C	1.893	0.382	6.7	5.9
D58C-05390	Vis	46.373	37.77	10.330	4.190	C	3.768	1.686	8.1	16.3
D58C-05932	Vis	45.943	37.32	10.278	4.051	C	3.699	1.628	8.1	15.8
Sak River system										
D55B-06615	Sak	4.498	3.357	1.570	1.170	C	0.479	0.235	10.6	15.0
D55B-06707	Sak	2.688	2.007	0.939	0.699	C	0.286	0.141	10.6	15.0
D55D-06429	Brak	1.542	1.317	0.304	0.192	B	0.233	0.095	15.1	31.3
D55D-06524	Brak	5.249	4.482	1.030	0.650	B	0.793	0.325	15.1	31.6
D55E-06496	Brak	11.352	8.892	3.320	2.220	B/C	1.507	0.674	13.3	20.3
D55F-06209	Gansvlei	3.135	3.134	0.552	0.553	C	0.341	0.139	10.9	25.2
D55G-06308	Gansvlei	4.661	3.427	0.820	0.190	C	0.421	0.063	9.0	7.7
D55J-06180	Sak	18.928	15.10	5.140	3.070	B/C	2.479	1.192	13.1	23.2
D55J-06243	Sak	17.079	13.33	4.350	2.637	B	2.621	1.204	15.3	27.7
D55K-06347	Klein Sak	1.100	1.100	0.240	0.240	B	0.159	0.057	14.5	23.7
D55L-06115	Sak	20.876	16.99	5.354	3.184	C	2.258	1.046	10.8	19.5
D55M-05697	Sak	22.115	18.14	5.420	3.410	B/C	2.874	1.300	13.0	24.0
D57A-05387	Sak	68.804	56.07	20.742	13.199	C	6.648	3.567	9.7	17.2
D57B-05325	Soutloot	0.886	0.456	0.174	0.093	B/C	0.101	0.037	11.3	21.3
D57C-05254	Sak	69.813	56.59	20.790	13.230	C	6.775	3.604	9.7	17.3
D57E-04374	Sak	72.377	47.13	21.850	16.440	B	9.793	6.069	13.5	27.8
D57E-04534	Sak	70.972	57.69	21.002	13.429	B	9.588	5.530	13.5	26.3
Hartbees River system										
D53B-04104	Hartbees	84.236	66.80	29.150	20.222	D	5.964	2.764	7.1	9.5
D53C-03807	Hartbees	86.535	68.62	29.648	20.297	B	12.591	6.346	14.6	21.4
D53D-03879	Tuins	2.008	1.906	0.204	0.193	A/B	0.253	0.079	12.6	38.7
D53E-03557	Hartbees	89.543	71.48	30.300	20.879	A/B	15.648	7.803	17.5	25.8
D53H-03564	Sout	1.783	1.783	0.090	0.090	A	0.237	0.050	13.3	55.6
D53J-03408	Hartbees	91.687	69.19	30.660	16.665	B	11.959	5.492	13.0	17.9
D54B-05160	Holsloot	2.790	1.194	0.553	0.225	B	0.363	0.130	13.0	23.5
D54D-04630	Carnaveronleegte	10.060	5.250	1.981	0.992	C	1.020	0.454	10.1	22.9
D54D-04896	Carnaveronleegte	8.335	3.567	1.653	0.670	C	0.826	0.341	9.9	20.6
D54F-04645	Verneukpan	6.342	4.703	1.229	0.895	B	0.919	0.404	14.5	32.9

Node	River name	Annual Runoff (10^6 m^3)				REC	Long-term EWR requirements			
		Mean		Median			(10^6 m^3)		% Natural	
		Natural	PD	Natural	PD		Mean	Median	Mean	Median
D54F-05004	Botterslaagte	2.713	1.161	0.538	0.218	B	0.353	0.126	13.0	23.4
D54G-04407	Hartbeespoort	21.295	14.72	4.141	2.798	B	3.061	1.346	14.4	32.5
Small West Coast Rivers										
F10B-03391		0.064	0.064	0.000	0.000	B	0.006	0.000	8.8	na
F20E-04290		0.738	0.738	0.140	0.140	B	0.090	0.057	12.2	40.7
F30A-04782		2.313	2.313	0.737	0.737	B	0.345	0.225	14.9	30.5
F30B-04742		1.731	1.731	0.553	0.553	B	0.258	0.168	14.9	30.4
F30C-04823		6.003	6.003	1.914	1.914	B	0.896	0.585	14.9	30.6
F30D-04598		7.158	7.158	2.282	2.282	B	1.068	0.697	14.9	30.5
F30E-04444		1.492	1.492	0.476	0.476	B	0.222	0.145	14.9	30.5
F30G-04539		11.199	11.19	3.570	3.570	B/C	1.407	0.909	12.6	25.5
F40B-04917		0.345	0.345	0.178	0.178	B	0.047	0.034	13.8	19.1
F40C-05007		0.519	0.519	0.268	0.268	B	0.072	0.052	14.0	19.4
F40D-04789		1.215	1.215	0.629	0.629	B	0.172	0.125	14.2	19.9
F40F-05159		1.282	1.282	0.664	0.664	B	0.181	0.132	14.2	19.9
F40G-05320		0.297	0.297	0.154	0.154	B	0.041	0.030	13.7	19.5
F40H-05480		0.630	0.630	0.326	0.326	D	0.041	0.027	6.5	8.3
F50A-05626		1.546	1.546	0.779	0.779	C	0.164	0.116	10.6	14.9
F50B-05636		0.715	0.715	0.360	0.360	B	0.107	0.077	15.0	21.4
F50C-05764		2.782	2.782	1.402	1.402	B	0.424	0.313	15.2	22.3
F50D-05726		3.597	3.597	1.813	1.813	B	0.550	0.405	15.3	22.3
F50F-05560		1.260	1.260	0.635	0.635	B/C	0.162	0.117	12.8	18.4
F50G-05620		5.458	5.458	2.750	2.750	B	0.835	0.615	15.3	22.4
F60A-05886		0.177	0.177	0.064	0.064	B	0.027	0.017	15.1	26.6
F60C-06147		0.450	0.450	0.161	0.161	B	0.068	0.042	15.2	26.1
F60D-06231		0.675	0.675	0.246	0.246	B	0.106	0.064	15.6	26.0

7 EWR ASSESSMENT OF THE BUFFELS, SWARLINTJIES, SPOEG, GROEN ESTUARIES

This report is summarised from: (DWS, 2017a)
Department of Water and Sanitation, South Africa, February 2017. Determination of Ecological Water Requirements for Surface water (River, Estuaries and Wetlands) and Groundwater in the Lower Orange WMA. Buffels, Swartlintjies, Spoeg, Groen and Sout Estuaries Ecological Water Requirement . Authored by CSIR: L van Niekerk, J Adams, SJ Lamberth, S Taljaard for Rivers for Africa. DWS Report No: RDM/WMA06/00/ CON/COMP/0316.

7.1 PURPOSE OF THE TASK

The purpose of this report is to:

- Summarise the ecological condition of the Buffels, Swartlintjies, Spoeg, Groen and Sout estuaries and reflect the level of resource utilisation in their catchments and environs.
- Provide the desktop EWRs for the Buffels, Swartlintjies, Spoeg, Groen and Sout estuaries.

7.2 PRESENT ECOLOGICAL STATE

The assessment of the ecological condition of the Buffels, Swartlintjies, Spoeg, Groen and Sout estuaries reflect the level of resource utilisation in their respective catchments and in their surrounding environs. A summary of some of the key pressures of the estuaries in the study area is provided in Table 7.1.

Table 7.1 Summary of the major pressures on the Buffels, Swartlintjies, Spoeg, Groen and Sout estuaries

Pressure	Buffels	Swart-lintjies	Spoeg	Groen	Sout
Groundwater abstraction resulting in loss of freshwater input	●		◖	◖	
Road infrastructure/embankments trapping river inflow/floods	●	●	◖	◖	●
Mining activities (slimes dams, dust, salinization)	●	●	Future	Future	
Roads crossing in the Estuary Functional Zone	●	◖		◖	●
Floodplain development e.g. golf course, houses	●			◖	
Diffuse sewage runoff (e.g. golf course irrigation, ablution)	●			◖	
Grazing in the catchment changing sediment structure	◖	◖	◖	◖	◖
Invasive aliens, e.g. *Acacia cyclops* (rooikrans)	●				
Human disturbance/activities	●			●	●
Saltworks					●
Artificial breaching/mouth manipulation	●				?

At first glance the surface water resources were relatively untransformed. However, it was estimated that floods reaching the estuaries were significantly reduced in frequency and magnitude because of poorly designed local infrastructure (e.g. poorly designed pipe culverts in mining roads) that trapped floods and in affect act as “farm dams”. This effect was especially apparent at the Buffels, Swartlintjies and Sout estuaries.

Ground water resources were severely over utilised in the Buffels Estuary catchment, while the Groen and Spoeg estuaries were also significantly affected by reduce groundwater input.

From a hydrodynamics perspective, estuary connectivity to the marine environment was disrupted, i.e. reduced breaching opportunities as a result of the reduced floods. Road infrastructure also severely impacted on the hydrodynamics (circulation and estuary longitudinal connectivity) of the Buffles and Sout estuaries - isolating the main water bodies from the upper and lower reaches. At the Buffels, Swartlintjies and Sout estuaries use of groundwater and mining activities have influenced interflow and ground water contribution to these systems, in turn changing the water table and the available water area and water depth.

Water quality showed the resulted of impact of reduced surface and groundwater input in the form of elevated salinities (Buffels and Spoeg) and extreme hyper salinity (Swartlintjies, Groen and Sout).

Except for the Buffels Estuary the water quality (as reflected in inorganic N and P, dissolved oxygen and turbidity) of the small systems in this WMA is still in a fairly good condition compared with reference. Because of the relatively high bird populations supported by these very small systems, avifauna is considered to contribute significantly to the nutrient loading. As a result, high algal productivity is often observed with ripple effects into turbidity and dissolved oxygen (associated with increased suspended algal growth/organic debris). However, in the case of the Buffels Estuary nutrient loading has increased markedly as a result of diffuse run-off from the adjacent golf course irrigated with sewage water. To a lesser extent, possible seepage from ablution facilities has increased loading in the Groen Estuary. A major uncertainty in terms of water quality relates to the extent to which extensive mining activities in the areas, as well as a salt works on the Sout Estuary, have contributed to the accumulation of toxic substances (e.g. trace metals) in these systems.

Road infrastructure has to a large extent impacted on most of the systems along this stretch of coast. Most of the estuaries had one or two roads a crossing them. Road berms have led to infilling of systems and consequential habitat destruction. Development in the floodplain and channel stabilisation has impacted circulation patterns and has resulted in localised disruption of scour and deposition processes. The catchment is also subjected to poor agricultural practise, overstocking and related increased sediment loads contributing to sedimentation and increased fines in the estuaries.

Because of the discontinuous nature of the estuaries microalgae did not show typical distribution patterns in biomass. Hypereutrophic conditions (>60 µg/l chlorophyll-a) were observed in the upper reaches of the Spoeg Estuary, lower reaches of the Groen Estuary and middle reaches of the Sout Estuary. In the Groen and Sout this was associated with hypersaline shallow conditions whereas in the Spoeg Estuary this was at a bird feeding site. Community composition reflected the prevailing salinity conditions; for example, the green alga, *Dunaliella salina* was abundant in hypersaline waters. Changes in the microalgae were in response to habitat loss i.e. decrease in water volume and increases in salinity as a result of surface and groundwater reduction.

In terms of the macrophytes the five small estuaries sampled represented a range of conditions and pressures; from the highly transformed Sout Estuary to the near pristine Spoeg Estuary. The Spoeg had patches of reeds in the upper and riverine reaches indicating seepage sites and the Groen had a stretch of reeds in the upper reaches indicating an important groundwater fed area. Submerged macrophytes only occurred in the fresher section of the Buffels and were abundant in the Spoeg Estuary indicating the biodiversity importance of this system. Macrophytes have mainly responded to the decrease in groundwater and increase in salinity as well as anthropogenic impacts that have disturbed or removed vegetation such as the mining activities at Buffels Estuary and the salt works at Sout Estuary.

Invertebrate diversity, abundance and community structure in all five estuarine systems were a function of changes in groundwater inflow, frequency and magnitude of floods, frequency and duration of breaching events and salinity gradients, including cycles within long periods of hypersalinity. Macroinvertebrates such as sandprawn Callichirus kraussi are absent from all five systems either from prolonged periods of low salinity (<16 psu) in the Buffels and Spoeg that preclude breeding or from the persistent and fatal hypersalinity in the Swartlintjies, Groen and Sout. The exceptions are freshwater crabs *Potamonautes* sp. in the pondweed and reed beds as well as in otter scat, in the upper reaches of the Groen and Spoeg and an anomalous population of the Caridean shrimp *Palaemon peringueyi* in a 70 m long pond / sump in the Sout. Based on historical accounts of the salt-works this population of *P. peringueyi* may have been isolated for more than 50 years. Small invertebrates in the Buffels, Spoeg and Groen (when not hypersaline) follow a salinity gradient with estuarine crustacean (amphipods, isopods) and oligochaetes in the lower reaches and insect larvae in the headwaters. The Swartlintjies, Sout and currently Groen are hypersaline each with a high biomass of brine shrimp *Artemia* spp. and limited diversity and abundance of halophilic Insecta. Broadly, *Artemia* hatch at salinities above 40 psu and encyst sinking to the bottom when salinities exceed 150 psu. Consequently, available biomass of *Artemia* in all three estuaries is cyclic according to salinity as is the diversity and abundance of flamingos and other birds that feed upon them. Lastly, three out of seven native *Artemia salina* populations in South Africa have been replaced by the invasive *Artemia franciscana* (Baxevanis *et al*., 2014). This includes the Berg Estuary Velddrift population so the status of those in other West Coast estuaries and wetlands needs to be verified.

Fish diversity, abundance and community structure in all five estuarine systems relies on recruitment that is largely a function of connectivity with the sea and driven by the frequency and duration of floods and breaching events and the degree of overwash during high seas. Fish survival depends mostly on groundwater inflow maintaining a salinity gradient and at least some areas with hypersalinity not exceeding 40 psu. Safe return to the sea is usually during flood events and depends on a quick breaching and fish not suffocating in sediment-laden water backing up against the berm. This said, most recruitment is “suicidal” via overwash with survival depending on wave size and the height and width of the berm. Consequently, overwash recruitment diminishes with time away from a breaching event. Survival after overwash recruitment is unlikely in the hypersaline Swartlintjies and Sout and high to medium in the Spoeg, Buffels and Groen. Survival in the latter three systems depends on whether these dry up or become hypersaline before the next flood and breaching event. Survival of 8 - 10 year-old harder *Liza richardsonii* and flathead mullet *Mugil cephalus* in the Spoeg and Buffels is evidence of tolerable conditions over the 8 - 10 years since last recruitment. Previous studies have recorded *Mugil cephalus* and *Liza richardsonii* in the Groen and Spoeg Estuaries and no fish in the other three systems. The ECRU survey also recorded freshwater mullet *Myxus capensis* in the Spoeg Estuary but this needs verification. Fish in the Buffels Estuary have now been verified and again none in the hypersaline Swartlintjies and Sout. *L. richardsonii* and *M. cephalus* were sampled in the Buffels and Spoeg estuaries as well as a breeding population of goby *Caffrogobius* spp. in the latter system. Fish are currently absent in the Groen Estuary in its hypersaline state. With the possible exception of the Spoeg, hypersalinity and fish mortality are characteristic of these West Coast systems. In addition to this, fish mortalities in the Buffels Estuary are a “regular” occurrence arising from eutrophication and low oxygen events or from suffocation in floodwaters backed up against poorly planned roads and causeways.

MINING ACTIVITIES

A major concern is the planned escalation of mining activities in and around the Namaqualand National Park. Mining in close proximity to the estuaries can hold the following risk for the Swartlintjies, Spoeg and Groen estuaries:

- Disruption of subsurface flow.
- Wind-blown sand that smother estuarine and wetland vegetation.
- Increase sedimentation.
- Loss of salinity gradient in soil and water body (fresh at top and saline in lower reaches).
- Possible leaching of heave metals from mine dumps.

Table 7.2 provides a summary of the Ecological Categories of the Buffels, Swartlintjies, Spoeg, Groen and Sout estuaries.

Table 7.2 Ecological categories of the Buffels, Swartlintjies, Spoeg, Groen and Sout estuaries

Component Category	Buffels	Swartlintjies	Spoeg	Groen	Sout
Hydrology	D/E	B	B/C	C	D/E
Hydrodynamics	D	B	B	C	E/F
Water quality	D	B	A/B	B	D
Physical habitat alteration	D	B	A/B	A	E
Habitat health	D	B	B	B	D/E
Microalgae	D	B	A/B	B	E
Macrophytes	E	C	A	B	E/F
Invertebrates	D	C/D	A	C	E
Fish	E	B	A	B	E/F
Birds	D	A/B	A	B	E
Biotic health	D/E	B/C	A	B	E
PES	↓ D	B	A/B	B	E
Confidence	Low	Low	Low	Low	Low

7.3 ESTUARY IMPORTANCE

7.3.1 Ecological Importance

The Estuary Importance Score for an estuary takes size, the rarity of the estuary type within its biographical zone, habitat diversity and biodiversity importance of the estuary into account (DWAF, 2008b). Biodiversity importance, in turn is based on the assessment of the importance of the estuary for plants, invertebrates, fish and birds, using rarity indices. These importance scores ideally refer to the system in its natural condition. The scores were determined by specialists during the November 2016 EWR workshop (DWAF, 2008b). The small estuaries of Lower Orange WMA were rated on a 0 to 100 scale to provide an indication of their biodiversity importance in the region (Table 7.3, 7.4 and 7.5) (DWAF, 2008b).

Table 7.3 Importance rating

Importance score	Comment
0 - 20	Little
20.1 - 40	Some
40.1 - 60	Important
60.1 - 80	Very important
80.1 -100	Extremely important

The functional importance of an estuary provides a measure of the role a specific estuary plays in the larger land- and seascape. The functional importance of these systems was relatively high as collectively they contribute to a very rare and limited "wetland habitat type" for estuarine and coastal birds along the dry Namaqualand Coast.

Table 7.4 The Functional Importance of the estuaries of the Buffels, Swartlintjies, Spoeg, Groen and Sout estuaries

Calculation of the functional importance score		Buffels	Swartlintjies	Spoeg	Groen	Sout
a)	Estuary derived detritus and nutrients to the sea	20	20	20	20	20
b)	Nursery function for marine-living fish	20	0	20	20	0
c)	Movement corridor for river invertebrates and fish breeding in sea	0	0	0	20	0
d)	**Contribute to a very limited wetland type habitat for estuarine and coastal birds along arid coast**	**80**	**60**	**80**	**60**	**60**
e)	Catchment sediments provided to the sea	40	40	40	40	20
f)	Coastal connectivity (way piont) for fish	40	10	40	10	0
g)	Movement corridor for mammals (mongoose and otters)	40	40	40	40	20
Functional importance score Max (a) to (g)		**80**	**60**	**80**	**60**	**60**
Functional importance rating		**Very important**	**Important**	**Very important**	**Important**	**Important**

Table 7.5 The Estuarine Importance of the estuaries of the Buffels, Swartlintjies, Spoeg, Groen and Sout estuaries

Estuarine Importance	Buffels	Swartlintjies	Spoeg	Groen	Sout
Size	50	70	70	70	100
Zonal Type Rarity	30	30	30	30	30
Habitat diversity	60	50	60	60	30
Biodiversity Importance	13	10	15	10	10
Functional importance	**80**	60	80	60	60
Estuarine Importance Score	**49**	44	52	46	43
Estuarine Importance	**Average Importance**	**Average Importance**	**Average Importance**	**Average Importance**	**Average Importance**

7.3.2 Conservation Importance of the Lower Orange WMA Estuaries

The National Biodiversity Assessment 2011 (NBA, 2011) (Van Niekerk and Turpie, 2012; Turpie *et al*., 2012) developed a biodiversity plan for the estuaries of South Africa by prioritising and establishing which of them should be assigned partial or full Estuarine Protected Area (EPA) status. This biodiversity plan followed a systematic approach that took pattern, process and biodiversity persistence into account. While the plan has not explicitly taken social and economic costs and benefits into consideration, it used ecosystem health as a surrogate for the former. This is because estuaries where the opportunity costs of protection are likely to be high are also likely to be heavily-utilised systems that are in a lower state of health.

The plan indicates that, on a national scale 133 estuaries (61 require full protection and 72 require partial protection) including those already protected, would be required to meet biodiversity targets (Turpie *et al*., 2012). Of these, three occur within the Lower Orange WMA, with a subset of two estuaries requiring full protection (Groen and Spoeg).

Fully protected estuaries are taken to be full no-take areas. Partial protection might involve zonation that includes a no-take area, or it might address other pressures with other types of action. In both these cases, the management objective would be to protect 50% of the biodiversity features of the partially protected estuary. Fully protected and partially protected estuaries can be considered Estuarine Protected Areas, whereas all other estuaries should be designated Estuarine Management Areas. All estuaries require a Management Plan and these plans should be guided by the results of this assessment.

7.3.3 Recommended Ecological Category

The REC signifies the level of protection assigned to an estuary. The relationship between Estuary Health Index (EHI) score, PES and minimum REC is given in Table 6. Table 7 summarised the degree to which the REC for the Buffels, Swartlintjies, Groen, Spoeg and Sout estuaries needs to be elevated above the PES depending on the estuary **importance** and the level of **protection** (**conservation importance)** of a particular estuary (Table 7.6).

Table 7.6 Estuary protection status and importance, and the basis for assigning a recommended ecological reserve category (modified from DWA, 2008b)

Protection status and importance	REC	Policy basis
Protected area	A or BAS*	Protected and desired protected areas should be restored to and maintained in the best possible state of health
Desired Protected Area		
Extremely important (Ranked as 1)	PES + 1, min B	Highly important estuaries should be in an A or B category
Very Important (Ranked as 2)	PES + 1, min C	Important estuaries should be in an A, B or C category
Of low to average importance (Ranked as 3)	PES, min D	Estuaries to remain in a D category

* BAS - Best Attainable State

The REC for the Buffels, Swartlintjies, Spoeg, Groen and Sout estuaries is listed in Table 7.7.

Table 7.7 The Recommended Ecological Category for the estuaries of the Buffels, Swartlintjies, Spoeg, Groen and Sout estuaries

Component	Buffels	Swartlintjies	Spoeg	Groen	Sout
Present Ecological Status	↓ D	B	A/B	B	E
Functional Importance as wetland/estuary type in along arid coast	Very important	Important	Very important	Important	Important
Estuarine Importance	Average Importance	Average Importance	Average Importance	Average Importance	Average Importance
Conservation Importance (in Namaqualand National Park)			High	High	
Recommended Ecological Category	D	B	A/B	A/B	D

7.4 EWR RECOMMENDATIONS

Table 7.8 provides an overview of the PES, estuary importance, REC and associated EWR requirements. In all but one system no additional freshwater water is required to maintain/achieve the REC. In the case of the Spoeg Estuary provisional results indicate that the system require additional groundwater to achieve the REC. This requirement needs to refined with additional monitoring results (e.g. boreholes, estuary salinity) as very little information is available on the long term trends and responses to groundwater on this coast.

Table 7.8 Estuaries EWR and recommendations

Component	Estuary				
	Buffels	**Swartlintjies**	**Spoeg**	**Groen**	**Sout**
Reference MAR (Mm^3/a)	11.2	1.2	1.3	5.5	0.7
Reference groundwater discharge (Mm^3/a)	0.23	0.63	0.36	0.13	1.24
Present groundwater discharge (Mm^3/a)	-0.84	0.59	0.22	0.08	1.13
Present Ecological Status	↓ D	B	A/B	B	E
Estuarine Importance	Average Importance	Average Importance	Average Importance	Average Importance	Average Importance
Conservation Importance (in Namaqualand National Park)			**High**	**High**	
REC	D	B	A/B	A/B	D
Surface water flow mitigations	↑ floods (road culverts)	↑ floods (road culverts)			↑ floods (weir)
Groundwater mitigations				↑ 20%	
Water Quality Mitigations	×			×	
Non-Flow related Mitigations	×			×	×
Potential for further water resource development without impacting on ecology	No	No	No	No	No

Table 7.9 list interventions required to maintain or achive the REC the Buffels, Swartlintjies, Spoeg, Groen and Sout estuaries.

Table 7.9 Detail recommendations on interventions/actions required to maintain or achieve the REC

Estuary	Recommendations on interventions/actions
Buffels	▪ Develop an Estuary Management Plan (in progress) to evaluate to what extent functionality can be restored. ▪ Restore connectivity with the marine environment during floods by the complete removal of the remnants of the mining road that still transects the mouth. This would allow for rapid breaching during floods and prevent fish getting smother by high silt content in floodwaters. ▪ Improve estuarine connectivity / freshwater flow through the removal of roads at bird hide and above golf course; ▪ Address diffuse runoff from golf course to prevent nutrient enrichment and associated fish kills. ▪ Control wind-blown dust (smother plants) and wastewater (seawater increase soil salinities) from mining activities. ▪ Remove alien invasive plant species (rooikrans) in upper estuary (ongoing process). ▪ No driving on the beach to facilitate sedimentary processes and protect bird life (ongoing process).
Swartlintjies	▪ Develop an Estuary Management Plan (in progress) to evaluate to what extend old slimes dam is impacting on estuary and how functionality can be restored if required. ▪ Protect groundwater input to ensure hypersalinity is below <150 psu (brine shrimp goes to cyst). ▪ Restore catchment connectivity (i.e. improve surface water flow) - increase culvert size / culverts at ground level in road crossings. ▪ Estuary in the process of recovering from previous mining activities, allow this process to continue. A concern is the impact of future mining prospects
Spoeg	▪ Restore / protect groundwater. ▪ Allow regrowth of vegetation on derelict access roads crossing the upper reaches to continue. ▪ Impact of proposed mining: Wind blow sand & increase salinity via surface/ground water flow.
Groen	▪ Restore/improve groundwater flow by 20% from current levels of 60% utilisation to 80%. ▪ Investigate possible organic/nutrient seepage from ablution facilities of offices/homes at SANParks and means to address these. ▪ The estuary has a strong dependency on groundwater fed springs to maintain salinity gradient, maintain water levels, limit occurrence of extreme hyper salinity (<150 psu). ▪ Future pressures include an escalation of mining activities in the national park and related disruption of subsurface flow.
Sout	▪ Develop an Estuary Management Plan (Western Cape Government in the processes of prioritising this system for a plan) to evaluate to what extend the current design and/or operations of the salt works can be improved to restore estuarine habitat and functionality of the upper reaches. ▪ Improve circulation (e.g. culverts in roads). ▪ Restore connectivity with catchment, i.e. investigate if weir can be partially removed to allow connectivity with western arm of estuary.

8 GROUNDWATER ECOLOGICAL WATER REQUIREMENT

This report is summarised from: (DWS, 2016c)
Department of Water and Sanitation, South Africa, October 2016. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Groundwater EWR report. Prepared by: WSM Leshika Consulting (Pty) Ltd. Authored by K. Sami. DWS Report No: RDM/WMA06/00/CON/COMP/0416.

The purpose of this chapter is to:

- Describe and prioritise the identified GRUs.
- Quantify the groundwater component of the Reserve in each GRU.
- Quantify the remaining allocable groundwater in each GRU.

Only catchments where groundwater contributes baseflow are considered to have a groundwater contribution to environmental water requirements. In most catchments, recharge is discharged via very localised seeps or via evapotranspiration in localities of shallow groundwater, which do not generate flow of importance to rivers and streams.

8.1 GROUNDWATER USE

Many communities within the WMA are dependent on groundwater for municipal supply. In addition to formal groundwater supply, a large segment of the population is dependent on boreholes and springs. Except for catchments through which the Orange River flows, or is adjacent, the bulk of the region is dependent on groundwater for domestic water supply.

Total groundwater use is 45.36 Mm^3/a, of which 38% is for irrigation. Industry and mining account for 8% of water use, and domestic water use is 32%. Figure 8.1 depicts the groundwater use summary in the Lower Orange WMA.

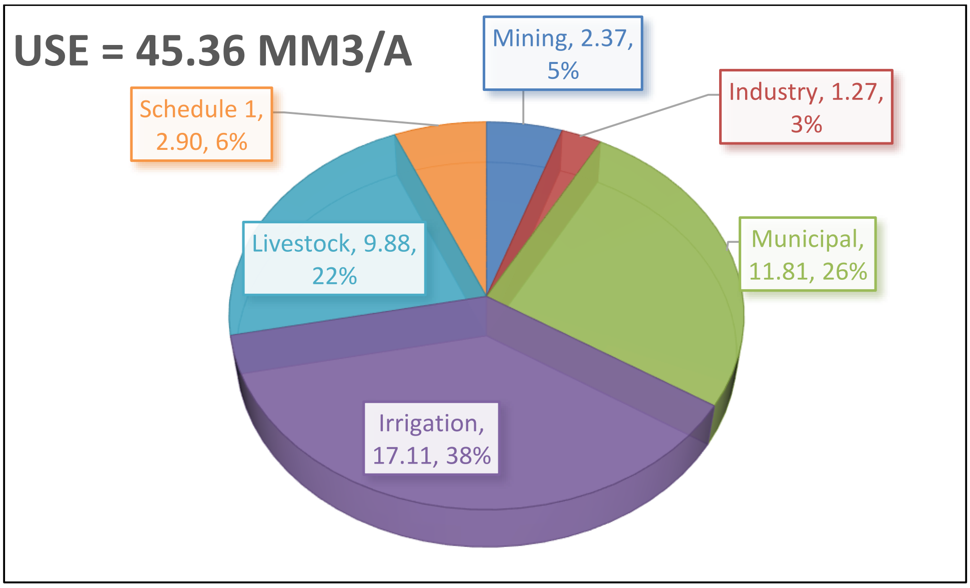


Figure 8.1 Groundwater use summary

8.2 IDENTIFIED GROUNDWATER RESOURCE UNITS

The Figure 8.2 below provides the identified GRUs.

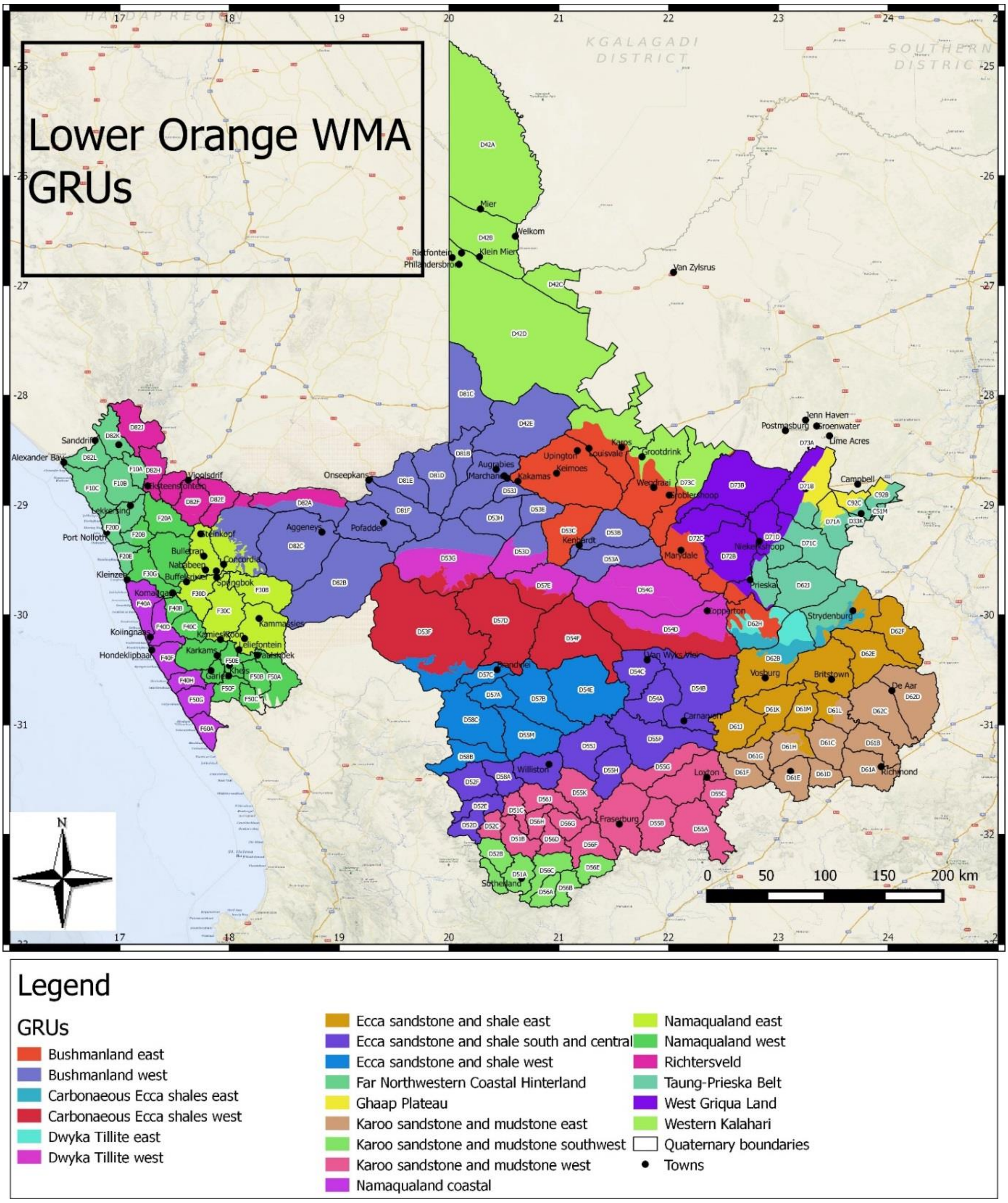


Figure 8.2 Lower Orange GRU delineation

In order to prioritise and select the most important GRUs, the criteria assessed per RU include:

- Importance of the RU to users (degree of groundwater dependence).
- Threat posed to water resource quality for users (aquifer vulnerability).
- Threat posed to water resource quality for the environment (baseflow).
- Degree of use (stress index).

Several areas are identified as being stressed in terms of high stress indices, declining water levels, and sole source dependency. These are depicted in Figure 8.3. Most of the priority catchments are located in the south, the Karoo sandstone and shale GRUs, which are the target area for potential fracking.

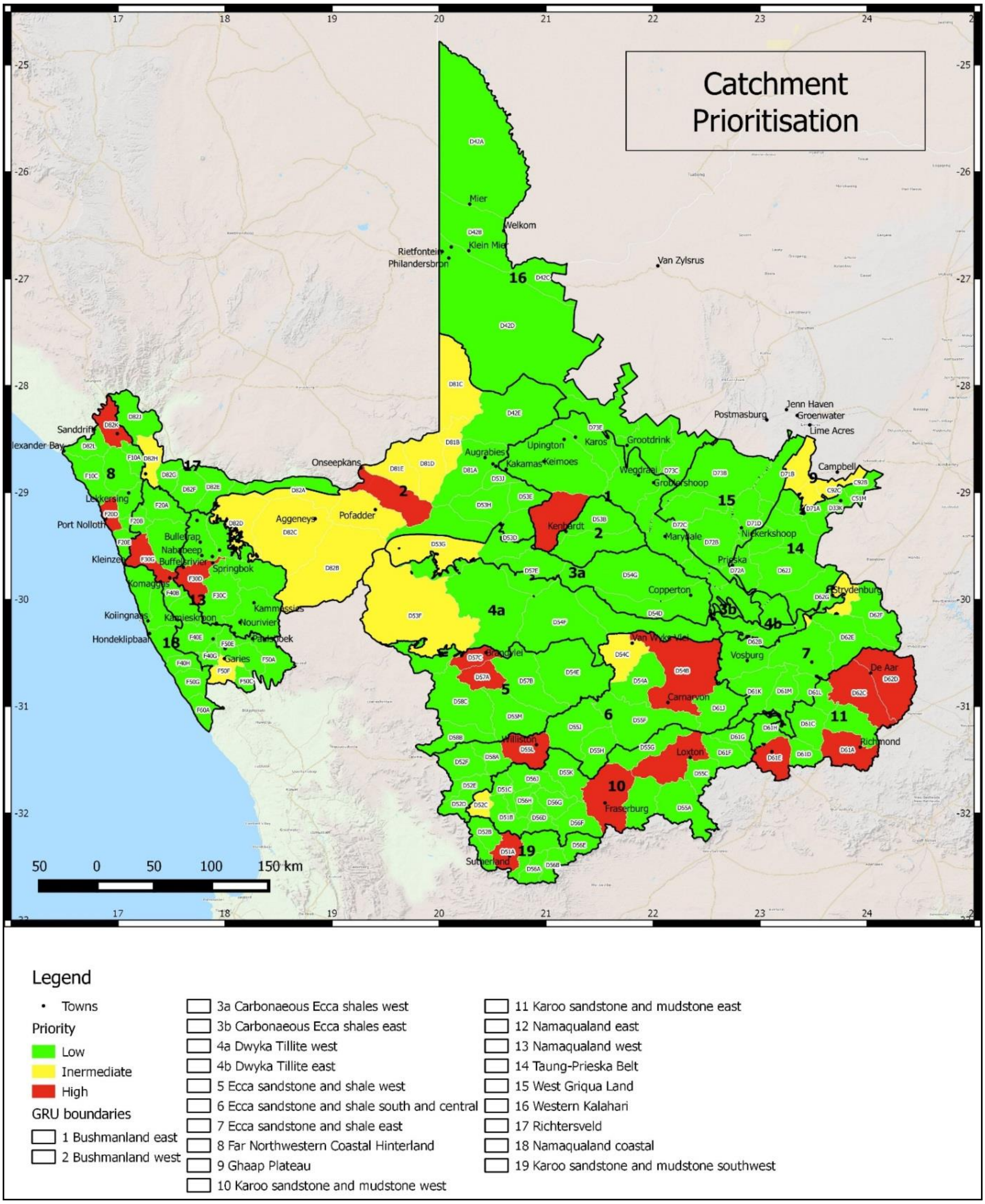


Figure 8.3 Catchment prioritisation of groundwater in the Lower Orange WMA

These GRUs are also classified as sole source aquifers for water supply, and highly dependent on groundwater with an already high stress index. Contamination or large abstractions from fracking or other activities could cause significant deterioration in water supply.

The **Present Status Category** of each Quaternary catchment is shown in Figure 8.4.

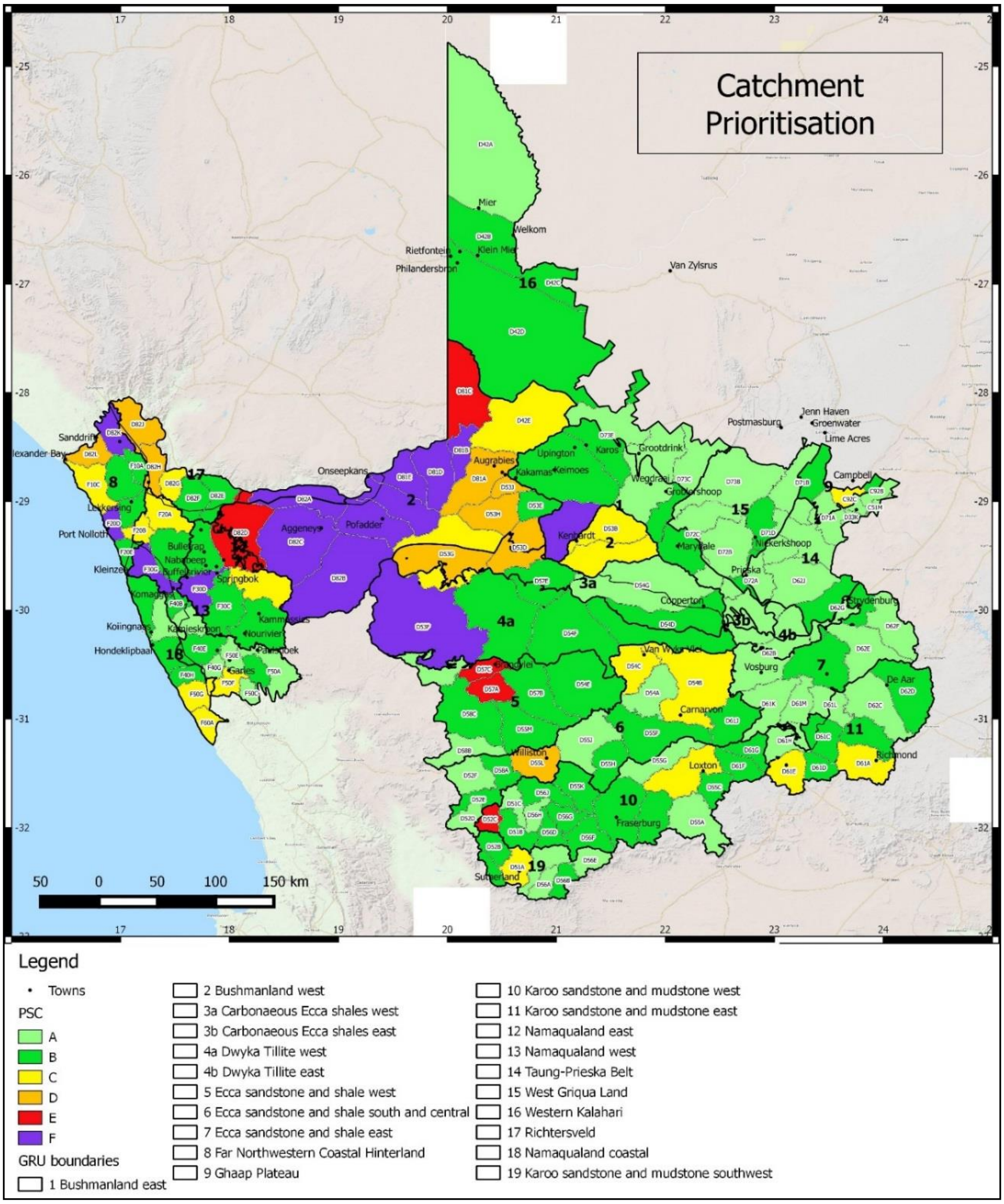


Figure 8.4 Present Status Category of groundwater in the Lower Orange WMA

8.3 DESCRIPTION OF GRUS

A description of the identified GRUs are provided below and the associated Groundwater Reserve and allocable groundwater information is provided.

8.3.1 Bushmanland East

Recharge is from less than 1 mm to over 3 mm/a increasing southeastward with rainfall. The aquifer is fractured in nature with yields of 0.5 - 2 l/s. Groundwater levels average 20 - 25 mbgl. 70 - 95% of boreholes are potable. Groundwater quality is less saline than in the western area and is generally of Class 2. Nitrates, Fluoride, Molybdenum and Arsenic are frequently a problem.

Groundwater dependency is low to moderate and the towns of Marydale and Kenhardt rely on groundwater. Groundwater use is high in D53C, with most of the groundwater use being for regional water supply schemes for the town of Kenhardt. The stress index is below 0.2 in the other

Quaternaries. Groundwater use is also low in D72C, where groundwater is used to supply Marydale. Groundwater levels have dropped 6 m in D53C since 1995 but appear to remain stable. Groundwater levels have dropped 1 m in D72C since the mid 1970s.

Based on the high level of groundwater dependence, and a high stress index, D53C is considered a high priority catchment in this GRU.

Table 8.1 Bushmanland East: Groundwater component of the Reserve and allocable groundwater information

Quat	Recharge (Mm^3/a)	Stress Index	GW[1] dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D53C	0.32	1.08	77.49	0	0.00384	0.00384	**-0.018***	High
D62H	4.37	0.05	70.15	0	0.00262	0.00262	2.703	Low
D72A	0.95	0.01	10.32	0	0.00100	0.00100	0.611	Low
D72B	1.26	0.01	4.46	0	0.00205	0.00205	0.809	Low
D72C	2.63	0.17	89.10	0	0.00620	0.00620	1.409	Low
D73C	2.89	0.08	82.72	0	0.00913	0.00913	1.721	Low
D73D	1.39	0.04	82.72	0	0.00873	0.00873	0.861	Low
D73E	1.02	0.08	2.26	0	0.00555	0.00555	0.609	Low
D73F	0.97	0.17	1.30	0	0.02515	0.02515	0.503	Low

1 Groundwater * Red text indicates negative allocable groundwater, therefore the quat is already over utilised.

8.3.2 Bushmanland West

Recharge is less than 1 mm/a. Mean groundwater level depth increases from less than 20 m near Kenhardt to over 50 m to the west near Aggeneys. Water quality is generally poor and of Class 3 or 4 due to high salinity, with the worst quality water being located in the north from Concordia to Augrabies. Nitrates, Fluoride and Arsenic are frequently a problem. The potability of groundwater is highly variable and ranges from 8 - 80% but is generally low and less than 50%.

The aquifer is considered poor and no communities rely on it for water supply. Groundwater dependency is low to moderate. Groundwater use is primarily for livestock watering, small scale local water supply schemes and Schedule 1 water use. The stress index is high due to livestock water use and many catchments are heavily utilised due to the very low recharge rates. Groundwater levels have dropped 3 m in D81C since 1996, which has a stress index of 0.74, but appear to remain stable.

Catchments with a high stress index (>0.65) were considered of intermediate priority since groundwater dependency in the GRU is limited by the poor water quality. Only B81F, in the Pofadder vicinity, has a high stress index and a groundwater dependency exceeding 50%.

Table 8.2 Bushmanland West: Groundwater component of the Reserve and allocable groundwater information

Quat	Recharge (Mm^3/a)	Stress Index	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D42E	0.69	0.32	27.59	0	0.01761	0.01761	0.292	Low
D53A	0.42	0.21	34.14	0	0.00408	0.00408	0.215	Low
D53B	0.44	0.24	55.76	0	0.00382	0.00382	0.216	Low
D53D	0.10	0.59	28.58	0	0.00140	0.00140	0.025	Low
D53E	0.36	0.13	28.34	0	0.00139	0.00139	0.205	Low
D53G	0.26	0.30	28.94	0	0.00291	0.00291	0.116	Low
D53H	0.16	0.55	28.34	0	0.00266	0.00266	0.046	Low
D53J	0.05	0.46	6.21	0	0.00167	0.00167	0.017	Low
D81A	0.22	0.56	5.77	0	0.01145	0.01145	0.054	Low
D81B	0.05	1.02	36.85	0	0.00111	0.00111	**-0.001***	intermediate
D81C	0.20	0.74	34.84	0	0.00462	0.00462	0.030	Intermediate
D81D	0.11	0.96	28.34	0	0.00304	0.00304	0.001	Intermediate
D81E	0.04	1.35	9.02	0	0.00240	0.00240	**-0.011***	Intermediate
D81F	0.05	3.80	61.06	0	0.00370	0.00370	**-0.088***	High
D81G	0.08	1.02	2.50	0	0.00293	0.00293	**-0.003***	Intermediate
D82A	0.01	5.63	69.43	0	0.00125	0.00125	**-0.042***	Intermediate
D82B	0.08	2.15	40.14	0	0.00427	0.00427	**-0.060***	Intermediate
D82C	0.07	2.03	8.51	0	0.00515	0.00515	**-0.051***	Intermediate
D82D	0.10	0.66	4.06	0	0.00244	0.00244	0.021	Intermediate

* Red text indicates negative allocable groundwater, therefore the quat is already over utilised.

8.3.3 Dwyka Tillite

Recharge is less than 1 mm/a, except in the eastern pocket where rainfall is higher. Groundwater levels are from 18 - 25 mbgl, but above 15 mbgl in the eastern portion. Borehole yields are below 0.5 l/s and the aquifer is considered poor. Groundwater is of unacceptable quality due to salinity of Class 4. Nitrates are frequently a problem, as well as fluorides in the west. The potability of groundwater is poor to unacceptable, except on the NE margins of the GRU, where boreholes are probably drilled through into the Bushmanland rocks. Nearly 80% of boreholes are potable in the Dwyka Tillite East, whereas only 13 - 47% is potable in the Dwyka Tillite West.

Only Copperton obtains water from the aquifer, however, it is a sole source aquifer for the rest of the GRU. Groundwater use is primarily for livestock watering, small-scale local water supply and schedule 1 water use. The stress index is low except in D53G, where some mining occurs at LaFarge gypsum. No groundwater level data are available.

All catchments have a stress index of below 0.65, and only D53G has a moderate stress index. Groundwater dependency for water supply is low except with for D54D, D62B and H, all of which have stress indices of less than 0.1. Consequently, the priority of all catchments, except D53G in the GRU is low.

Table 8.3 Dwyka Tillite East: Groundwater component of the Reserve and allocable groundwater information

Quat	Recharge (Mm^3/a)	Stress Index	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D53D	0.12	0.37	28.58	0	0.00170	0.00170	0.04734	Low
D53G	0.33	0.64	28.94	0	0.00368	0.00368	0.07434	Intermediate
D54D	2.52	0.07	73.18	0	0.00535	0.00535	1.52209	Low
D54G	4.28	0.04	48.52	0	0.01093	0.01093	2.67637	Low
D57E	0.61	0.09	32.25	0	0.00242	0.00242	0.35986	Low
D62B	2.63	0.04	94.18	0	0.00238	0.00238	1.64851	Low
D62H	2.09	0.01	70.15	0	0.00126	0.00126	1.33939	Low

8.3.4 Ecca Carbonaceous Shale

Recharge is less than 1 mm/a, except in the eastern portion where rainfall is higher. Borehole yields also vary across the GRU, being 0.6 - 0.8 l/s in the west and 0.8 - 1.0 l/s in the east. Groundwater levels are from 15 - 25 mbgl. Groundwater quality is poor and of Class 3. Nitrates and arsenic are frequently of concern in the west, and nitrates in the east. The potability of groundwater is poor to unacceptable in the west, and good in the east. 70 - 90% of of 288 boreholes are potable in the east, whereas potability drops to less 15% of 186 boreholes towards the west.

The aquifer is not utilised for municipal water supply. Groundwater use is for primarily for livestock watering, small-scale local water supply and Schedule 1 water use, except for D53F in the west where salt mining takes place. The stress index is low except in D53F, where it exceeds 1. No groundwater level data are available.

All catchments have a stress index of below 0.3 except D53F, and groundwater dependency for water supply is high, except with for D53G and D57E, where poor groundwater quality precludes its use for water supply. Consequently, the priority of all catchments in the GRU is low, except for D53F, which is considered intermediate due to only a moderate dependence for water supply.

Table 8.4 Ecca Carbanacious Shale: Groundwater component of the Reserve and allocable groundwater information

Quat	Recharge (Mm^3/a)	Stress Index	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D53F	0.81	1.47	51.46	0	0.00983	0.00983	**-0.25***	Intermediate
D53G	0.11	0.30	28.94	0	0.00119	0.00119	0.05	Low
D54D	2.87	0.09	73.18	0	0.00608	0.00608	1.69	Low
D54F	2.93	0.08	89.19	0	0.00816	0.00816	1.75	Low
D57D	1.85	0.20	92.00	0	0.01263	0.01263	0.96	Low
D57E	0.37	0.14	32.25	0	0.00147	0.00147	0.21	Low
D62B	2.38	0.03	94.18	0	0.00215	0.00215	1.50	Low
D62G	3.27	0.02	95.21	0	0.00947	0.00947	2.08	Low
D62H	2.22	0.01	70.15	0	0.00133	0.00133	1.42	Low

* Red text indicates negative allocable groundwater, therefore the quat is already over utilised.

8.3.5 Ecca Sandstone and Shale West

The Ecca sandstones and shales overlie the carbonaceous shales and have a recharge of 0.5 - 1 mm/a. The aquifer is of the fractured type and mean borehole yields are 0.8 - 1 l/s. Groundwater levels are shallow and are 10 - 15 mbgl. Groundwater quality is Good to Marginal and of Class 1 - 2 although nitrates and fluoride can be of concern. The potability of groundwater is variable and declines towards the north near the vicinity of ans. Potability of groundwater in catchments rages from 17 to 100%.

The aquifer is a sole source aquifer and the town of Brandvlei relies on the aquifer. Groundwater use is for livestock watering, and small-scale local water supply, of which Brandvlei is the most significant. The high registered water usage for irrigation in D57A cannot be observed. One of the allocations for irrigation is for water services to Brandvlei. A significant industrial water use is registered by the NRF in D54E. The stress index is low, except for D57A, if the irrigation allocation were to be used. Groundwater levels have dropped 3 - 4 m in D57A and B since 2011 but appear to remain stable.
Catchments with a high stress index (>0.65) were considered of high priority since groundwater dependency in the GRU is very high and the stressed catchments are associated with water supply to Brandvlei.

Table 8.5 Ecca Sandstone and Shale West: Groundwater component of the Reserve and allocable groundwater information

Quat	Recharge (Mm^3/a)	Stress Index	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D53F	0.11	0.05	51.46	0	0.00137	0.00137	0.069	Low
D54E	2.70	0.10	90.57	0	0.00692	0.00692	1.585	Low
D55M	0.86	0.09	92.14	0	0.00365	0.00365	0.506	Low
D57A	0.26	0.86	91.98	0	0.00176	0.00176	0.022	High
D57B	2.40	0.07	92.15	0	0.00460	0.00460	1.447	Low
D57C	0.19	0.75	97.94	0	0.00203	0.00203	0.029	High
D58B	1.71	0.01	94.88	0	0.00291	0.00291	1.095	Low
D58C	0.99	0.10	91.90	0	0.00529	0.00529	0.578	Low

8.3.6 Ecca Sandstone and Shale Central and Southwest

The Ecca sandstones and shales overlie the carbonaceous shales and have a recharge of from 1 - 3.5 mm/a, increasing towards the east. The aquifer is of the fractured type and mean borehole yields are 1 - 2 l/s. Groundwater levels are shallow and 10 - 15 mbgl. Groundwater quality is highly variable but generally of Class 1 - 2, although fluoride and arsenic can be of concern. There is no natural source of Arsenic in sandstone, and a potential source could be the upwelling of deeper groundwater. The potability of groundwater is variable and declines from nearly 100% to 50% towards the north and west.

The towns of Carnarvon, Van Wyks Vlei and Willistion are dependent on the aquifer. Groundwater use is for small-scale irrigation near the main ephemeral rivers, livestock watering, and small scale to moderate size local water supply. A significant industrial water use is registered by Carnarvon in D54B. The stress index is low, except for D55L due to abstraction by Williston and for significant irrigation. Groundwater levels have dropped 15 m in D54B since 2011 and continue to drop. Water levels in in D55L appear to remain stable. This suggests localised over abstraction could be occurring near Carnarvon in D54B.

The GRU is highly dependent on groundwater for water supply. Catchments with an observed decline in water level and moderate to the moderately high stress index (0.56) were considered priority catchments. D54B was considered of high priority due to the observed water level decline and D55L due to the moderately high groundwater use.

Table 8.6 Ecca Sandstone and Shale Central and Southwest: Groundwater component of the Reserve and allocable groundwater information

Quat	Recharge (Mm^3/a)	Stress Index	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D52D	2.63	0.03	91.86	0	0.00135	0.00135	1.651	Low
D52E	1.84	0.16	91.86	0	0.00127	0.00127	1.009	Low
D52F	1.90	0.00	91.86	0	0.00240	0.00240	1.231	Low
D54A	1.82	0.06	86.69	0	0.00340	0.00340	1.109	Low
D54B	6.97	0.26	97.85	0	0.01565	0.01565	3.334	High
D54C	0.88	0.22	86.69	0	0.00301	0.00301	0.442	Intermediate
D55F	4.48	0.06	87.21	0	0.00734	0.00734	2.734	Low
D55H	1.33	0.09	92.15	0	0.00233	0.00233	0.781	Low
D55J	2.63	0.02	92.15	0	0.00402	0.00402	1.677	Low
D55L	1.71	0.56	98.84	0	0.00482	0.00482	0.489	High
D58A	0.77	0.06	91.92	0	0.00160	0.00160	0.470	Low

8.3.7 Ecca Sandstone and Shale East

The Ecca sandstones and shales overlie the carbonaceous shales. They have a recharge of from 4 - 11 mm/a, increasing from west east of Britstown due to increasing rainfall. The aquifer is of the fractured type and mean borehole yields are between 1 - 2 l/s. Groundwater levels are shallow and 7 - 15 mbgl. Groundwater quality is Good and of Class 1, although arsenic can be of concern. There is no natural source of arsenic in sandstone, and a potential source could be the upwelling of deeper groundwater. Groundwater potability is more than 80%.

The towns of Strydenburg, Britstown and Vosburg depend on the aquifer. Groundwater use is largely for small-scale irrigation near the main ephemeral rivers, livestock watering, and moderate size local water supply supplying the main towns in the GRU. The stress index is low and below 0.06 in all catchments. Groundwater levels are stable and only in D62G, in the Strydenburg vicinity, has a water level decline of 5 m been observed since 1991. This suggests localised over abstraction could be occurring.

The GRU is highly dependent on groundwater for water supply. D62G was considered of intermediate priority due to the observed water level decline near Strydenburg.

Table 8.7 Ecca Sandstone and Shael East: Groundwater component of the Reserve and allocable groundwater information

Quat	Recharge (Mm^3/a)	Stress Index	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D61H	1.46	0.02	86.42	0	0.00101	0.00101	0.935	Low
D61J	5.99	0.05	86.51	0	0.00451	0.00451	3.696	Low

D61K	7.54	0.02	87.45	0	0.00465	0.00465	4.787	Low
D61L	3.71	0.02	90.36	0	0.00181	0.00181	2.371	Low
D61M	5.88	0.03	89.54	0	0.00332	0.00332	3.688	Low
D62A	11.71	0.06	97.51	0	0.01790	0.01790	7.150	Low
D62B	8.22	0.04	94.18	0	0.00215	0.00215	5.146	Low
D62E	15.51	0.04	90.76	0	0.00704	0.00704	9.717	Low
D62F	19.42	0.02	86.28	0	0.00651	0.00651	12.305	Low
D62G	5.14	0.05	95.21	0	0.00947	0.00947	3.156	Intermediat e

8.3.8 Far Northwestern Coastal Hinterland

The Far Northwestern Coastal Hinterland has recharge of less than 1 mm/a. The fractured aquifer is classified as poor, with borehole yields being low and around 0.1 l/s. Groundwater levels are from 25 - 45 mbgl. Groundwater is of Poor to Unacceptable quality, Class 3 and 4, with high Fluoride levels. Groundwater is of poor quality, except adjacent to the Orange River. This indicates recharge of fresh water from the river. The high salinity precludes groundwater use over large parts of the GRU. The potability is less than 15% in the southern half of the GRU.

Groundwater dependency is low on the coast and close to the margins of the Orange River, but increases inland. The towns of Sanddrift, Port Nolloth, Kuboes and Lekkersing are dependent on groundwater. Groundwater use is primarily for water supply, of which Port Nolloth is the main groundwater user. Additional groundwater is used for livestock. The stress index is high due to the very low recharge rates. D82K and F20D have very high stress indices, however, the aquifers utilised are likely recharged by surface water during flood events, and hence rainfall recharge is not a good indicator of recharge to the aquifers. Groundwater levels in F20D do not indicate stress and have risen from 1984 to present.

The GRU is only marginally dependent on groundwater for water supply due to the poor quality; consequently, the catchments are of low priority, except for D82K and F20D, which are used for local water supplies.

Table 8.8 Far Northwestern Coastal Hinterland: Groundwater component of the Reserve and allocable groundwater information

Quat	Recharge (Mm^3/a)	Stress Index	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D82K	0.04	2.63	81.85	0	0.00223	0.00223	**-0.04***	High
D82L	0.07	0.44	2.64	0	0.00188	0.00188	0.02	Low
F10A	0.12	0.17	34.83	0	0.00005	0.00005	0.06	Low
F10B	0.26	0.19	34.83	0	0.00012	0.00012	0.14	Low
F10C	0.19	0.27	34.83	0	0.00013	0.00013	0.09	Low
F20B	0.02	0.25	44.29	0	0.00005	0.00005	0.01	Low
F20C	0.28	0.19	81.67	0	0.00217	0.00217	0.15	Low
F20D	0.15	2.78	54.96	0	0.00032	0.00032	**-0.18***	High
F20E	0.29	0.07	67.55	0	0.00010	0.00010	0.17	Low

* Red text indicates negative allocable groundwater, therefore the quat is already over utilised.

8.3.9 Ghaap Plateau

The Ghaap Plateau GRU is underlain by Ghaap Plateau dolomites, which are covered by Kalahari and Tertiary sediments in some places. It is the most significant aquifer in the WMA in terms of recharge, permeability and aquifer storage. Recharge is from 7 - 10 mm/a. The aquifer is of the karts type and mean borehole yields are 1.5 - 2 l/s. Groundwater levels are 15 - 20 mbgl. Groundwater quality is of Class 1, and nitrates are the only nuisance constituent. Groundwater is of Good quality and mostly of Class 1. The potability of groundwater is almost 100%.

Griekwastad is dependent on the aquifer. Groundwater use is primarily for water supply, of which Campbell and Griekwastad are the main municipal users. Irrigation also occurs, as does mining at Lime Chem Resources. The stress index is low due to the high recharge rates of the dolomites. Groundwater levels in D71B show that water levels are stable since 2001.

The GRU is moderately dependent on groundwater for water supply, except for D71B, which is heavily dependent. Due the dolomitic nature of the terrain, the catchments are considered of intermediate priority in spite of the low stress index.

Table 8.9 Ghaap Plateau: Groundwater component of the Reserve and allocable groundwater information

Quat	Recharge (Mm^3/a)	Stress Index	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
C92B	1.45	0.06	51.73	0	0.00725	0.00725	0.880	Intermediate
C92C	3.93	0.22	6.18	0	0.01967	0.01967	1.974	Intermediate
D71A	3.01	0.02	61.22	0	0.00192	0.00192	1.909	Intermediate
D71B	7.41	0.10	92.62	0	0.00687	0.00687	4.331	Intermediate

8.3.10 Karoo Sandstone and Shale West

Recharge increases from 1 - 3 mm/a from north to south, being highest in the Sutherland vicinity. The aquifer is of the fractured type and mean borehole yields are 1 - 2.5 l/s, hence the aquifer is moderately productive. Groundwater levels are from 5 - 15 mbgl. Groundwater quality is of Class 1 - 2, however arsenic and molybdenum can be encountered. The potability of groundwater is over 90%.

The aquifer is a sole source aquifer and Fraserburg and Loxton rely on groundwater. Groundwater use is primarily for irrigation, however, water supply to Fraserburg and Loxton are a significant component of the water use. The stress index is variable but is high in D52C due to irrigation. Groundwater levels in D55D and D55E indicate dropping water levels of 5 m in the Loxton vicinity and Fraserburg since 2010, despite only low to moderate stress indices in those catchments, suggesting that localised dewatering is occurring due to local aquifers not being connected hydraulically to the remainder of the catchment.

The GRU is highly dependent on groundwater for water supply, consequently, catchments used for water supply are considered of high priority if they exhibit dropping water levels. D52C warrants being considered of intermediate priority due to a high stress index resulting from irrigation.

Table 8.10 Karoo Sandstone and Shale West: Groundwater component of the Reserve and allocable groundwater information

Quat	Recharge (Mm^3/a)	Stress Index	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D51B	2.54	0.19	92.14	0	0.00176	0.00176	1.335	Low
D51C	0.82	0.01	92.02	0	0.00103	0.00103	0.523	Low
D52C	0.63	0.74	92.1	0	0.00093	0.00093	0.103	Intermediate
D55A	4.97	0.02	94.33	0	0.01137	0.01137	3.154	Low
D55B	3.01	0.09	91.73	0	0.00260	0.00260	1.770	Low
D55C	2.96	0.07	92.09	0	0.00339	0.00339	1.788	Low
D55D	4.51	0.28	96.33	0	0.00710	0.00710	2.107	High
D55E	3.16	0.11	98.78	0	0.00664	0.00664	1.820	High
D55G	1.93	0.05	88.27	0	0.00362	0.00362	1.195	Low
D55K	1.40	0.07	92.15	0	0.00253	0.00253	0.847	Low
D56D	0.93	0.08	92.15	0	0.00123	0.00123	0.556	Low
D56F	1.61	0.18	92.15	0	0.00207	0.00207	0.861	Low
D56G	0.91	0.06	92.15	0	0.00130	0.00130	0.555	Low
D56H	0.47	0.04	92.15	0	0.00091	0.00091	0.296	Low
D56J	1.24	0.07	92.15	0	0.00188	0.00188	0.749	Low

8.3.11 Karoo Sandstone and shale East

Recharge increases from 3 mm/a near Loxton, to nearly 12 mm/a around De Aar. The aquifer is of the fractured type and mean borehole yields are 1.5 - 2.5 l/s, hence the aquifer is moderately productive. Groundwater levels are from 5 - 15 mbgl. Groundwater quality is Good to Marginal, of Class 1 - 2, with the marginal groundwater found in the South East between Richmond and De Aar. Arsenic and Molybdenum can be encountered. The potability of groundwater is over 90%, however some boreholes exhibit unexpectedly high salinity, which could be indicative of upwelling deeper groundwater. Since the GRU forms a high lying recharge area with no potential for groundwater flow from upgradient, it has higher recharge than the Karoo further west, and the rocks are of a continental environment not of marine origin, high salinity would not be expected, as is the case in over 90% of boreholes. The pockets of higher salinity could indicate areas of upwelling groundwater.

The aquifer is a sole source of supply for De Aar, Richmond, and Victoria West. Groundwater use is primarily for irrigation, however, water supply to De Aar, Richmond and Victoria West are a significant component of the water use. The stress index is low to moderate. Groundwater levels in D61A near Richmond indicate dropping water levels despite only a moderate stress index, suggesting that localised dewatering is occurring due to local aquifers not being hydraulically connected to the remainder of the catchment. Water levels in D61E and in the De Aar vicinity in D62C and D62D remain stable over the long term since the mid 1970s despite periods of dropping water levels during dry periods.

The GRU is highly dependent on groundwater for water supply, consequently, catchments used for water supply are considered of high priority if they exhibit dropping water levels.

Table 8.11 Karoo Sandstone and shale East: Groundwater component of the Reserve and allocable groundwater information

Quat	Recharge (Mm^3/a)	Stress Index	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D61A	8.46	0.26	89.11	0	0.00892	0.00892	4.069	High
D61B	5.81	0.10	85.45	0	0.00428	0.00428	3.404	Low
D61C	6.96	0.06	86.66	0	0.00390	0.00390	4.264	Low
D61D	2.66	0.19	86.42	0	0.00216	0.00216	1.392	Low
D61E	5.99	0.24	96.36	0	0.00827	0.00827	2.949	High
D61F	2.79	0.08	86.42	0	0.00290	0.00290	1.659	Low
D61G	2.88	0.10	86.42	0	0.00250	0.00250	1.677	Low
D61H	3.83	0.04	86.42	0	0.00263	0.00263	2.388	Low
D61L	3.76	0.02	90.36	0	0.00181	0.00181	2.405	Low
D62C	15.81	0.03	96.04	0	0.01091	0.01091	9.951	High
D62D	28.50	0.15	98.97	0	0.02021	0.02021	15.719	High

8.3.12 Namaqualand East

Recharge is from less than 1 mm to 2 mm. The aquifer is of the fractured and weathered type and mean borehole yields are 0.5 - 2 l/s. Groundwater levels are from 12 - 30 mbgl. This GRU was separated from the rest of Namaqualand Groundwater Region due to a higher water levels and recharge than the rest of Namaqualand and a better water quality class, which is of Class 2 - 3, for domestic purposes. Groundwater is of very variable quality, however, approximately 50% of boreholes are potable. Arsenic is present in groundwater.

Springbok, Kammassies and Paulshoek utilise groundwater, and groundwater use is primarily for water supply for all communities between Kamieskoon and Springbok. The stress index is high in F30D due to abstraction for Springbok. Groundwater level data is of too short a duration to observe water level trends. The groundwater stress index is high in D82D; however, it is uncertain if this can be attributed to too low a recharge estimate for the Quaternary, since much of the remainder of the catchment lies in the drier Bushmanland West GRU that has lower recharge.

The GRU is only moderately dependent on groundwater for water supply, consequently, only catchments where water supply result in a high stress index are considered of high priority.

Table 8.12 Namaqualand East: Groundwater component of the Reserve and allocable groundwater information

Quat	Recharge (Mm^3/a)	Stress Index	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D82D	0.05	0.66	4.06	0	0.00119	0.00119	0.010	Low
F30A	1.24	0.14	43.41	0	0.00613	0.00613	0.694	Low
F30B	0.38	0.25	44.29	0	0.00152	0.00152	0.184	Low
F30C	1.94	0.13	81.67	0	0.00310	0.00310	1.102	Low
F30D	0.62	1.80	54.96	0	0.00258	0.00258	**-0.326***	High
F30E	0.69	0.13	67.55	0	0.00418	0.00418	0.386	Low

8.3.13 Namaqualand West

Recharge is less than 1 mm but can range to over 3 mm in the Garies vicinity due to higher rainfall in the highlands. The aquifer is of the fractured and weathered type and mean borehole yields are low, being 0.1 - 0.5 l/s. Groundwater levels are from 12 to 50 mbgl, being deeper near the coast. Groundwater is generally of Poor to Unacceptable quality, Class 3 - 4. Arsenic and Molybdenum are also present. Groundwater can be of very variable quality, and areas of Class 0 - 2 water also exist, however, less than 40% of boreholes are potable.

The Garies cluster to Kamaggas is reliant on groundwater and most groundwater use is for water supply for the communities of Kamaggas and Garies. De Beers and Bontekoe mine also are significant water users. The stress index is low, except in F30G where mining takes place. Kamaggas also abstracts water from this catchment, however, at a significant distance from De Beers. No water level data is available to determine the level of stress. Groundwater level data in other catchments do not indicate declining water levels.

The GRU is moderately to heavily dependent on groundwater for water supply, consequently, where abstraction results in a high stress index, those catchments are considered of high priority.

Table 8.13 Namaqualand West: Groundwater component of the Reserve and allocable groundwater information

Quat	Recharge (Mm^3/a)	Stress Index	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
F20A	0.25	0.20	43.41	0	0.00038	0.00038	0.132	Low
F20B	0.08	0.23	44.29	0	0.00016	0.00016	0.039	Low
F30F	0.41	0.17	46.63	0	0.00109	0.00109	0.221	Low
F30G	0.23	4.57	94.23	0	0.00186	0.00186	**-0.544***	High
F40B	0.15	0.13	49.54	0	0.00039	0.00039	0.086	Low

Quat	Recharge (Mm^3/a)	Stress Index	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
F40C	1.14	0.04	82.12	0	0.00194	0.00194	0.711	Low
F40E	2.01	0.07	93.37	0	0.00243	0.00243	1.207	Low
F40G	0.68	0.03	97.78	0	0.00062	0.00062	0.430	Low
F50A	1.09	0.04	70.91	0	0.00356	0.00356	0.677	Low
F50B	0.81	0.06	73.68	0	0.00046	0.00046	0.494	Low
F50C	0.57	0.05	64.67	0	0.00086	0.00086	0.353	Low
F50E	1.60	0.02	96.7	0	0.00161	0.00161	1.015	Low
F50F	1.36	0.28	96.37	0	0.00117	0.00117	0.638	Intermediate

* Red text indicates negative allocable groundwater, therefore the quat is already over utilised.

8.3.14 Taung-Prieska Belt

Recharge is from 3.5 mm/a near Prieska rising to 9.5 mm/a near Douglas. The aquifer is of the fractured type and mean borehole yields are 0.5 - 1.5 l/s. Groundwater levels are 15 - 20 mbgl. Groundwater quality is of Class 1 - 2, which is Good to Marginal, however, elevated nitrates can occur. Class 3 water is found in D72A near Prieska. The potability of groundwater ranges from 76% near Prieska to 100%.

No towns rely on groundwater. Groundwater use is primarily for irrigation and livestock, with the major towns obtaining water from the Orange and Vaal systems. The stress index is low due to the low level of groundwater usage. Groundwater levels in D62G and D72A indicate that water levels are stable since 1995 and 2005 respectively.

The GRU is moderately to heavily dependent on groundwater for Schedule 1 water use in areas at a distance from Orange River water. However, due to the low stress indices, all of the catchments are considered of low priority.

Table 8.14 Taung-Prieska Belt: Groundwater component of the Reserve and allocable groundwater information

Quat	Recharge (Mm^3/a)	Stress index	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
C51M	0.84	0.03	53.90	0	0.00748	0.00748	0.523	Low
C92B	3.40	0.04	51.73	0	0.01697	0.01697	2.121	Low
C92C	2.02	0.03	6.18	0	0.01009	0.01009	1.268	Low
D33K	1.44	0.01	7.56	0	0.00219	0.00219	0.924	Low
D62G	7.70	0.12	95.21	0	0.02229	0.02229	4.398	Low
D62J	10.13	0.03	70.52	0	0.00633	0.00633	6.384	Low
D71A	5.33	0.03	61.22	0	0.00340	0.00340	3.353	Low
D71B	2.90	0.03	92.62	0	0.00269	0.00269	1.824	Low
D71C	5.98	0.02	64.61	0	0.00507	0.00507	3.805	Low
D71D	2.70	0.02	87.25	0	0.00320	0.00320	1.719	Low
D72A	2.75	0.03	10.32	0	0.00289	0.00289	1.738	Low

8.3.15 West Griqualand

Recharge is from 2 - 6 mm/a and increases from west to east. The aquifer is of the fractured type and mean borehole yields are low, being 0.5 - 1 l/s. Groundwater levels are 20 - 35 mbgl. Groundwater quality is of Class 1 - 2 but elevated nitrates can occur. Towards the west, south of the Orange River, some Class 2 and 3 boreholes are found near the margins of the Bushmanland East GRU. The potability of groundwater is over 90%.

Niekerkshoop is reliant on groundwater. Otherwise, groundwater use is primarily for irrigation and livestock. The stress index is low due to the low level of groundwater usage. Groundwater levels only indicate a drop of about 1 m in D71D and D72A since 2005.

The GRU is moderately to heavily dependent on groundwater for Schedule 1 water use and for Niekerkshoop, however, due to the low stress indices, all of the catchments are considered of low priority.

Table 8.15 West Griqualand: Groundwater component of the Reserve and allocable groundwater information

Quat	Recharge (Mm^3/a)	Stress Index	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D71B	9.22	0.04	92.62	0	0.00856	0.00856	5.75	Low
D71C	1.02	0.02	64.61	0	0.00087	0.00087	0.65	Low
D71D	4.34	0.11	87.25	0	0.00516	0.00516	2.42	Low
D72A	1.17	0.13	10.32	0	0.00123	0.00123	0.66	Low
D72B	6.52	0.04	4.47	0	0.01064	0.01064	4.08	Low
D72C	2.61	0.01	89.10	0	0.00615	0.00615	1.67	Low
D73B	18.31	0.04	57.83	0.11163	0.01768	0.12931	11.39	Low

8.3.16 Western Kalahari

The GRU consists of largely of Kalahari duneveld. The Molopo River flowing through the GRU does generate sufficient flow to reach the Orange River and much of the flood is lost by evaporation, or seepage to recharge the sand aquifer. This process makes recharge estimation based purely on rainfall problematic and recharge may be higher than estimated. Recharge is less than 1 mm. Three aquifer types exist:

- The surficial intergranular Kalahari sand aquifer, which has yields of 0.5 - 2 l/s;
- The Stampriet confined aquifer system, which underlies the Kalahari in the north and fractured in nature. It has low yields of 0.1 - 0.5 l/s; and
- Other fractured aquifers of the Dwyka, Brulpan Volop and Koras Groups, which have yields of 0.5 - 2 l/s.

Groundwater levels are from 25 to 90 mbgl, being deepest in the northern Kalahari.

The Stampriet Transboundary Aquifer System (STAS) is an international aquifer that stretches from Central Namibia into Western Botswana and into South Africa. It covers a total area of 86 647km^2, for which 73% of the area is in Namibia, 19% in Botswana, and 8% is in South Africa. It is unexposed at surface in South Africa and underlies the Kalahari sands in D42A-D. Over 20 million m^3/year are abstracted rom the Stampriet aquifer, most of which occurs in Namibia (over 95%). The largest consumer of water is irrigation (~46%) followed by stock watering (~38%) and domestic use (~16%).

In the Southeastern quadrant of the aquifer within South Africa, groundwater seeps upward from the confined aquifers and discharges into the Kalahari Formations, from where it evaporates in pans and wetlands. Groundwater salinity in this zone therefore is rather high.

In South Africa, the aquifer has only limited potential for further development because, apart from the poor water quality, the permeability and storativity is low.

Groundwater quality in the GRU generally of Poor to Unacceptable quality, being largely of Class 3 and 4, and only improves in the SE around Karos and Grootdrink in the D73 catchments, where it is of Class 2. In the Kalahari sands, groundwater can be very alkaline. Nitrates are fluorides are elevated in the GRU. In the D73 catchments the Kalahari sands are thinner and recharge is higher hence groundwater quality improves. Fresh groundwater also exists near Philandersbron, where the Kalahari cover disappears and Karoo rocks are exposed, and wetlands exist. The potability of groundwater is about 20% over large parts of the region, and nearly 80% in the D73 catchments.

The Rietfontein and Mier cluster of communities are reliant on groundwater from fractured Dwyka aquifers. Groundwater use is primarily for livestock and water supply, which the remainder for salt mining. The stress index is low due to the low level of groundwater usage. Groundwater levels only indicate a slight drop of about 1 m in D42A Since 2002, but a significant drop of 8 m since 1998 in some boreholes in D73C. Other boreholes indicate stable levels, hence stresses are localised.

The GRU is heavily dependent on groundwater for Schedule 1 water use and for water supply to the towns in the Kalahari Panhandle. However, due to the low stress indices, all of the catchments are considered of low priority.

Table 8.16 Western Kalahari: Groundwater component of the Reserve and allocable groundwater information

Quat	Recharge (Mm^3/a)	Stress Index	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D42A	19.79	0.01	84.53	0	0.00623	0.00623	12.732	Low
D42B	1.71	0.08	91.94	0	0.00707	0.00707	1.017	Low
D42C	1.90	0.19	72.42	0	0.04201	0.04201	1.104	Low
D42D	14.84	0.07	75.92	0	0.03552	0.03552	8.979	Low
D73C	5.08	0.04	82.72	0	0.00931	0.00931	3.172	Low
D73D	1.09	0.04	5.47	0	0.00687	0.00687	0.677	Low
D73E	1.10	0.05	2.26	0	0.00593	0.00593	0.674	Low

8.3.17 Richtersveld

Recharge is less than 1 mm. The aquifer is of the fractured and weathered type and mean borehole yields are very low, being 0 - 0.1 l/s. Groundwater levels are from 30 - 50 mbgl, being deeper to the east. Groundwater is of Marginal to Unacceptable quality, Class 2 - 4. The potability of groundwater ranges from 0 - 60%.

Eksteenfontein is the only community reliant on groundwater. Groundwater use is primarily for livestock and water supply. The stress index is moderate to high due to the very low recharge rates.

The GRU is only moderately dependent on groundwater, except for D82H, where Eksteenfontien derives its water supply from boreholes. This catchment is considered to be only of intermediate importance due to the moderate stress index of 0.42.

Table 8.17 Richtersveld: Groundwater component of the Reserve and allocable groundwater information

Quat	Recharge (Mm^3/a)	Stress Index	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D82A	0.01	2.58	69.43	0	0.00110	0.00110	**-0.013***	Low
D82D	0.01	0.66	4.06	0	0.00022	0.00022	0.002	Low
D82E	0.22	0.16	47.29	0	0.00091	0.00091	0.118	Low
D82F	0.26	0.14	8.09	0	0.00098	0.00098	0.148	Low
D82G	0.10	0.22	6.29	0	0.00094	0.00094	0.049	Low
D82H	0.10	0.42	96.87	0	0.00044	0.00044	0.037	Intermediate
D82J	0.10	0.43	34.83	0	0.00006	0.00006	0.037	Low

8.3.18 Namaqualand Coastal

Recharge is from less than 1 mm to 2 mm. The aquifer is of the fractured and weathered type but mean borehole yields are very low, being less than 0.1 l/s. Groundwater levels are from 40 - 50 mbgl. Groundwater is generally of Class 3 and 4, Poor to Unacceptable, except in the north, in F40A and F40D, where Classes 2 and 3 water exist. The potability of groundwater is less than 30%.

The aquifer is a sole source of supply for Kleinzee, Hondeklipbaai and Kolingnaas. Groundwater use is primarily for livestock and water supply. The stress index is low to moderate due to the small population and very low recharge rates.

The GRU moderately to heavily dependent on groundwater despite the poor quality, as no surface water source is available. The catchments are considered to be of low importance due to the low to moderate stress indices.

Table 8.18 Namaqualand Coastal: Groundwater component of the Reserve and allocable groundwater information

Quat	Recharge (Mm^3/a)	Stress Index	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
F40A	1.49	0.14	88.89	0	0.00117	0.00117	0.831	Low
F40D	0.95	0.04	62.3	0	0.00066	0.00066	0.591	Low
F40F	0.70	0.19	97.31	0	0.01048	0.01048	0.363	Low
F40H	0.14	0.17	73.68	0	0.00040	0.00040	0.074	Low
F50G	0.17	0.30	73.68	0	0.00059	0.00059	0.077	Low
F60A	0.14	0.28	81.59	0	0.00103	0.00103	0.065	Low

8.3.19 Karoo Sandstone and Shale Southwest

The Karoo sandstones and shales of the Beaufort Group overlie the Ecca Group. Small volumes of baseflow potentially exist in the Sutherland vicinity due to higher rainfall, however, any baseflow is lost further down the channel. Recharge increases from 3 - 8 mm/a from north to south, being highest in the Sutherland vicinity. The aquifer is of the fractured type and mean borehole yields are 1.5 - 2.5 l/s, hence the aquifer is moderately productive. Groundwater levels are from 5 - 13 mbgl.

Groundwater quality is of Class 1 - 2, however, high fluorides can be encountered. The potability of groundwater is over 90%.

The aquifer is a sole source of supply for Sutherland. Groundwater use is primarily for irrigation, however, water supply to Sutherland is a significant component of the water use. The stress index is low, but is moderate in D51A due to irrigation and water supply to Sutherland. Groundwater levels in D51A indicate dropping water levels 12 m below original water levels in 2011, despite only a moderate stress index, suggesting that localised dewatering is occurring due to local aquifers not being connected hydraulically to the remainder of the catchment.

The GRU is highly dependent on groundwater for water supply, consequently, catchment D51A with a dropping water level is considered of high priority.

Table 8.19 Karoo Sandstone and Shale Southwest: Groundwater component of the Reserve and allocable groundwater information

Quat	Recharge (Mm^3/a)	Stress Index	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D51A	5.05	0.23	99.64	0.1594	0.00347	0.16287	2.438	High
D52A	3.06	0.09	92.15	0	0.00078	0.00078	1.808	Low
D52B	3.29	0.14	92.15	0	0.00130	0.00130	1.840	Low
D56A	3.00	0.02	92.15	0	0.00104	0.00104	1.922	Low
D56B	2.46	0.06	92.06	0	0.00107	0.00107	1.503	Low
D56C	3.01	0.02	92.15	0	0.00188	0.00188	1.928	Low
D56E	1.41	0.03	92.15	0	0.00136	0.00136	0.888	Low

9 BASIC HUMAN NEEDS

This report is summarised from: (DWS, 2016d)
Department of Water and Sanitation, South Africa, October 2016. Determination of Ecological Water Requirements for surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Basic Human Needs report. Prepared by: Nomad Consulting. Authored by G. Huggins. DWS Report No: RDM/WMA06/00/CON/COMP/0516.

9.1 INTRODUCTION

The National Water Act (36 of 1998) ensures that everyone has access to sufficient water by setting aside a certain amount of water to meet everyone's basic needs. This amount of water set aside for basic human needs is called the Basic Human Needs Reserve (BHNR). The BHNR is based upon the current and projected population of those either living within the catchment and directly dependant on the catchment or, critically, not being supplied with water from a recognised formal source. It does not include the population outside of the catchment who may be utilising the water. This chapter sets out the results of the analysis of the population within the study area with respect to the Basic Human Needs (BHN).

9.2 APPROACH

To calculate the BHNR the following steps were specifically undertaken:

- Analysis was based on quaternary division. There are 145 quaternary divisions each of which were analysed by source of water and by households and individuals who are dependent on these sources. While the national census asks respondents about their water source it reports these in an amalgamated fashion using its own geographical conglomeration. As these do not coincide with quaternary divisions the results were reanalysed to ensure that the population is allocated to the relevant quaternary. This was done using Geographical Information System (GIS) technology.
- Quaternary catchment boundaries were superimposed upon the smallest aggregations of census data available. For the 2011 National census these are known as "sub-place names". SSA collects information and then amalgamates in a manner that is not geographically consistent with the analysis required for the BHNR. SSA makes data available at sub-place name level. Each sub-place name has to be allocated to a quaternary. As such all "sub-place names" either wholly or partially within the quaternary catchments were captured. Where "sub-place names" were partially within the quaternary catchments then the percentage area that fell within was applied to the population. As such, where a "sub-place name" was only 50% within a quaternary catchment then only 50% of the population was deemed to fall within the area. The total population for the Lower Orange River WMA, as recorded by the 2011 Census, was 451,620. Extrapolated to 2016 using an average growth rate of 0.25%[11] for the years for 2011 to a current population figure for 2016 of 457,324 is derived.
- Those receiving water from a recognised formal water source and therefore not likely to be dependent on direct abstraction from the rivers were excluded. Given the nature of the WMA, as set out in Section 2, most of the population fall within the ambit of those likely to be receiving a formal water supply. The remainder are deemed to be part of the "qualifying population".
- For the purposes of the BHNR estimating the population likely to be BHNR dependant were classified as that dependant on boreholes, springs, dams and pools, rivers and streams, water

[11] The population of the WMA is growing at a slower rate than the national average of 1.00% per annum and reflects lack of economic opportunities in the general area and out migration.

tankers and other means of supply but excluding formal water schemes. The 2016 population in this category was estimated at 95,957[12].

- Those dependent on boreholes were in terms of calculations as these were deemed to be part of the Groundwater Reserve (and schedule 1 users) and covered in report RDM/WMA06/00/CON/COMP/0416. Towns that are heavily dependent on groundwater with their usage are listed in Table 9.1. It should be noted that the bulk of the geographical spread of the population in the area is either supplied out of formal water supplied by groundwater or personal boreholes and are thus directly groundwater dependent.
- As such the final population that was included in the non-groundwater dependant BHNR amounted to 55,901 people or 12.2% of the recorded population. If those that are reliant on boreholes and not serviced by formal schemes is retained within the calculation the figure remains at 95,957 as above.
- The BHNR was initially calculated at 25l per day per person. The number was aligned with initial RDP targets set as minimum standards for the South African population. During 2002 (Thukela Reserve study) and confirmed during the description of the method (DWAF, 2008c) the DWS suggested that more acceptable volumes of water per day such as 55 or 60 liters was also to be investigated. This was confirmed during a recent meeting (DWS, 2017d) and stated as part of the recent study providing frameworks for the Reserve and describing available tools (DWS 2016e). It must therefore be noted that the BHN during this step of a Reserve study is calculated for various scenarios that includes 25 and 60 litres and as for the Ecological Reserve, the DWS will then determine which is suitable for the Reserve or Preliminary Reserve to be accepted.

Table 9.1 Towns Served by Groundwater[13]

Town	Assumed Use (MCM/a)
Campbell	0.473
Mier LM Combined Clusters Groot Meir	0.15
Klein Mier	0.01898
Welkom	0.01241
Van Zylsrust	0.132
Loubos	0.01825
Rietfontein	0.078475
Philandersbron	0.04015
Sutherland	0.15
Kenhardt	0.248
Carnarvon	0.485
Vanwyksvlei	0.1
Loxton	0.445
Fraserburg	0.192355
Williston	0.221
Brandvlei	0.137
Richmond	0.564
Victoria West	0.722
Britstown	0.349

[12] The figure for 2016 is virtually identical for 2011 as little no growth is expected in this sector of the population.
[13] Refer to DWS (2016c).

Town	Assumed Use (MCM/a)
Vosburg	0.146
De Aar	2.798
Strydenburg	0.146
Griekwastad	0.5
Niekerkshoop	0.148
Marydale	0.245
Groenwater	0.01533
Jenn Haven	0.01022
Postmasburg	1.12
Pofadder	N/A
Eksteenfontein	0.01533
Khubus	0.064605
Lekkersing	0.02044
Port Nolloth	0.409
Kammassies	0.01898
Leliefontein	0.026
Nourivier	0.01095
Kamieskroon	0.16
Buffelsrivier	0.03504
Bulletrap	0.0219
Kleinsee	0.09125
Komaggas	0.170455
Koingnaas	0.077015
Karkhams	0.091615
Hondeklip	0.066795
Klipfontein	0.002555
Paulshoek	0.00584
Kheis	0.009125
Garies	0.348
Springbok	0.851
TOTAL	**12.16107**

9.3 RESULTS

As per the TOR the BHN associated with all resources has been determined, using guidelines as set out in DWAF (1999; 2008c).

The BHNR report follows a standard typology developed for DWS. The typology was first used for the Vaal Reserve and is an evolution of the method used previously. The Census 2011 gives a breakdown of reliance on water sources and was key in determining the sources used by the population. Sources typically specified in the census include Regional Water supply schemes, boreholes, springs, rainwater dams, rivers or streams, water vendors, and water tanks. The WMA was analysed in terms of these types of services provided as well as source of supply. This allows for the geographical spread of service types within the WMA. As such the BHNR is based upon the current and projected population of those either living within the catchment and directly dependant on the catchment or, critically, not being supplied with water from a recognised formal source. It does not include the population outside of the catchment who may be utilising the water.

The BHNR for this portion of the population, with models assuming allocations of 25 and 60 litres of water per capita (person) per day (l/c/d) were then calculated and summarised in Table 9.2.

Table 9.2 Summary of BHNR at 25 litres per person per day

Total Population	457,324	**Cubic metres per day**	**Million m^3/a**
Population not serviced	95,957		
Population not serviced excluding borehole	55,901		
Population borehole dependant	40,056		
Surface water BHNR 1: @ 25 l/c/d - excluding those on a formal scheme	1,378,947	1,378	0.503
Groundwater BHNR 1@ 25 l/c/d - excluding those on a formal scheme	1,019,980	1,019	0.373
BHNR 1: @ 25 l/c/d including borehole dependant - - excluding those on a formal scheme	2,398,926	2,399	0.876

In terms of million m^3/a the surface water volume (obviously excluding groundwater) would be 0,503 at BHNR1 levels at 25l per person per day. The bulk of surface water abstraction is from the Orange River although there is other ad hoc and seasonal abstraction of surface water from other sources. Including groundwater usage, and in terms of million m^3/a the volume would be 0,876 at BHNR1 levels at 25l per person per day. At 60 litres per person per day the figures are as per Table 9.3.

Table 9.3 Summary of BHNR at 60 litres per person per day

Total Population	457,324	**Cubic metres per day**	**Million m^3/a**
Population not serviced	95,957		
Population not serviced excluding borehole	55,901		
Population borehole dependant	40,056		
Surface water BHNR 1: @ 25 l/c/d - excluding those on a formal scheme	3,354,059	3,354	1.216
Groundwater BHNR 1@ 25 l/c/d - excluding those on a formal scheme	2,403,363	2,403	0.877
BHNR 1: @ 25 l/c/d including borehole dependant - - excluding those on a formal scheme	5,757,423	5,757	2.101

The BHN component of the Reserve is readily calculated by multiplying the number of people living within the confines of a resource unit AND WITHOUT A CURRENT FORMAL SOURCE OF WATER SUPPLY by 25 l/d. Where a large proportion of the population already has access to a formal regional water system, setting aside a BHN for this portion and adding it to existing lawful groundwater use would result in a double accounting of water allocations. Hence this study took the approach of only calculating a BHN for the population without access to a formal regional water supply. However, since the bulk of users included in the Reserve are Schedule 1 users, a per capita consumption of 200 l/c/d was utilised to calculate current water use. This use incorporates 25 l/c/d which fall under the BHN Reserve.

The BHNR can thereafter be split into the surface and groundwater component of the BHNR to avoid double accounting. The Groundwater component of the BHNR utilised in this study was the proportion of people reliant on groundwater without a formal source of supply (Table 9.4).

Table 9.4 The BHN for the Lower Orange WMA at quaternary level

Catchment	Population not on formal scheme	Population on bore hole (Schedule 1)	GW dependency % of population	Total BHN (MCM/a @25l/p/d)	GW BHN (MCM/a @25l/p/d)	SW[1] BHN (MCM/a @25l/p/d)
C51M	627	342	53.898	0.006	0.003	0.003
C92B	1641	1106	51.725	0.015	0.010	0.005
C92C	3496	1359	6.180	0.032	0.012	0.019
D33K	157	100	7.564	0.001	0.001	0.001
D42A	365	284	84.533	0.003	0.003	0.001
D42B	425	323	91.938	0.004	0.003	0.001
D42C	3192	1918	72.419	0.029	0.018	0.011
D42D	3356	1622	75.921	0.031	0.015	0.015
D42E	2408	804	27.591	0.022	0.007	0.014
D51A	171	158	99.636	0.002	0.001	0.000
D51B	89	80	92.136	0.001	0.001	0.000
D51C	53	47	92.022	0.000	0.000	0.000
D52A	39	36	92.149	0.000	0.000	0.000
D52B	65	59	92.149	0.001	0.001	0.000
D52C	47	42	92.101	0.000	0.000	0.000
D52D	70	62	91.860	0.001	0.001	0.000
D52E	66	58	91.860	0.001	0.001	0.000
D52F	125	109	91.860	0.001	0.001	0.000
D53A	711	186	34.142	0.006	0.002	0.005
D53B	626	174	55.761	0.006	0.002	0.004
D53C	1522	175	77.491	0.014	0.002	0.012
D53D	1299	142	28.581	0.012	0.001	0.010
D53E	602	64	28.339	0.005	0.001	0.005
D53F	1115	512	51.464	0.010	0.005	0.005
D53G	2984	356	28.942	0.027	0.004	0.024
D53H	1149	121	28.339	0.010	0.001	0.009
D53J	884	76	6.212	0.008	0.001	0.007
D54A	180	155	86.689	0.002	0.001	0.000
D54B	907	715	97.845	0.008	0.007	0.002
D54C	159	137	86.689	0.001	0.001	0.000
D54D	752	522	73.185	0.007	0.005	0.002
D54E	354	316	90.572	0.003	0.003	0.000
D54F	430	373	89.191	0.004	0.003	0.001
D54G	1091	499	48.523	0.010	0.005	0.005
D55A	560	519	94.326	0.005	0.005	0.000
D55B	132	119	91.734	0.001	0.001	0.000
D55C	175	155	92.092	0.002	0.001	0.000
D55D	382	324	96.328	0.003	0.003	0.001
D55E	347	303	98.779	0.003	0.003	0.000
D55F	393	335	87.207	0.004	0.003	0.001
D55G	192	165	88.267	0.002	0.002	0.000
D55H	118	107	92.149	0.001	0.001	0.000
D55J	202	184	92.149	0.002	0.002	0.000

Catchment	Population not on formal scheme	Population on bore hole (Schedule 1)	GW dependency % of population	Total BHN (MCM/a @25l/p/d)	GW BHN (MCM/a @25l/p/d)	SW[1] BHN (MCM/a @25l/p/d)
D55K	127	115	92.149	0.001	0.001	0.000
D55L	263	220	98.844	0.002	0.002	0.000
D55M	184	167	92.137	0.002	0.002	0.000
D56A	52	47	92.149	0.000	0.000	0.000
D56B	54	49	92.057	0.000	0.000	0.000
D56C	95	86	92.149	0.001	0.001	0.000
D56D	62	56	92.149	0.001	0.001	0.000
D56E	69	62	92.149	0.001	0.001	0.000
D56F	105	95	92.149	0.001	0.001	0.000
D56G	65	59	92.149	0.001	0.001	0.000
D56H	46	41	92.149	0.000	0.000	0.000
D56J	95	86	92.149	0.001	0.001	0.000
D57A	91	80	91.975	0.001	0.001	0.000
D57B	232	210	92.149	0.002	0.002	0.000
D57C	126	92	97.943	0.001	0.001	0.000
D57D	770	577	91.996	0.007	0.005	0.002
D57E	1115	178	32.247	0.010	0.002	0.008
D58A	83	73	91.918	0.001	0.001	0.000
D58B	156	133	94.882	0.001	0.001	0.000
D58C	275	242	91.895	0.003	0.002	0.000
D61A	1031	407	89.109	0.009	0.004	0.005
D61B	240	195	85.451	0.002	0.002	0.000
D61C	211	178	86.661	0.002	0.002	0.000
D61D	117	99	86.419	0.001	0.001	0.000
D61E	704	378	96.356	0.006	0.004	0.003
D61F	158	132	86.419	0.001	0.001	0.000
D61G	136	114	86.419	0.001	0.001	0.000
D61H	198	166	86.419	0.002	0.002	0.000
D61J	243	206	86.508	0.002	0.002	0.000
D61K	247	213	87.452	0.002	0.002	0.000
D61L	187	167	90.364	0.002	0.002	0.000
D61M	172	152	89.541	0.002	0.001	0.000
D62A	962	817	97.510	0.009	0.008	0.001
D62B	648	546	94.182	0.006	0.005	0.001
D62C	562	498	96.043	0.005	0.005	0.001
D62D	1269	923	98.969	0.012	0.009	0.003
D62E	357	321	90.759	0.003	0.003	0.000
D62F	350	297	86.279	0.003	0.003	0.000
D62G	2298	2130	95.210	0.021	0.019	0.001
D62H	342	238	70.152	0.003	0.002	0.001
D62J	416	289	70.521	0.004	0.003	0.001
D71A	414	243	61.223	0.004	0.002	0.002
D71B	1396	828	92.625	0.013	0.008	0.005
D71C	432	271	64.613	0.004	0.003	0.001
D71D	645	382	87.249	0.006	0.004	0.002
D72A	464	234	10.324	0.004	0.002	0.002
D72B	1166	580	4.466	0.011	0.005	0.005
D72C	934	564	89.099	0.009	0.005	0.003

Catchment	Population not on formal scheme	Population on bore hole (Schedule 1)	GW dependency % of population	Total BHN (MCM/a @25l/p/d)	GW BHN (MCM/a @25l/p/d)	SW[1] BHN (MCM/a @25l/p/d)
D73A	5098	1504	100.000	0.047	0.014	0.033
D73B	1466	807	57.826	0.013	0.008	0.006
D73C	1754	1150	82.721	0.016	0.011	0.005
D73D	3339	713	5.470	0.030	0.007	0.024
D73E	2352	524	2.256	0.021	0.005	0.017
D73F	9112	1148	1.300	0.083	0.011	0.073
D81A	4225	523	5.770	0.039	0.005	0.034
D81B	501	51	36.847	0.005	0.001	0.004
D81C	1401	211	34.836	0.013	0.002	0.011
D81D	1313	139	28.339	0.012	0.001	0.011
D81E	707	110	9.023	0.006	0.001	0.005
D81F	1143	169	61.055	0.010	0.002	0.009
D81G	560	134	2.505	0.005	0.001	0.004
D82A	411	107	69.435	0.004	0.001	0.003
D82B	556	195	40.139	0.005	0.002	0.003
D82C	774	235	8.514	0.007	0.002	0.005
D82D	635	176	4.062	0.006	0.002	0.004
D82E	126	42	47.288	0.001	0.000	0.001
D82F	184	45	8.094	0.002	0.000	0.001
D82G	199	43	6.294	0.002	0.000	0.001
D82H	37	20	96.873	0.000	0.000	0.000
D82J	8	3	34.831	0.000	0.000	0.000
D82K	296	102	81.849	0.003	0.001	0.002
D82L	439	86	2.637	0.004	0.001	0.003
F10A	7	2	34.831	0.000	0.000	0.000
F10B	17	5	34.831	0.000	0.000	0.000
F10C	19	6	34.831	0.000	0.000	0.000
F20A	54	17	43.407	0.000	0.000	0.000
F20B	29	9	44.291	0.000	0.000	0.000
F20C	168	99	81.666	0.002	0.001	0.001
F20D	112	15	54.956	0.001	0.000	0.001
F20E	14	5	67.545	0.000	0.000	0.000
F30A	401	280	93.266	0.004	0.003	0.001
F30B	207	69	58.267	0.002	0.001	0.001
F30C	330	142	93.525	0.003	0.001	0.002
F30D	457	118	97.249	0.004	0.001	0.003
F30E	543	191	4.411	0.005	0.002	0.003
F30F	151	50	46.628	0.001	0.000	0.001
F30G	290	85	94.227	0.003	0.001	0.002
F40A	134	53	88.891	0.001	0.001	0.001
F40B	48	18	49.539	0.000	0.000	0.000
F40C	155	89	82.120	0.001	0.001	0.001
F40D	56	30	62.303	0.001	0.000	0.000
F40E	250	111	93.373	0.002	0.001	0.001
F40F	494	478	97.311	0.005	0.004	0.000
F40G	40	28	97.782	0.000	0.000	0.000
F40H	25	18	73.684	0.000	0.000	0.000
F50A	729	163	70.911	0.007	0.002	0.005

Catchment	Population not on formal scheme	Population on bore hole (Schedule 1)	GW dependency % of population	Total BHN (MCM/a @25l/p/d)	GW BHN (MCM/a @25l/p/d)	SW[1] BHN (MCM/a @25l/p/d)
F50B	30	21	73.684	0.000	0.000	0.000
F50C	125	39	64.672	0.001	0.000	0.001
F50E	106	73	96.703	0.001	0.001	0.000
F50F	128	53	96.375	0.001	0.001	0.001
F50G	38	27	73.684	0.000	0.000	0.000
F60A	143	47	81.591	0.001	0.000	0.001
TOTAL	**95957**	**40056**		**0.876**	**0.373**	**0.503**

1 Surface water

10 WETLAND ECOLOGICAL WATER REQUIREMENT

This report is summarised from: (DWS, 2016f)
Department of Water and Sanitation, South Africa, November 2016. Determination of Ecological Water Requirements for surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Wetland EWR report. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. Authored by J. Mackenzie. DWS Report No: RDM/WMA06/00/CON/COMP/0616.

The chapter addresses the following:

- Desktop assessment of the EcoClassification for wetlands at the SQ scale.
- Refinement of the wetland priorities to include potential fracking.
- EWRs for high priority wetlands.

10.1 INTRODUCTION

The purpose of this chapter is to quantify the EWRs for wetland recommended ecological states. Once the desired Ecological Category has been set, thereafter called the REC, the EWR is determined according to wetland type, for high priority wetlands. The process for determining wetland priority is ultimately adjusted by WRUI, which frequently produces higher priority wetlands that are less ecologically important and vice versa. What follows is the determination of the EWR for high priority wetlands, but the WRUI has been adjusted upwards to cater for proposed and possible fracking in the catchment.

10.2 APPROACH

The approach is in keeping with outlined techniques for the rapid ecological reserve determination of inland wetlands (Rountree *et al.*, 2013), and is to provide conditions that support the hydrological functioning of wetlands for the maintenance of a desired ecological state (Wetlands tools report, in prep). These conditions will vary depending on wetland type. For each priority wetland the EWR will be determined according to the following steps:

1) Determine dominant wetland HGM type
2) Determine appropriate level of RDM study for wetland/s
3) Assess EcoStatus of priority wetland/s
4) Determine EWR (or other RDM) to achieve REC

The Hydrogeomorphic (HGM) wetland type dictates the method of RDM study, as there are different types of assessment methods and EWR determination approaches for different types of wetlands. For the Rapid Reserve methods for wetlands, the DWS (2007b), and Rountree and Batchelor (2013) HGM wetland classification was used.

Rountree *et al.* (DWA, 2013) provide a framework for selecting the appropriate level of RDM study for wetlands. This approach uses the type of wetland and main impact or threat to identify an appropriate level of RDM assessment. The RDM assessment may be either a quantitative EWR determination, a qualitative EWR determination or, in the most simple (low risk) situations, the determination of simple conditions to achieve the REC.

10.3 RESULTS

10.3.1 Wetland EcoClassification

The assessment of wetland ecoclassification relied on both of the riparian/wetland metrics rated in the PESEIS database (DWS, 2014): The underlying assumption is that these two metrics incorporate wetlands within each SQ (where SQs exist), and as such should provide a useful measure of a more detailed investigation (visual assessment by specialist using satellite imagery) of overall ecological state. Furthermore, it is assumed that although these metrics include the riparian area, they remain a more realistic assessment of PES than the "wetcon" condition values within NFEPA data. Results of the assessment are shown in Figure 10.1.

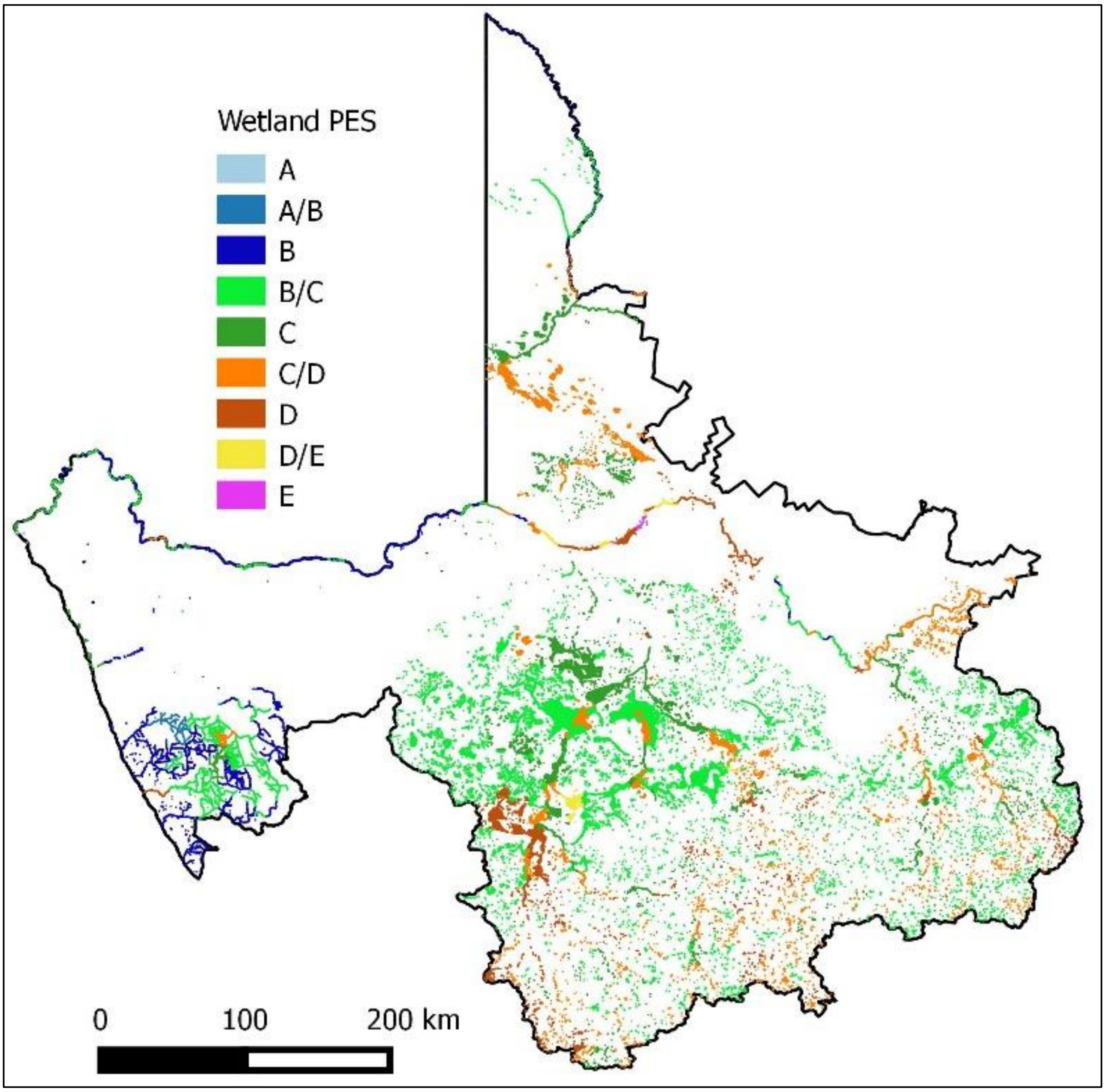


Figure 10.1 PES values assigned to wetlands within each SQ (where wetlands occurred according to the NFEPA coverage, and SQs occurred according to the SQ delineation)

10.3.2 Wetland Priority

The desktop EcoClassification of wetlands was summarised at the SQ level and formed the basis of a preliminary prioritisation. This prioritisation showed that the ecologically important wetlands were frequently those with low WRUI and vice versa. High and Very High priority wetlands formed three distinct groupings of wetland HGM types (Figure 10.2). These were floodplain wetlands associated with the main stem of the Orange River, depressions (some large but mostly small pans) towards the southern part of the catchment and higher density channelled and unchannelled valley bottom wetlands in quaternary catchments D62C (Elandsfontein), D62D (Brak) and D55E.

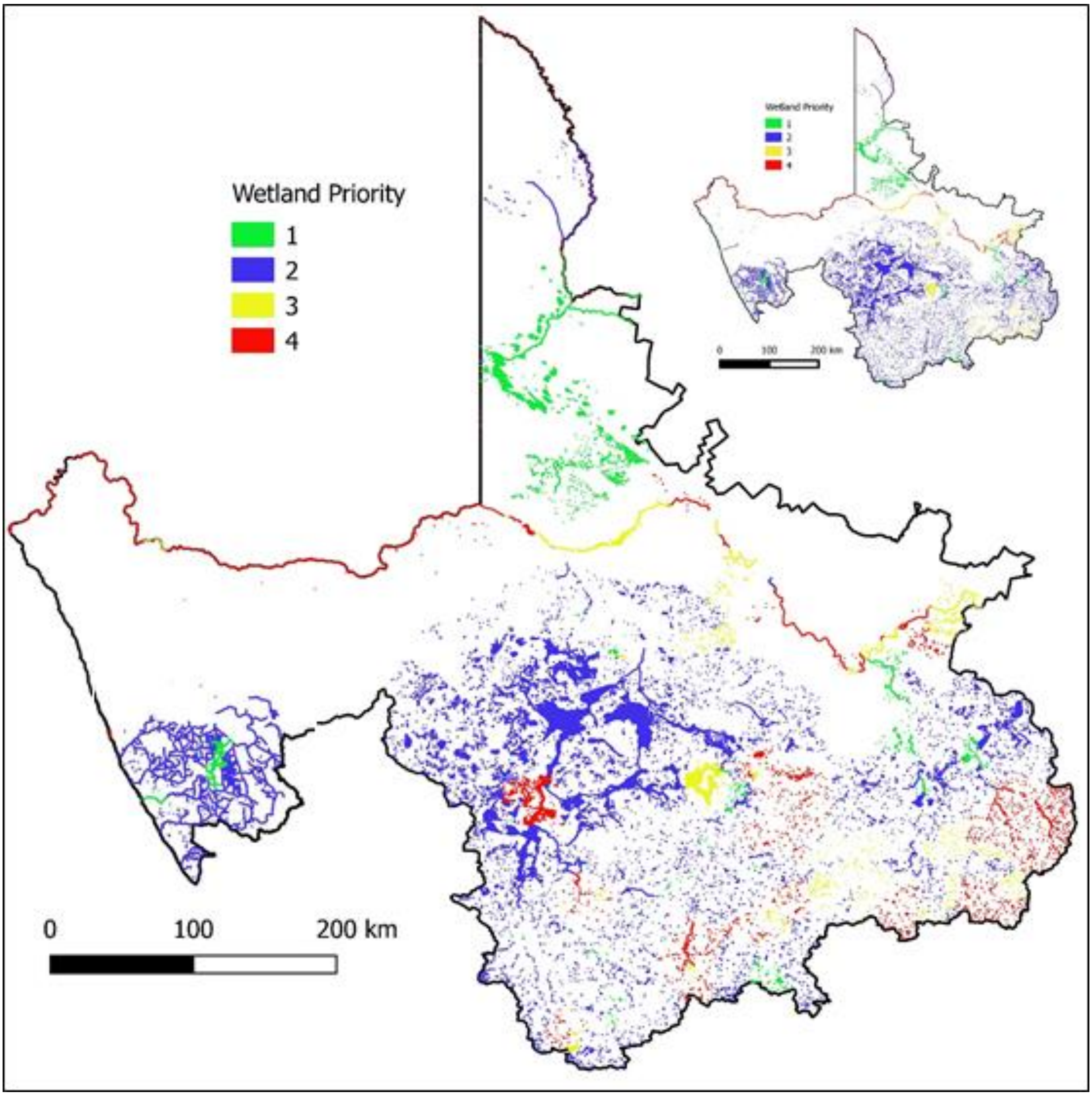


Figure 10.2 Wetland priority, where 1 = Low and 4 = Very High with the inclusion of fracking and highly important GRUs. (Inset shows wetland priority without fracking)

10.3.3 Wetland EWR

Floodplains along the Orange River are mostly in-channel features such as inset benches, flood benches or terraces and are not comparable to meandering floodplains outlined by Rountree *et al*.

(DWA, 2012). These floodplains are assessed when the riparian zone is assessed e.g. EWR 3 and 4 at Augrabies and Vioolsdrift respectively. The EWR for floodplain wetlands will therefore be a quantitative flow regime, mostly related to specific flood events that are required for floodplain inundation and sediment and nutrient dynamics. Such a flow regime could be adjusted for extrapolation to upstream and downstream similar floodplains (as per procedures used in the determination of the EWR for rivers).

High priority pans are numerous in the catchment. Some of these pans are extensive e.g. Verneuk Pan, Grootvloer, Boesmankop, Bitterputs and can be in excess of thousands of hectares. Procedures outlined in DWA (2012) for the desktop Reserve of pans outline Fluvius (2007) as the method to use (see appendix A8.4. in Rountree *et al*. (2013) for the example). The example (of a single pan) in Fluvius (2007) merely relates annual rainfall (Sep to Aug) to area of pan inundated at end of the dry season. It was decided instead that for each of the large pans a Level 1 WET-Health would be conducted using Google Earth © to assess the vegetation PES (which is based on current land use within each pan) as a measure of the wetland PES (MacFarlane *et al*., 2007). The EWR of high priority pans is expressed through ecological specifications that protect the habitat. To provide these specifications, the EWRs were expressed in terms of a REC (Table 10.1), which is dependent on the PES, and the ecological importance denotes whether the REC is the same as the PES or an improvement, if at all possible. Where the REC is an improvement of the PES, this will involve management of land use. The most common method to achieve the REC where it is higher than the PES is the removal of alien vegetation (notably *Prosopis glandulosa*), reduced agricultural encroachment of wetlands and management of grazing pressures and watering points for livestock.

Table 10.1 Updated PES using vegetation component of WET-Health for high priority pans

Name	HGM	Size (Ha)	PES	EI	ES	SCI	Trajectory of change	REC
Bosduiflaagte	Depression (Pans)	24029	B	Very High	Very Low	Low	→	B
Grootvloer B	Depression (Pans)	17069	B	Very High	Low	Low	↓	B
Grootvloer NW	Depression (Pans)	7556	C	High	Low	Low	↓	B/C
Grootvloer-Sak	Depression (Pans)	74429	B	High	Very Low	Low	↓	B
Skerpionkolk	Depression (Pans)	1470	C	Very High	Very Low	Low	↓	B/C
Van Wyksvlei	Depression (Pans)	24435	C	High	Low	Low	↓	B/C
Verdorstkolk	Depression (Pans)	4208	A	Very High	Very Low	Low	→	A
Verneukpan	Depression (Pans)	57656	C	Very High	Very Low	Low	↓	B/C

Channelled and unchannelled valley bottom wetlands in quaternary catchments D62C (Elandsfontein), D62D (Brak) and D55E (Sak and Sout) were assessed during the PESEIS project (DWS, 2014) as part of the riparian / wetland component assessment. These metrics were used in this study to denote values for the EI, ES and PES and verified using Google Earth ©. The EWR of high priority channelled and unchannelled valley bottom wetlands are also expressed through ecological specifications that protect the habitat. To provide these specifications, the EWRs are expressed in terms of a REC (see Table 10.2). This table also outlines the strategy required in order to achieve the REC.

Table 10.2 Results of PES and REC assessment for High priority channelled and unchannelled valley bottom wetlands

SQ Reach PESEIS	Name	PES	Reason for PES	REC	Strategy to achieve REC
D55E-06496	Sak	C	Alien vegetation, grazing	B	Can improve wetland modification by reducing alien vegetation and grazing pressure
D55E-06529	Sout	D/E	Alien vegetation, grazing, agricultural encroachment, small to medium dams	D	Can improve wetland modification by reducing alien vegetation and grazing pressure
D55E-06663	Sout	C	Alien vegetation, grazing	B/C	Can improve wetland modification by reducing alien vegetation and grazing pressure
D55E-06713	Sout	C	Alien vegetation, grazing	B/C	Can improve wetland modification by reducing alien vegetation and grazing pressure
D55E-06728		C/D	Alien vegetation, small dams	C	Can improve wetland modification by reducing alien vegetation
D55E-06729	Sout	C/D	Alien vegetation, grazing, agricultural encroachment, small to medium dams	C	Can improve wetland modification by reducing alien vegetation and grazing pressure
D55E-06768		C/D	Agricultural encroachment, small dams, infrastructure, alien vegetation	C	Can improve wetland modification by reducing alien vegetation and agricultural encroachment
D55E-06825	Sout	C	Alien vegetation, grazing, agricultural encroachment	B/C	Can improve wetland modification by reducing alien vegetation and grazing pressure
D55E-06854	Sout	C/D	Alien vegetation, grazing, agricultural encroachment	C	Can improve wetland modification by reducing alien vegetation and grazing pressure
D62C-05303	Elands-fontein	C/D	Small dams, watering points, infrastructure, alien vegetation, grazing	C	Can improve wetland modification by reducing alien vegetation
D62C-05419		C	Small dams, watering points, alien vegetation, grazing	B/C	Can improve wetland modification by reducing alien vegetation, and continuity by removal unnecessary infrastructure
D62C-05422	Elands-fontein	C	Small to medium dams, watering points, pivot agriculture, infrastructure, grazing, alien vegetation	B/C	Can improve wetland modification by reducing alien vegetation and encroaching agriculture, and continuity by removal unnecessary infrastructure
D62C-05576	Elands-fontein	D	Small to medium dams, watering points, pivot agriculture, infrastructure, grazing, alien vegetation	C/D	Can improve wetland modification by reducing alien vegetation
D62D-05183	Brak	C	Alien vegetation, grazing, infrastructure	B/C	Can improve wetland modification by reducing alien vegetation and grazing pressure
D62D-05227	Brak	C	Alien vegetation, grazing, infrastructure, small dams	B/C	Can improve wetland modification by reducing alien vegetation and grazing pressure
D62D-05332	Brak	C/D	Alien vegetation, grazing, infrastructure, small dams, agricultural encroachment	C	Can improve wetland modification by reducing alien vegetation and encroaching agriculture

SQ Reach PESEIS	Name	PES	Reason for PES	REC	Strategy to achieve REC
D62D-05391	Brak	C/D	Alien vegetation, grazing, infrastructure, small dams, agricultural encroachment	C	Can improve wetland modification by reducing alien vegetation and encroaching agriculture
D62D-05486	Brak	D	small and medium dams, alien vegetation, infrastructure, grazing	C/D	Can improve wetland modification by reducing alien vegetation and grazing pressure
D62D-05553	Brak	D	small dams, encroaching agriculture, alien vegetation, overgrazing	C/D	Can improve wetland modification by reducing alien vegetation and grazing pressure
D62D-05613	Brak	D/E	small dams, encroaching agriculture, alien vegetation, overgrazing	C/D	Can improve wetland modification by reducing alien vegetation and grazing pressure

11 SCENARIO DESCRIPTIONS

This report has been summarised from: (DWS, 2017b)
Department of Water and Sanitation, South Africa, May 2017. Determination of Ecological Water Requirements for surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Report on consequences of scenarios. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. DWS Report No: RDM/WMA06/00/CON/COMP/0117.

11.1 GENERAL

Although scenario (Sc) evaluation and comparison of alternatives will be dealt with comprehensively in the subsequent Classification of the water resources of the Lower Orange, a preliminary assessment of scenarios was undertaken in this study to estimate how proposed scenarios (changes in the operation of the system) could influence the ecological flows at key EWR sites along the Orange River and its estuary.

Scenarios, in context of water resource management and planning are plausible definitions (settings) of all the factors (variables) that influence the water balance and water quality in a catchment and the system as a whole. The scale (resolution) of the analysis requires the aggregation of land use effects and therefore individual and localised small scale developments will not significantly influence the study results.

The recommended intervention options described in the Orange Reconciliation Strategy study represent the most likely future water resource developments or scenarios that may change the flow regime along the Orange River. DWS is progressively implementing this strategy and is currently undertaking the Vioolsdrift Dam Feasibility study jointly with Namibia.

The proposed scenarios defined in this document aim to augment previous work and avoid duplication, while considering more recent information from other water resource planning activities in the Orange River. To this end, a recently completed study carried out for the Lesotho Highlands Development Authority, with report titled "Instream Flow Requirements for the Senqu River" (LHDA, 2016) was completed and made available only by the end of 2016. Results from this report indicate that both the hydrological time series and the recommended Ecological Water Requirements to be released from Polihali Dam (Phase 2 of the Lesotho Highlands Water Project) is different to those applied in the parallel Vioolsdrift Dam Feasibility study.

Due to the fact that the recalibrated hydrology has not been reviewed, nor accepted for use by ORASECOM, it was decided that the new recalibrated hydrology would not be used, however that the new EWR would be included along with the ORASECOM hydrology to drive it. This approach was also agreed to be used in the current parallel study for the LHWC titled "Determination of the operating rule for the operation of Phase II – LHWC contract no. 15".

11.2 NATURAL HYDROLOGY

The natural flow forms the baseline against which all scenarios will be assessed and Figure 11.1 presents the summarised MAR for the indicated sub-catchments as well as the contributions from the Vaal and Upper Orange WMAs. The bulk of the natural flows (6 695 million m^3/a on average) is generated in the Upper Orange which includes the entire country of Lesotho where the Orange is known as the Senqu River. The second largest contribution is from the Vaal River catchment which contributes 4 024 million m^3/a on average under natural conditions.

The Ongers and Hartbees rivers are the two main RSA tributaries along the Lower Orange and contribute respectively 50 and 92 million m^3/a on average under natural conditions. Although runoff under natural conditions is generated in the Molopo River catchment, none of these flows reach the main Orange River, as they disappear in the Kalahari Desert.

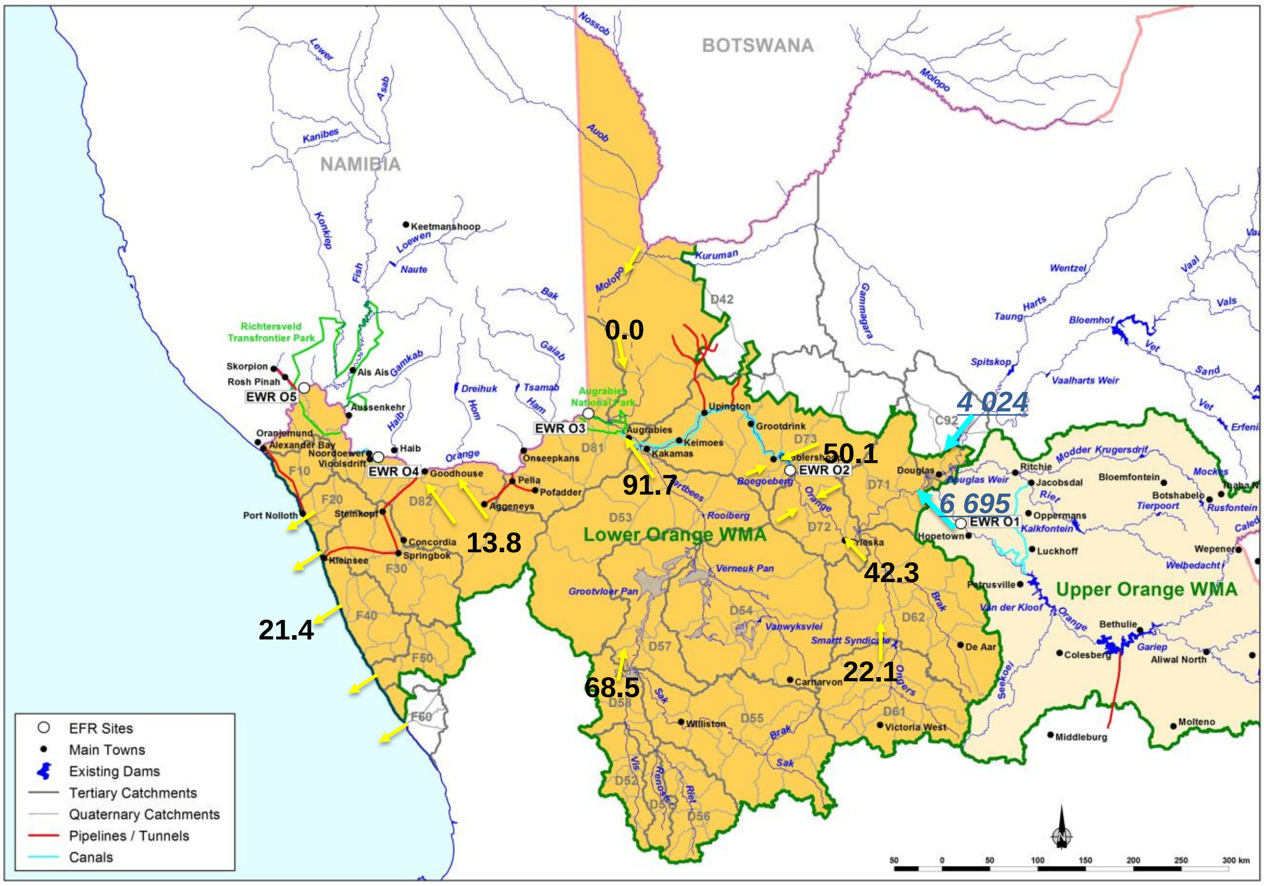


Figure 11.1 Natural flows generated from the Lower Orange within the RSA (flows in million m^3/a)

11.3 IDENTIFICATION OF OPERATIONAL SCENARIOS

A large number of water resource related studies for the Orange River Basin were carried out over time, with some only focussing on specific areas within the basin. The most recent of these completed studies is the Orange River Reconciliation Strategy Study (Development of Reconciliation Strategies for Large Bulk Water Supply Systems: Orange River) (DWA, 2014). The purpose of this study was to develop a reconciliation strategy for the bulk water resources of the Orange River System, to ensure that sufficient water can be made available to supply the current and future water needs of all the users up to the year 2040.

The outcome of the Orange River Reconciliation Strategy Study included specific interventions with particular actions that will be required to balance the water needs with the availability of water through the implementation of regulations, demand management measures as well as infrastructure development options. One of the main tasks of the Orange River Reconciliation Strategy Study was to produce a Literature Review Report, which lists and briefly describes past reports that were reviewed with the aim of capturing relevant information that can be used in the Orange River Reconciliation Strategy Study, as well as to prepare a list of augmentation schemes, management measures and planned bulk infrastructure options that were investigated in the past. All previous water resource related work done within the Orange River basin was thus taken into account and used where appropriate for the development of the Orange River Reconciliation Strategy Study.

The next major water resource development to take place within the Orange River Basin is Phase II of the Lesotho Highlands Water Project (LHWP). Phase II of the LHWP comprise of Polihali Dam located in the Lesotho Highlands. This dam will be connected to the existing Katse Dam by means of a tunnel and will increase the yield capability of the LHWP, to be able to supply in the ever-growing water requirements within the Integrated Vaal System with Gauteng as the main water user. It is expected that Polihali Dam will start inundating water by around 2025. This will immediately cut off a significant portion of the runoff currently entering Gariep Dam, that will in turn result in significant deficits in water supply from the Orange River Project (Gariep and Vanderkloof Dams and related supply area). The Orange River Reconciliation Strategy Study had to address this problem to ensure a positive water balance within the Orange River Project (ORP) at least until 2040.

Various measures and intervention options form part of the recommended Orange River Reconciliation Strategy. The following are the main intervention options and measures recommended from the Orange River Reconciliation Strategy:

- The existing EWR needs to be maintained and to avoid immediate large negative socio-economic implications, additional releases towards an alternative EWR can only be implemented as soon as a new dam is commissioned. Further optimisation of the EWR in combination with the proposed augmentation options is recommended. That is to achieve an acceptable balance between protection of the ecology and use of water for socio-economic purposes.
- All water requirements can be balanced by availability through the implementation of the following measures:
  - Shared utilisation of LHWP Phase II between the Vaal River and Orange River systems is an essential measure to postpone large capital expenditure that would otherwise be required at the same time Polihali Dam becomes operational.
  - Plan and implement Water Conservation/Water Demand Management (WC/WDM) in the domestic and irrigation water use sectors.
  - Limit operational losses through real time monitoring of river flows in the Orange and Vaal rivers to maximise the beneficial use of the spillages from the Vaal River System.
  - Utilising a greater portion of Vanderkloof Dam’s storage capacity by lowering the minimum operating level in the dam.
  - Commission Vioolsdrift Dam at the decided date for alternative EWR implementation. This dam is located on the lower Orange just upstream of Vioolsdrift and Noordoewer irrigation schemes.
  - Creating additional yield in the system by raising Gariep Dam by 10 m or by building the Verbeeldingskraal Dam, located on the main Orange River upstream of Aliwal North.
  - Investigating further management measures, such as lowering the assurances of supply, eliminating unlawful water use, and eradicating invasive alien plants in the Kraai River catchment.

The above mentioned development and intervention options and measures will result in significant changes in the flow patterns along the Orange River over time, and in particular downstream of Gariep and Vanderkloof dams. To be able to determine possible impacts of these developments and measures on the environment, specifically at the selected EWR sites along the Lower Orange, it is important to capture these developments and intervention options in the scenarios to be analysed as part of this study.

Currently the Vioolsdrift Feasibility Study as recommended by the Orange River Reconciliation Strategy Study is almost completed. More detailed information on the expected size of the proposed future Vioolsdrift Dam, as well as the operating rules required for this dam, can be obtained from the Vioolsdrift Feasibility Study. Two types of possible dams are considered at Vioolsdrift:

- A smaller dam with the main purpose to re-regulate water released from Vanderkloof Dam to reduce the operational losses within the ORP.
- A larger dam that will increase the yield of the ORP system and at the same time also be used for re-regulation purposes to reduce the operational losses.

The above mentioned two studies therefore contain the information and recommendations on the most possible future developments within the Orange River that will impact on future flows in the Lower Orange main river. This information was used as the basis for the development and defining of the operational scenarios to be considered for the purpose of this study, as summarised in Table 11.1.

The EWR currently used on the Orange River was originally determined as part of the Orange River Development Project Replanning Study (ORRS), carried out in the middle 1990's based on an outdated environmental requirement methodology. These environmental flow requirements are currently still being released from Vanderkloof Dam and will be replaced once the Reserve was determined and sufficient yield capability created to be able to support the increased environmental requirements. **Scenario A** represents the present day system at 2016 development level.

Scenario A2 allowed for improvement to the ORRS environmental requirement in line with the latest REC defined for EWR O5. The purpose of this scenario is to improve the current EWR releases without impacting on the ORP yield (see Appendix A for more detail).

Scenario A3 is as Scenario A2 but using the current Namibian water allocations along the Lower Orange which is higher than the current actual water use by Namibia.

Scenario B serves as the base scenario for the 2035 development level when the expected major future water resource development options are in place, but with the ORRS EWR still being released from Vanderkloof and Vioolsdrift dams.

Scenario C1b is as Scenario B, but replaced the ORRS EWR with the "preferred" REC environmental flows as used in the Orange River Reconciliation Strategy Study, which was basically the Recommended EWR "without high flows" for the summer months only at EWR O3. This means that the winter months EWR in the model were set to zero, assuming that the flows released to supply the downstream users during the winter months will be sufficient for environmental purposes at EWR O3.

Scenario C2b is as Scenario C1b but using the Recommended EWR "without high flows" for all the months at EWR O3, thus winter and summer months.

Scenario D2 is as Scenario C2b but using a smaller dam at Vioolsdrift.

Scenarios D2i and D2ii are both as Scenario D2 but included slightly higher flows in the months of December and January. These higher flows were based on assessments done for the Estuary by environmental specialists based on the results obtained from Scenario D2.

Scenario D3 is as Scenario D2, but with some floods added to EWR O5 requirement.

Table 2.1 presents the scenario definition matrix indicating the identified variables as columns and the selected variable settings for the proposed scenarios in the respective rows. The matrix content primarily originates from the recommendation of the Orange River Reconciliation Strategy and also reflects the likely outcomes from the current Vioolsdrift Feasibility Study. For easy interpretation, the main change between a given Scenario and the previous Scenario was underlined and in italic format. Appropriate explanatory notes are provided in the notes following Table 11.1.

Several of the scenarios were developed as result of the findings and evaluation of results from other preceding scenarios.

Table 11.1 Scenario Definition Matrix

Sc	Scenario Variables						Ecological Water Requirements			Comment
	Development Horizon (year)	Limit operational losses	Adjust Vanderkloof Dam's storage capacity	Polihali Dam	Vioolsdrift/ Noordoewer Dam	Verbeel-dingskraal Dam	EWRO3: Augrabies	EWRO5: Sendelingsdrift	Estuary	
	(a)	(b)	(c)	(d)	(e)	(f)	(i)	(j)	(h)	
A	2016(*)	N	N	N	N	N	-	-	Current (ORRS)	
A2	2016(*)	N	N	N	N	N	Monitor	_ORRS/REC 5 scaled[1]_	Monitor	REC at EWR O5 scaled according to ORRS.
A3	2016(*)	N	N	N	N	N	Monitor	_ORRS/REC 5 scaled[1]_	Monitor	Sc A2 _with current Namibian allocations resulting in an increase of 92.5 million m^3/a (A2 was with current Namibian use)._
B	**2035**	Y	Y	Y	Y	Y	-	-	_Current (ORRS)_	_With Namibia 2035[2] demand._
C1b	2035	Y	Y	Y	Y	Y	_REC (summer low flows only, no winter flows)_	_REC (excl. high flows)_	Monitor	With Namibia 2035[2] demand (ORP System yield reduced by 425 million m^3/a in comparison with Sc B).
C2b	2035	Y	Y	Y	Y	Y	_REC (excl. high flows)_	REC (excl. high flows)	Monitor	With Namibia 2035[2] demand (ORP System yield reduced by 825 million m^3/a in comparison with Sc B).
D2	2035	Y	Y	Y	_Y (smaller)_	Y	REC (excl. high flows)	REC (excl. high flows)	Monitor	With Namibia 2035[2] demand.
D2i	2035	Y	Y	Y	Y (smaller)	Y	REC (excl. high flows)	REC (excl. high flows) _Increase December EWR_	Monitor _and Improve_	With Namibia 2035[2] demand.
D2ii	2035	Y	Y	Y	Y (smaller)	Y	REC (excl. high flows)	REC (excl. high flows) _Increase December and January EWR_	Monitor _and Improve_	With Namibia 2035[2] demand.
D3	2035	Y	Y	Y	Y (smaller)	Y	REC (excl. high flows)	_REC (excl. high flows with Class I flood (60m^3/s) releases)_	Monitor	With Namibia 2035[2] demand.

1 - REC at EWR O5, scaled according to ORRS EWR volume, with yield impact similar to ORRS EWR.

2- Namibia 2035 demand based on data from the Vioolsdrift Feasibility Study.

(*)Present Day scenario based on the 2016 Annual Operating Analysis (AOA) configuration. The systems model configuration that was received from the Vioolsdrift feasibility study was used to incorporate changes in the 2016 AOA configuration.

(a) Development level or development horizon defines the water requirement and return flows to be imposed on the system. (Note that the scenario simulations was carried out at the indicated constant development level.) Revised water requirement information for the Lower Orange WMA was provided by the current Vioolsdrift Feasibility Study.

(b) Application of real time monitoring and operations to reduce the operating losses by an estimated 80 million m^3/a.

(c) Vanderkloof Dam to be operated at a lower Minimum Operating Level (MOL) with an increase in live storage and estimated system yield increase of approximately 137 million m^3/a.

(d) Polihali Dam with conveyance infrastructure to augment the Vaal River System (LHWP Phase II). The latest EWR releases from Polihali Dam as confirmed by LHDA and DWS representatives were used (same as used in the current LHWP Operating rule study).

(e) The function of the dam at Vioolsdrift is either to only regulate the river flow (small dam size) or to also increase the system yield by constructing a large storage dam. The water loss that can be saved if Vioolsdrift is used as a regulating dam is 120 million m^3/a. The current Vioolsdrift feasibility study indicated a 73.5 m high yield dam or alternatively a 35 m high re-regulation dam. Scenario D2 and D3 used a relative small Vioolsdrift Dam with a storage of 470 million m^3.
(f) Options (f) Verbeeldingskraal Dam and option (g) raising of Gariep Dam are alternatives and the selection of the appropriate option and dam size for these analyses is dependent on the findings (optimisation) of the current Vioolsdrift Feasibility Study. The Vioolsdrift Feasibility Study recommended the use of Verbeeldingskraal Dam. The (g) (g) - raising of Gariep Dam was thus excluded from the scenario analysis.
(i) EWRs for the river supported by releases from the existing and proposed dams upstream of Vioolsdrift in the Orange River System. “Low flows only” means low flows for winter and summer months.
(j) EWRs for the river supported primarily from the future Vioolsdrift Dam, with support from the existing and proposed dams upstream of Vioolsdrift in the Orange River System. “Low flows only” means low flows for winter and summer months.

12 CONSEQUENCES OF SCENARIOS

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12.1 ECOLOGICAL CONSEQUENCES

12.1.1 Ecological consequences at the river EWR sites

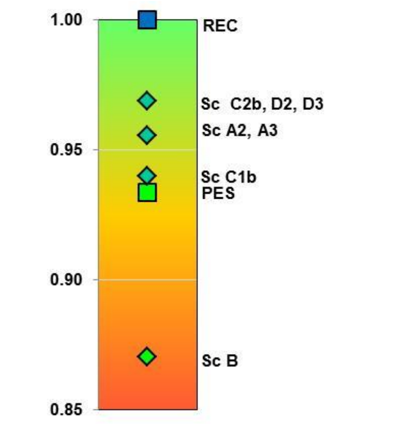
A summary of the ecological consequences are provided at each EWR site in Table 12.1.

Table 12.1 Summary of the detailed ecological consequences determined for the EWR sites situated in the Lower Orange River

Ecological consequences as ECs | **Ranked scenarios**

EWR O3 (AUGRABIES)

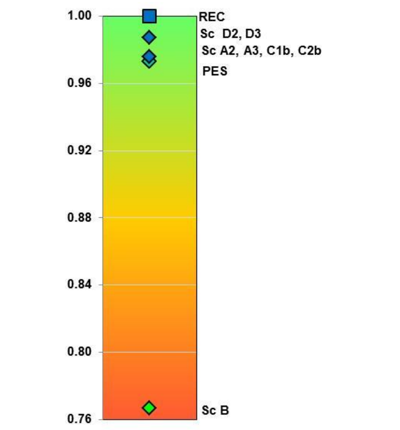
Component	PES	REC	Sc A2	Sc C2b	Sc C1b	Sc B
Physico chemical	C	C	B/C	B	C	C
Riparian vegetation	B/C	B	B/C	B/C	B/C	C
Fish	C	B	B/C	B	C	C
Inverts	C	B	B/C	B/C	C	C
EcoStatus	C (77.2%)	B (83.6%)	B/C (79.1%)	B/C (81.7%)	B/C (77.7%)	C (70.9%)



Ranking rationale: The ranking of the scenarios show that all the scenarios, apart from Sc B, result in an improvement of the PES but do not achieve the REC. The best scenarios are Sc C2b, D2/D3 followed closely by Sc A2/A3. As the recommendations are likely to be set for pre-dam situation, Sc A2/A3 will be the recommended scenario. The best post dam scenarios are Sc C2b and Sc D2 and D3.

EWR O5 (SENDLINGSDRIF)

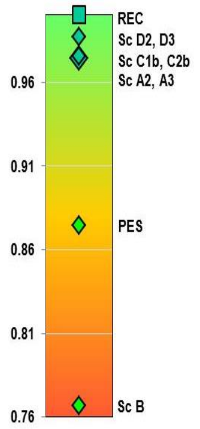
Component	PES	REC	Sc D3	Sc C2b	Sc A2	Sc B
Physico chemical	C	C	B/C	B/C	B/C	D
Riparian vegetation	B/C	B	B	B	B	C
Fish	B/C	B	B	B	B	C
Inverts	B/C	B/C	B/C	B/C	B/C	C
EcoStatus	B/C (80.5%)	B (82.7%)	B (82.9%)	B (82.7%)	B (82.2%)	C (71.8%)



Ranking rationale: The ranking of the scenarios show that all the scenarios, apart from Sc B achieve the REC. The best scenarios are D2/D3 followed closely by Sc C2b/C1b. As the recommendations are likely to be set for a pre-dam situation, Sc A2/A3 will be the recommended scenario prior to the dam construction. When a decision is made on future dams, then the recommendation will be the scenario associated with D2/3.

EWR O4 (VIOOLSDRIFT)

Component	PES	REC	Sc D3	Sc C2b	Sc A2	Sc B
Physico chemical	C/D	C/D	C	C	C	D
Riparian vegetation	C	B	B/C	B/C	B/C	C
Fish	C	B/C	B/C	C	C	C/D
Inverts	C	B/C	B/C	B/C	B/C	D
EcoStatus	C (69.1%)	B/C (81%)	B/C (79.9%)	B/C (78%)	B/C (77.9%)	C (62.6%)



Ranking rationale: The ranking of the scenarios show that all the scenarios, apart from Sc B achieve the REC EcoStatus. It should be noted that although the EcoStatus is met under these scenarios all the component of the REC is not met. The best scenarios are D2/D3 followed closely by Sc C1b/C2B. As the recommendations are likely to be set for pre-dam situation, A2/A3 will be the recommended scenario prior to the dam construction. When a decision is made on future dams, then the recommendation will be the scenario associated with D2/3.

12.1.2 Integrated river ecological ranking

The first step to determine an integrated river ecological ranking was to determine the relative importance of the different EWR sites occurring in the study area. The site weight indicated that EWR O5 carried the highest weight due to the High EIS as EWR O5 is situated in the /Ai-/Ais-Richtersveld Transfrontier Park. This site is also the most downstream site in the Orange River and the accumulated impact of the scenarios will be the highest in spite of the relatively short river reach (141 km).

The weight was applied to the ranking value for each scenario at each EWR site and this provided an integrated score and ranking for the operational scenarios. The ranking of '1' refers to the REC and the rest of the ranking illustrates the degree to which the scenarios meet the REC. The results are provided in Table 12.2 after the weights have been taken into account.

Table 12.2 Ranking value for each scenario resulting in an integrated score and ranking

	PES	REC	A2,A3	B	C1b	C2b	D2, D3
EWR O3	0.33	0.35	0.33	0.30	0.33	0.34	0.34
EWR O4	0.22	0.25	0.24	0.19	0.24	0.24	0.25
EWR O5	0.39	0.40	0.40	0.34	0.40	0.40	0.40
Integrated	**0.93**	**1.00**	**0.97**	**0.84**	**0.97**	**0.99**	**0.99**

The above results are plotted on a traffic diagram to illustrate the integrated ecological ranking.

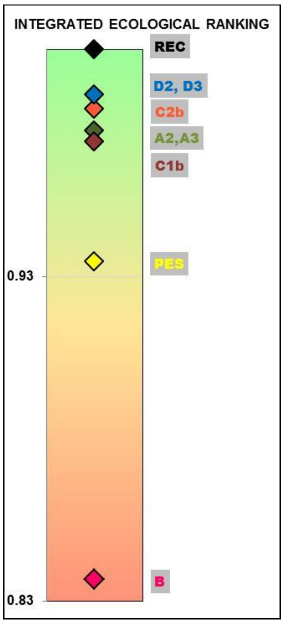


Figure 12.1 Rivers: Integrated ecological ranking of the scenarios on the Lower Orange River system

Scenarios D2 and D3 are the best option as it is closest to meeting the ecological objectives, with Sc C2b close behind. However, the purpose of setting the preliminary Reserve is to provide management guidance that is legally binding. Therefore, the focus is on the pre-dam situation/pre Classification study (and Reserve determination) as is relevant for a Preliminary Reserve and associated management and immediate implementation. As the recommendations are likely to be set for pre-dam situation, Sc A2/A3 will be the recommended scenario.

12.1.3 Ecological consequences: Estuary

A comparison of the overall ecological condition of the estuary under each of the proposed scenarios relative to the PES (D Category) and REC (C Category) are presented in the Figure 12.2. Results can be summarised as follows:

- The Ecological Categories (ECs) of the PES and all proposed scenarios are well below the REC (EC C) for the Orange Estuary.
- The PES of the estuary is currently in a D EC, but with two biotic components, i.e. microalgae and birds (a key biotic component protected under Ramsar Convention) already below the ecological functional threshold of an D Category.
- Scenario A3 shows an improvement on the Present as a result of the redistribution of flow in the low flow period and the estuary mouth conditions moving towards a more natural regime. Scenario A2 showed a slight decline in condition from the present state. The overarching condition for the A scenarios is a D EC.
- Scenario D2 results in all components showing a significant decline in health, with hydrodynamics, physical habitat, macrophytes, microalgae, invertebrates, fish and birds below a functional level of a D EC. The overarching condition is also reduced to an E EC. Of note is that the fish, an additional Ramsar listing criteria, declines to an E EC under the D scenarios. Scenario D3 represents a slight improvement on Sc D2 from a macrophyte perspective. A key driver of the decline in condition is non-flow related impacts, the loss of floods, infilling and decline in baseflows. Preliminary sensitivity testing shows that opportunities exist to improve the D scenarios by 1 or 2% by elevating some of the baseflows above 10m^3/s. These incremental improvements would assist in reducing stagnant conditions in the estuary and reduce the risk of fish recruitment failure.

- Scenario C1b and C2b results in all components showing severe decline in health, with hydrology, hydrodynamics, Physical habitat, macrophytes, microalgae, invertebrates, fish and birds below a functional level of a D EC. The overarching condition is also reduced to an E EC. Of note is that the fish, an additional Ramsar listing criteria, declines to an E EC under the C scenarios. A key driver of the decline in condition is non-flow related impacts, the loss of floods, infilling and decline in baseflows and potential recruitment failure of fish.
- Scenario B represents the worst case scenario with its highly regulated flows forcing most components (with the exception of water quality and hydrodynamics) below the functional level of an EC D. Abiotic components range between D to E Category, while biotic component decline to an E Category (with the exception of the Macrophyte component in a D/E EC). The overarching condition is also reduced to an E EC.

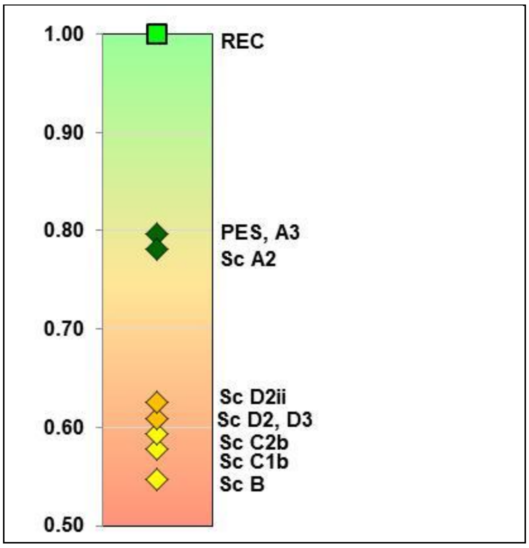


Figure 12.2 Orange Estuary: Relative ranking of the scenarios versus REC

Key findings from this assessment are:

- All the proposed dam development scenarios will reduce the ecological condition of the Orange Estuary from the present state in one or more of the individual abiotic and biotic components significantly. The small dam development (D scenarios) is associated with 12% decline in health (D/E EC), while large dam developments (scenarios B and C) are associated with a 13 to 16% decline in health (E EC).
- As with the PES, the ecological condition associated with all proposed scenarios are well below that required for the REC, also for most of the individual abiotic and biotic components.
- Scenario A3 is the operational scenario associated with the least ecological degradation.
- A key flow related requirement to achieve the REC will be to reduce present winter base flows sufficiently to allow for mouth closure and related back-flooding of the saltmarshes with brackish water to reduce soil salinities, but not to the point where the estuary mouth remains closed for longer than 2 to 4 times in 10 years by decreasing river inflow to less than 5 m^3/s. An additional requirement is the need to elevate base flows above 10 m^3/s from December onwards. After long periods of very low flow the instream habitat becomes very reduced and/or shallow.
- As per the 2013 Estuary EWR study (Van Niekerk *et al*., 2013a,b), the REC for the Orange Estuary cannot be achieved through flow interventions only.

The REC for the Orange Estuary cannot be achieved through flow interventions only. Specialists estimate that the estuary condition can be improved by about 10% through non-flow related interventions. Critical non-flow related mitigation measures include:

- Control the fishing effort on both the South African and Namibian side through increased compliance and law enforcement. This also requires the alignment of fishing regulations (e.g. size and bag limits) and management boundaries on either side of the transboundary estuary;
- Enhance nursery function for estuarine dependant fish species.
- Remove the remnant causeway that still transects the saltmarshes to improve circulation during high flow and floods events. This will also assist with increasing the water circulation into the lower marsh areas.
- Decrease nutrient input from the catchment downstream of Vioolsdrift, through improved agricultural practices.
- Control windblown dust and wastewater from mining activities; and
- Reduce/remove grazing and hunting pressures (which have significantly escalated in the last 5 years).

The recommendation is defined as the flow scenario (or a slight modification thereof to address low-scoring components) that represents the highest change in river inflow that will still maintain the estuary in the REC. The recommended scenario for the Orange Estuary for the pre-dam situation is the Present or Sc A3 that maintains the D EC.

12.2 ECOSYSTEM SERVICES CONSEQUENCES

The consequences of the scenarios at all three EWR sites situated in the Orange River indicated that scenario groups A2, C1b and C2b were positive with Sc B being negative. Provisioning services remained constant against the status quo score or improved under all scenarios at the EWR sites. Regulating and Cultural services were negatively impacted by Scenario B while these services improved under the rest of the scenarios. No discernible change was noted for Supporting services under any scenario. Scenario A2, A3, B, C1b, C2b, D2 and D3 were deemed to be negative in terms of ecosystem services associated with the estuary with Sc D3, D2 and C1b regarded as particularly negative.

The results of the scenarios for the Orange River were ranked with the EWR sites weighted (Figure 12.3). The Ecosystem Services ranking for the estuary is also provided.

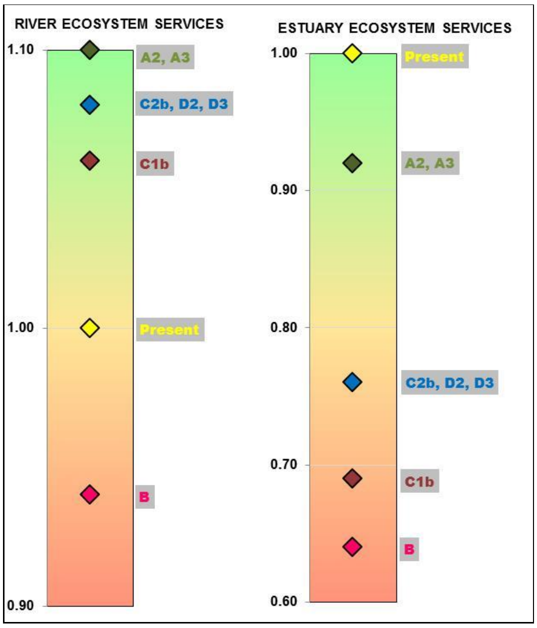


Figure 12.3 Ranking of impact of scenarios on Ecosystem Services in the Orange River system

12.3 ECONOMIC SERVICES CONSEQUENCES

Table 12.3 presents the economic results associated with the different volumes available for production purposes after the removal of the volume of water to maintain the EWR.

Table 12.3 Economic production per Scenario

Scenario	Gross Domestic Product (GDP) (Rand Million)		Employment (Number)		Household Income (Rand Million)	
	Direct	Total	Direct	Total	Total	Low
2016 Baseline	3.472	5.617	27.380	40.110	4.501	1.325
Impact Sc A2	3.472	5.617	27.380	40.110	4.501	1.325
Impact Sc A3	4.008	6.484	31.604	46.297	5.196	1.529
2035 Baseline	13 011.02	21 048.02	102 596	150 294	16 866.29	4 964.44
Impact Sc C1b	10 718.44	17 339.31	84 519	123 812	13 894.41	4 089.69
Impact Sc C2b	8 560.73	13 848.76	67 504	98 887	11 097.35	3 266.40
Impact Sc D2	8 560.73	13 848.76	67 504	98 887	11 097.35	3 266.40
Impact Sc D3	8 776.50	14 197.81	69 205	101 379	11 377.05	3 348.73

In the evaluation of the results it must be kept in mind that the 2016 Baseline and Sc A2 and A3 is only based on the Lower Orange. The results of the 2035 baseline and accompanying results is representative of the total river basin and the Table12.4 presents the economic impacts of the different scenarios.

Table 12.4 Economic impacts of the Scenarios

Scenario	GDP (Rand Million)		Employment (Number)		Household Income (Rand Million)	
	Direct	Total	Direct	Total	Total	Direct
2016 Baseline	0	0	0	0	0	0
Impact Sc A2	0	0	0	0-	0	0
Impact Sc A3	535.65	866.53	4 224	6 187	694.37	204.38
2035 Baseline	0	0	0	0	0	0
Impact Sc C1b	-2 292.57	-3 708.71	-18 078	-26 482	-2 971.88	-874.75
Impact Sc C2b	-4 450.29	-7 199.26	-35 092	-51 406	-5 768.94	-1 698.04
Impact Sc D2	-4 450.29	-7 199.26	-35 092	-51 406	-5 768.94	-1 698.04
Impact Sc D3	-4 234.51	-6 850.21	-33 391	-48 914	-5 489.24	-1 615.71

The above results indicate that Sc A2 has no negative or positive economic impact measured in terms of the 2016 Baseline in the Lower Orange. Scenario A3 produces a positive economic impact and in line with the defining parameters of the scenario the impacts will be mostly on the Namibian side of the river. The economic impacts measured in 2016 prices in terms of 2035 projected water demand for all the scenarios indicate a negative economic impact. Using just the economic impact it appears as if Sc C1b is the preferable scenario, followed by Sc D3 and then Sc C2b and D2 indicating the same economic impact. The estimated social and economic impacts of the different scenarios based on the 2035 baseline is drastic and it is necessary to also take into consideration the costs of the identified additional infrastructure to maintain the EWR and the economic activities.

Table 12.5 provides the results for the scenarios applicable over the total river expressed in terms of the capital and operational costs involved.

Table 12.5 Selected data applied and results estimated in the Cost-Benefit Analysis (CBA) model

Scenario	Volume Involved (mm^3)	Capital Cost (Rand million)	Operational Cost (Rand million)	NPV[1]: Direct Discounted GDP Benefit (Rand million)	Benefit (Net GDP)/Water Savings ($Rand/m^3$)
C1b – Large Dam	425	1,715.22	7.44	15,161.9	3.36
C2b – Large Dam	825	1,715.22	7.44	32,035.9	3.66
D2 – Small Dam	825	1,102.79	1.14	32,653.4	3.73
D3 – Small Dam	785	1,102.79	1.14	30,966.0	3.72

1 Net Present Value.

The benefit/m^3 metric is used to express the benefit saved, expressed in terms of the GDP, per cubic metre of water, if the supply of the irrigation and urban water is not reduced. The 3.73 Rand/m^3 is there for the more beneficial value and therefore Sc D2 is the best economic feasible option using this approach.

From the above it appears that Sc C1b will be the most beneficial in economic terms if only the negative impact on the economy is measured. However, if the cost of the provision of the infrastructure to maintain the EWR as well as the economic activities is considered, Sc D2 is the most beneficial. The only difference between Sc D2 and C2b is that benefit/m^3 metric of Sc D2 is slightly better than Sc C2b as the rest of the parameters are similar. When only evaluating the scenarios with the infrastructure costs component, Sc D3 is the most preferred with the net water savings indicator followed closely by Sc D2 and C1b. The larger the savings ratio, the better the economics of scale is applied.

The economic impact comparisons of GDP for all the scenarios as well as the water saving benefit using the Nett Benefit and volume involved as drivers are presented in Figure 12.4.

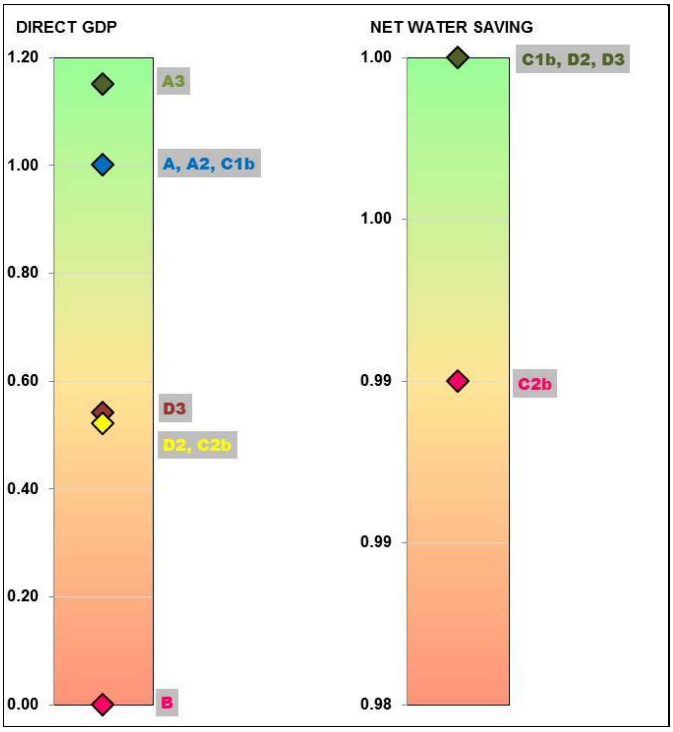


Figure 12.4 Ranking of scenarios in terms of Direct GDP and Net Water Saving benefit

12.4 YIELD IMPLICATIONS

For each scenario, the results in the form of a time series of monthly average flows past each site dating from 1920 to 2004 were provided to the study team for further assessment. A summary of those flows is presented in Table 12.6, representing the average annual flow in million m^3/a at the given site and representative scenario. The reduction in yield refers to the decrease in yield of the ORP as result of the different EWRs included for the specific scenario.

Table 12.6 Average annual flow (million m^3/a) at the given site and representative scenario

Scenario	EWR O3	Vioolsdrift	EWR O5	Estuary	Yield reduction (million m^3/a)
A	4280.45	3984.34	4430.61	4346.46	Current base
A2	4287.76	3991.62	4437.89	4353.74	0*
A3	4306.79	3925.12	4371.37	4285.71	90*
B	3531.35	2953.75	3183.12	3059.03	2035 Base
C1b	3708.39	3110.33	3298.13	3173.97	425**
C2b	3708.39	3110.33	3375.86	3251.63	825**
D2	3747.05	3205.22	3493.33	3369.03	825**
D2i	3747.05	3205.63	3493.50	3369.19	825**
D2ii	3747.05	3205.76	3493.62	3369.32	825**

Scenario	EWR O3	Vioolsdrift	EWR O5	Estuary	Yield reduction (million m^3/a)
D3	3747.15	3206.49	3494.21	3369.90	865**

* Yield reduction relative to Sc A.. ** Yield reduction relative to Sc B.

12.5 CONCLUSIONS AND RECOMMENDATIONS

The determination of the Reserve and the National Water Resources Classification is a legal requirement according to the National Water Act. The Reserve can only be gazetted once the Classification has been determined and gazetted. The Act allows for a Preliminary Reserve to be determined prior to Classification. Although not gazetted, the Preliminary Reserve is signed off by the Minister (or the delegated authority) and is legally binding. As such, the Preliminary Reserve is undertaken prior to Classification or as part of a Classification study. The decisions taken can be reviewed and updated during Classification as detailed consideration is given to the socio-economic issues.

The Orange River study is a Preliminary Reserve study prior to Classification. Further development of the Orange River is being investigated. This will allow for more management options of amongst others, the EWRs. The scenarios and recommendations which are made for this phase pertain to the post-dam recommendations. Immediately applicable is the provision of EWRs through the operation of the system without additional storage. These scenarios represent the pre-dam recommendations. This will be legally binding until the Classification has been determined and gazetted. The Reserve will then follow and be gazetted. Therefore, the focus of this Preliminary Reserve study is on pre-dam situation. Recommendations are also made for the post-dam situation regarding scenarios as well as further work required in preparation for Classification.

12.5.1 Pre-dam recommendations

Prior to the development of additional storage, the only option for improving the estuary and rivers are to improve on the distribution of the existing EWR allocation. These are scenarios A2 and A3. These scenarios will improve the rivers significantly, especially at EWR O5 where the REC may be achieved. The A2/3 scenario will only maintain the PES at the estuary, but it is likely that with the improvement at EWR O5, that some improvement may be noted at the estuary. If the anthropogenic issues are addressed, the estuary status will improve to a C/D. The Ecosystem Services show no negative impact of the implementation of the A2/3 scenarios. As the A2/3 scenarios are a marked improvement for the rivers, these scenarios rather than the current EWR allocation would be strongly recommended from an ecological perspective.

The impact on yield of Sc A2 and A3 are very low. Scenario A2 versus the 2016 Base Scenario shows no difference in yield. A relative small reduction in yield due to potential full use of Namibian allocations of 92 million m^3/a is applicable to Sc A3. The recommendation is that Sc A2 or A3 be immediately implemented.

12.5.2 Post-dam development scenarios

Five scenarios were evaluated that included future dam development. The scenarios (D range) that represent a small Vioolsdrift Dam (35 m) scored the highest. One of the D scenarios, Sc D2 was further optimised for the estuary (Sc D2ii) and showed a slight improvement. The Ecosystem Services showed an improvement of all the scenarios over the present provisioning. The recommendation from an ecological perspective is therefore Sc D2ii. It must be noted that the REC for the EcoStatus is achieved at both EWR O4 (Vioolsdrift) and O5 (Sendelingsdrift) and that the PES is improved at EWR O3. Although there is no improvement and even further degradation at the estuary, it is possible that with monitoring to better understand conditions under low flows and with further optimisation during the National Water Resources Classification study a scenario can be devised that maintains or improves the estuary.

It must be noted that the Sc C2b that represents the large Vioolsdrift Dam is only marginally worse than the small dam scenarios. However, these rankings do not take into account the severe impact of the barrier effect of the dam for fish and other biota as well as the sedimentation impacts on the estuary and in general, the marine environment. Mitigation measures such as fishways are a possibility for the smaller dam but are unlikely to be structurally feasible or cost effective for the large dam.

From a yield perspective, it is important to note that there is a significant difference between Sc C1b and C2b. Both scenarios include the large Vioolsdrift Dam with the main difference being that for Sc C1b no winter low flows are supplied at EWR O3 (Augrabies) and for Sc C2b both summer and winter low flows were supplied. This resulted in a reduction in yield of Gariep and Vanderkloof dams by 400 million m^3/a. Although the yield for the large Vioolsdrift Dam also increased due to the higher inflows into Vioolsdrift, this increased yield cannot be utilized downstream of Vioolsdrift Dam, due to limited downstream demands. Sc C2b (supply of inter flows at EWR O3) therefore eliminates the option of a large Vioolsdrift Dam as a smaller Vioolsdrift will be able to provide sufficient yield for downstream users. This leads to Sc D2, using a smaller Vioolsdrift Dam, that was able to provide sufficient yield for the expected future demands downstream, similar to that of the large Vioolsdrift Dam for the option when no winter low flow were supplied at EWR O3 (Sc C1b).

When the summer and winter low flows are supplied at EWR O3, the deficit in the upstream yield from Gariep and Vanderkloof is just too much to overcome with a dam at Verbeeldingskraal. During the Orange Reconciliation Strategy Study, the Boskraai Dam was discarded due to various reasons and Verbeeldingskraal Dam, which unfortunately produces a much lower yield, was recommended. Environmental concerns related to Boskraai Dam contributed to this decision, but these environmental implications were not weighed against the environmental implications in the lower Orange River and Estuary. It is likely that the presence of a National Park, a Transfortier Park and a Ramsar Site (the estuary) could play an important role in the analysis.

The ecological consequences of the large dam based purely on proposed flow regimes that will be achieved at the EWR sites and estuary seems to be not that much worse than the small dam scenarios. It must be acknowledged though, that some detailed studies on flood routing and sedimentation, migration, marine impacts, etc. are still required to, with mitigatory flow releases, understand the consequences. In essence, an ecological cost-benefit and an economic cost-benefit analysis must be undertaken in conjunction and then to weigh the different possible combination of scenarios.

To make a decision on the small versus the large dam, a decision is also required on the two main EWR related options:

- 1. With releases for winter low flows at EWR O3 included.
- 2. Without releases for winter low flows at EWR O3.

For option 1 above, a smaller Vioolsdrift Dam can be used and the ecological benefit against high capital expenditure for Boskraai Dam must be evaluated, or the impact of upstream irrigation reduction (400 million m^3/a reduction) must be investigated. If option 2 is considered, and a larger Vioolsdrift Dam is used, the full impact on ecology for a larger dam (system in balance, no additional expenditure required for upstream resource development) should be evaluated. Or the smaller Vioolsdrift Dam can be used with option 2, requiring then that the ecological benefit against capital expenditure for a raised Gariep Dam wall be evaluated or the impact of irrigation reduction (approximately 200 million m^3/a reduction) be investigated.

In conclusion and taking into account the implications on yield of supplying winter flows at EWR O3, the following is recommended: A scenario without winter flows at EWR 3 with a small Vioolsdrift Dam and additional storage upstream should be investigated. Further optimisation of the flow scenarios to achieve the estuary improvement is also essential.

13 PRELIMINARY RESERVE RECOMMENDATIONS

This report is partially summarised from: (DWS, 2017c)
Department of Water and Sanitation, South Africa, July 2017. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Ecological specifications and monitoring report. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. DWS Report No: RDM/WMA06/00/CON/COMP/0217.

The purpose of setting Preliminary Reserves is to provide the management guidance for the system that is legally binding. The Preliminary Reserve will be superseded once Classification has been undertaken and gazetted, followed by the gazetting of the Reserve based on the Classification decisions. Considering this, and based on the assumption that the future dam development will not be in place prior to Classification taking place, the Preliminary Reserve that is recommended is based on the pre-development (dam) situation. The EC linked to the recommended pre-development scenario is referred to as the Preliminary Ecological Reserve Category (PERC). As the Recommended Ecological Category (REC) cannot always be met, the PERC represents the realistic EC that will be signed off. The PERC may be the REC, or any other category that is attainable.

The PERC is summarised in Table 13.1 below and is based on Scenario A2 and A3. More details on the PERC are available in Chapter 14.

Table 13.1 PERC for the EWR sites and the Estuaries

EWR Site	PES	REC	PERC	Comment
O3	C	B	B/C	With current constraints, improvement is only possible to a B/C.
O4	C	B/C	B/C	Although the EcoStatus is met, all component RECs are not met.
O5	B/C	B	B	REC is fully met.
Estuary	D	C	C/D	C/D can only be achieved with non-flow related mitigation. Without a dam, flow to achieve the additional improvement to get to a C is not available.
Buffels	D	D	D	The PERC is the same as the PES and REC.
Swartlintjies	B	B	B	The PERC is the same as the PES and REC.
Spoeg	A/B	A/B	A/B	The PERC is the same as the PES and REC.
Groen	B	A/B	A/B	Improve water quality: Investigate possible organic/nutrient seepage from ablution facilities of offices/homes at SANParks and means to address these.
Sout	E	D	D/E →D	Develop an Estuary Management Plan, improve circulation (e.g. culverts in roads) and restore connectivity with catchment.

There are specific links between the Preliminary Reserve, Classification, Reserve and Resource Quality Objectives. An explanatory text block is provided below.

INTRODUCTION: PRELIMINARY RESERVE, CLASSIFICATION, RESERVE

- Determination of the Reserve and the National Water Resources Classification is a legal requirement according to the National Water Act.
- The Reserve can only be gazetted once the Classification has been determined and gazetted.

- The act allows for a Preliminary Reserve to be determined prior to Classification. Although not gazetted, the Preliminary Reserve is signed off by the Minister (or the delegated authority) and is legally binding.
- As such, the Preliminary Reserve is undertaken prior to Classification or as part of a Classification study.
- The decisions taken can be reviewed and updated during Classification as detailed consideration is given to the socio-economic issues.
- The Orange River study is determining the Preliminary Reserve prior to Classification.
- Further development of the Orange River is on the table and will happen. This will allow for more management options of amongst others, the EWRs.
- The scenarios and recommendations which are made for this phase pertain to the ***post-dam recommendations***.
- Immediately applicable is the provision of EWRs through the operation of the system without additional storage.
- These are referred to as the ***pre-dam scenarios*** and will be immediately applicable.
- **Therefore, the focus of this (Preliminary) Reserve study is on pre-dam situation.**
- Recommendations are also made for the post-dam situation regarding scenarios as well as further work required in preparation for Classification.

Difference between the Preliminary Reserve and Classification:

The Preliminary Reserve focusses on ecological objectives and BHN.
Classification considers the balance between protection and use.

The Preliminary Reserve is signed off based on the Preliminary Reserve Ecological Category (PERC).
Classification is gazetted and based on the Target Ecological Category (TEC).
The TEC and PERC have the same definition and the different terminology is applicable to the different type of studies.

The PERC for other components of the system are as follows:

- Desktop Biophysical Nodes: Desktop nodes will require mostly non-flow related interventions to achieve the REC at the few nodes where REC is an improvement: Recommendation: PERC will be the same as the REC.
- Wetlands: Wetlands not addressed through rivers were assessed at desktop level and it is recommended that the PERC is the same as the REC. If future developments impact on specific high priority wetlands, then further work will be required.
- Groundwater: The contribution to the Preliminary Reserve has been determined. Information is available to evaluate whether sufficient groundwater is available for future developments such as fracking within the context of the river and wetland PERC.

14 ECOSPECS

This report has been summarised from: (DWS, 2017c)
Department of Water and Sanitation, South Africa, July 2017. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Ecological specifications and monitoring report. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. DWS Report No: RDM/WMA06/00/CON/COMP/0217.

The purpose of this chapter is to document the Ecological Specifications (EcoSpecs) and Threshold of Potential Concern (TPC) for the rivers and estuary.

14.1 ECOSPECS AND TPCs

EcoSpecs are biological specifications that are numerical values or narrative statements that define a desired biological condition (Ecological Category). EcoSpecs indicates the level of habitat integrity that is required to attain a specific biological condition for the river and therefore provides the ecological detail that characterises the Ecological Category. For a Preliminary Reserve, it would be the biological conditions relating to the PERC. EcoSpecs must be quantifiable, measurable, verifiable and enforceable and ensure protection of all components. TPCs indicate the numerical values around the EcoSpecs that, if approached, would initiate more detailed investigations or even management actions. TPCs are therefore upper and lower levels along a continuum of change.

The EcoSpecs are provided in the sections below as a summary in terms of the PERC. For the full detailed numerical tables, the report from which this section has been summarised must be consulted.

14.2 EWR O3: ECOSPECS

The PERC for the components for which EcoSpecs are set are provided Table 14.1. Note that the estimated changes for the EcoSpecs associated with a post dam development scenario are also provided.

Table 14.1 EWR O3: PERC

Driver components	PES	REC	Pre-Dam recommendation PERC (Sc A2; A3)	Post-Dam recommendation D Scenarios*
Physico chemical	C	C	B/C	B
Fish	C	B	B/C	B
Invertebrates	C	B	B/C	B/C
Riparian vegetation	B/C	B	B/C	B/C
EcoStatus	**C**	**B**	**B/C**	**B/C**

* Further investigations are necessary on dam sizes to finalise the post-dam scenario recommendations. However, as the differences between the D and C Scenarios are relatively small, an indication of EcoSpecs and TPCs associated with the D scenarios (small dam) has been provided. This will be updated during the Classification study that will folllow.

14.3 EWR O4: ECOSPECS

The PERC for the components for which EcoSpecs are set are provided in Table 14.2. Note that the estimated changes for the EcoSpecs associated with a post dam development scenario are also provided.

Table 14.2 EWR O4: PERC

Driver components	PES	REC	Pre-Dam recommendation PERC (Sc A2; A3)	Post-Dam recommendation D Scenarios*
Physico chemical	C/D	C/D	C	C
Fish	C	B/C	C	B/C
Invertebrates	C	B/C	B/C	B/C
Riparian vegetation	C	B	B/C	B/C
EcoStatus	**C**	**B/C**	**B/C**	**B/C**

* Further investigations are necessary on dam sizes to finalise the post-dam scenario recommendations. However, as the differences between the D and C Scenarios are relatively small, an indication of EcoSpecs and TPCs associated with the D scenarios (small dam) has been provided. This will be updated during the Classification study that will folllow.

14.4 EWR O5: ECOSPECS

The PERC for the components for which EcoSpecs are set are provided in Table 14.3. Note that the estimated changes for the EcoSpecs associated with a post dam development scenario are also provided.

Table 14.3 EWR O5: PERC

Driver components	PES	REC	Pre-Dam recommendation PERC (Sc A2; A3)	Post-Dam recommendation D Scenarios*
Physico chemical	C	C	B/C	B/C
Fish	B/C	B	B	B
Invertebrates	B/C	B/C	B/C	B/C
Riparian vegetation	B/C	B	B	B
EcoStatus	**B/C**	**B**	**B**	**B**

* Further investigations are necessary on dam sizes to finalise the post-dam scenario recommendations. However, as the differences between the D and C Scenarios are relatively small, an indication of EcoSpecs and TPCs associated with the D scenarios (small dam) has been provided. This will be updated during the Classification study that will folllow.

14.5 ORANGE ESTUARY ECOSPECS

The PERC for the components for which EcoSpecs are set as well as the actions required to achieve the PERC are provided in Table 14.4.

Table 14.4 Summarised Orange EcoSpecs

Components	PES	PERC	Actions
Hydrology	D	D	Decrease baseflows in winter under current configuration*.
Hydrodynamics	C	C	Increase retention time in winter (this could possibly also facilitate mouth closure under turbulent sea conditions).
Water quality	D	C	Reduce nutrient input in lower Orange River.
Physical habitat alteration	B	B	No improvement required.
Microalgae	E	D	Decrease nutrient input and reduce base flows in winter where possible under current configuration.
Macrophytes	D	C	Reduce nutrient input, remove causeway, control grazing and alien vegetation, reduce soil salinities.
Invertebrates	D	C	Reduce baseflows in winter under current configuration.
Fish	D	C	Reduce baseflows in winter under current configuration, control fishing.
Birds	E	D	Reduce baseflows in winter under current configuration.

Components	PES	PERC	Actions
EcoStatus	D	C/D	Reduce flows under current configuration, allow for sporadic mouth closure under turbulent sea conditions, and improve vegetation cover and food sources (invertebrates and fish).

* While Scenario A2 and A3 does not show substantial benefits for the estuarine ecology indications are that further refinements can possibly facilitate low enough flows under the present configuration to allow for mouth closure under turbulent sea conditions.

14.6 WEST COAST ESTUARY ECOSPECS

The PERC for the EcoStatus are provided in Table 14.5. As these estuaries were investigated at a broad level (desktop to rapid), mostly qualitative EcoSpecs are provided per component.

Table 14.5 West Coast Estuary EcoSpecs

Estuary	PES	REC	PERC	Recommendation to maintain/achieve the PERC
Buffels	D	D	D	The system is on a negative trajectory of change and therefore requires the following interventions to maintain the PERC: ▪ Remove roads/causeways dividing the estuary in three isolated sections (i.e. remnant of mining road at mouth; road at bird hide; road above the golf course). ▪ Improve connectivity with catchment by increasing/establishing culverts in roads in catchments. ▪ Remove invasive alien plants (rooikrans) in upper reaches (in progress). ▪ Enforce the no driving on the beach legislation to allow for natural sediment processes to re-establish themselves and protect birds (in progress). ▪ Investigate mitigations to reduce nutrient enrichment from golf course irrigation.
Swartlintjies	B	B	B	Maintain PES.
Spoeg	A/B	A/B	A/B	Maintain PES.
Groen	B	A/B	A/B	Components that require interventions or protection to achieve the PERC: ▪ Hydrology: Maintain groundwater flow to near natural levels. ▪ Hydrology: The estuary has a strong dependency on groundwater fed springs to maintain salinity gradient, maintain water levels, limit occurrence of extreme hyper salinity (<150 PSU). ▪ Water Quality: Improve water quality: Investigate possible organic/nutrient seepage from ablution facilities of offices/homes at SANParks and means to address these. ▪ Sediment processes and Macrophytes: Future pressures include an escalation of mining activities in the national park and related disruption of subsurface flow.
Sout	E	D	D/E →D	Components that require interventions to achieve the PERC (and ultimately the REC): ▪ Flow, hydrodynamics, sediment processes and macrophytes: Develop an Estuary Management Plan to evaluate to what extent the current design and/or operations of the salt works can be improved to restore estuarine habitat and functionality of the upper reaches. In progress: Western Cape Government has prioritised this. ▪ Hydrodynamics: Improve circulation (e.g. culverts in roads). ▪ Flow: Restore connectivity with catchment, i.e. investigate if weir can be partially removed to allow connectivity with western arm of estuary.

15 ESTUARY MONITORING PROGRAMME

This report has been summarised from: (DWS, 2017c)
Department of Water and Sanitation, South Africa, July 2017. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Ecological specifications and monitoring report. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. DWS Report No: RDM/WMA06/00/CON/COMP/0217.

Ecological monitoring is the collection and analysis of repeated observations or measurements to evaluate change in the condition of the resource and the progress towards meeting the management objective (Elzinga *et al* 1998). As used with DWS, it is the measurement of EcoSpecs to determine if the PERC is attained (Kleynhans *et al.,* 2009). The PES acts as the baseline against which change is monitored.

River monitoring with the emphasis on the biological aspects falls into the DWS monitoring programme, the River Ecosystem Monitoring Programme (REMP) (DWS, 2016g). The driver monitoring (hydrology and water quality) is also part of standard DWS monitoring programmes.

With regards to estuaries, the process is somewhat different as there is more than one responsible authority involved. Estuarine monitoring is currently not a routine activity of national departments. Where routine estuarine monitoring activities do occur, it is undertaken by fisheries research (Department of Agriculture, Forestry and Fisheries on large temperate systems), conservation authorities, provincial authorities or local authorities, and only includes a limited selection of variables. More recently the DWS (Resource Quality Information Services) commenced with the role out of a national estuarine water quality monitoring programme. Currently, implementation of water quality compliance monitoring activities in the Orange Estuary is dependent on collaboration with other responsible authorities or non-governmental organisation (NGOs). It is strongly recommended that the estuarine management planning process (a requirement under the Integrated Coastal Management Act), be used as a vehicle to coordinate the implementation of these compliance monitoring activities.

South Africa’s estuaries have a diversity of management requirements, often unique to individual systems, and are governed by a variety of authorities, from national to local level. Consequently, it was necessary to develop a flexible, but legally defensible National Estuarine Management Protocol (NEMP) providing guidance to estuarine managers at all levels to develop sound management plans to suit individual systems. In the case of estuaries, protection is not only effected by localised management actions but also through ensuring adequate quantity and quality of freshwater flows into the estuary. The outcome of a Reserve Study therefore informs and supports other estuary planning initiatives, and products developed as part of this process are aligned as much as possible with other management initiatives. In turn, the interventions required to achieve a specific ecological state, and the monitoring actions required to measure if such targets are achieved, will be taken up in individual Estuary Management Plans. Monitoring is incorporated in the Estuary Management Plans.

15.1 ORANGE ESTUARY: EXISTING BASELINE AND ADDITIONS

The surveys undertaken during January and June 2012 serve as the baseline. However, some additions are required to improve the baseline. The existing baseline is summarised in Table 15.1 and the additional work is required to improve the confidence in the baseline is also provided.

Table 15.1 Orange Estuary: Existing baseline survey data and additional recommendations to support the baseline information

Baseline Survey	Data available
Existing baseline	
Hydrology	
Continuous river flow gauging at the head of the estuary (e.g. Brandkaros).	No, only long-term data available from Vioolsdrift 1935 to 2016. The recently installed flow gauge Sendelingsdrift has insufficient data at this stage.
Hydrodynamics	
Additional continuous water level recordings near mouth of the estuary and in the salt marsh area near the beach.	Only at the bridge.
Daily observations on the state of the mouth, if the mouth is closed or almost closed state.	No.
Aerial photographs of estuary - colour, geo-referenced rectified aerial photographs at 1: 5 000 scale covering the entire estuary (based on the geographical boundary), and taken at low tide in summer, are required. These photographs must include the breaker zone near the mouth.	1937, 1943, 1951, 1962, 1964, 1976, 1977, 1979, 1980, 1987, 1988, 1990.
Sediment	
Series of cross-section profiles along the beach, bar, mouth and lower basin region (at about 25 m intervals) as well as upstream along the entire estuary (at ~300 m intervals from the +5 m MSL contour on the left bank, through the estuary to the +5 m MSL contour on the right bank), using D-GPS and echo-sounding). This should be done every 3 years (and immediately after a flood) to quantify the sediment deposition rate in the estuary.	Partial: 1987, 1988, 1990.
Series of sediment grab samples for the analysis of Particle Size Distribution (PSD), cohesive nature and organic content, taken every 3 years (and immediately after a flood) along the length of the estuary (at ~ 100 to 300 m intervals across the estuary including the inter- and supratidal areas). Representative samples should also be collected from the adjacent beach and sand bar.	Partial: 1988, 2008.
A series of sediment core samples for historical sediment characterisation taken once-off, but ideally just after a medium to large flood as well as a year (or two) later along the same grid as the grab samples (see above).	No.
Sediment load near the head of estuary (including grain size distribution and particulate carbon - detritus component): Daily intervals for a minimum 5 years. Ideally, both suspended- and bed-load should be monitored. The measurements could be done at Brandkaros, but ideally within a few kilometres upstream of the Oppenheimer Bridge.	Upstream 1988.
Water quality	
Monthly water quality measurements on system variables (conductivity, temperature, pH, DO, turbidity, suspended solids), inorganic nutrients (e.g. nitrate, ammonium and reactive phosphate) and, if possible, toxic substances in river water entering at the head of the estuary (Oppenheimer Bridge). Ideally, particulate organic carbon input (see also sediment dynamics) should be recorded.	Available Ernst Oppenheimer Bridge (D8H012Q01) and Vioolsdrift (D8H083Q01).
Longitudinal salinity and temperature profiles (in situ) collected over a spring and neap tide during high and low tide at: ▪ Low flow season (i.e. period of maximum seawater intrusion), but when the mouth is still open. ▪ During mouth closure (this may require a series of surveys to capture the dynamic nature of this state).	Feb 2004, Aug 2004, Feb 2005, Feb 2012, Aug 2012.
Water quality measurements (pH, DO and turbidity) taken along the length of the estuary (surface and bottom samples) on a spring and neap high tide at:	Once-off Jan 1979, Sep 1993, Feb 2004, Aug 2004,

Baseline Survey	Data available
▪ end of low flow season ▪ peak of high flow season	Feb 2005, Feb 2012, Aug 2012.
Water quality measurements (inorganic nutrients) taken along the length of the estuary (surface and bottom samples) on a spring and neap high tide at: ▪ End of low flow season. ▪ Peak of high flow season.	Once-off Jan 1979, Feb 2012 and Aug 2012.
Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary.	Trace metal in sediment (1979).
Microalgae	
Chlorophyll-a measurements taken at five stations (at least) at the surface, 0.5 m and 1 m depths thereafter. Cell counts of dominant phytoplankton groups including flagellates, dinoflagellates, diatoms, chlorophytes and blue-green algae. Measurements should be taken coinciding with the different abiotic states, particularly State 1 (closed mouth) and State 5 (freshwater dominated). These data will complement existing data ('normal' flow).	Once-off August 2012 low flow RDM sampling session. Limited data from Harrison *et al*. (CSIR, unpub. data).
Intertidal and subtidal benthic chlorophyll-a measurements taken at five stations. Epipelic diatoms need to be collected for identification. Measurements should be taken coinciding with the different abiotic states, particularly State 1 (closed mouth) and State 5 (freshwater dominated). These data will complement existing data ('normal' flow).	Once-off August 2012 low flow RDM sampling session.
The microalgal survey must be done at the same time as the water quality survey.	Once-off August 2012 low flow RDM sampling session. Limited data from Harrison *et al*. (CSIR, unpub. data).
Macroalgae	
Aerial photographs of the estuary (ideally 1:5000 scale) reflecting the present state, as well as the reference condition (earliest year available). A GIS map of the estuary must be produced indicating the present and reference condition distribution of the different plant community types.	2012 GIS map from Spot 5 imagery (2010) and ground-truthing in August 2012.
Number of plant community types, identification and total number of macrophyte species, number of rare or endangered species or those with limited populations documented during a field visit. The extent of anthropogenic impacts (e.g. trampling, mining) must be noted.	Data available, updated from 2012 field survey.
Permanent transects (fixed monitoring stations that can be used to measure change in vegetation in response to changes in salinity and inundation patterns) must be set up along an elevation gradient: Measurements of percentage plant cover of each plant species in duplicate quadrats (1 m^2). Measurements of sediment salinity, water content, depth to water table and water table salinity.	Recent data not available although SAEON did sample transects in January 2012. Data set from 2006 used in this study.
Invertebrates	
Collect a set of benthic samples from ten sites, each consisting of six replicate grabs stored separately.	2004, 2005 and 2012.
Collect replicated hyperbenthic samples.at the same benthic sites (i.e. two replicates at each of the ten sites).	2004, 2005 and 2012.
Collect replicated zooplankton samples at each of the ten benthic sites (i.e. two replicates at each of the ten sites) at night.	2004, 2005 and 2012.
During each survey, collect sediment samples for analysis of grain size 1 and organic content 2 at the ten benthic sites. Compile a sediment distribution map of the estuary. Obtain a detailed determination of the extent and distribution of shallows and tidally exposed substrates.	2004, 2005 and 2012.
Fish	
The Orange Estuary needs to be sampled from the mouth to Brandkaros 35 km upstream.	Brown, 1959; Day, 1981; Cambray, 1984; Morant and O'Callaghan, 1990; Harrison, 1997; Seaman and van As,

Baseline Survey	Data available
	1998; unpublished data: 2004, 2005 and 2012.
Seine-nets to sample small and juvenile fish and gillnets to sample adults are the appropriate gear.	Unpublished data: 2004, 2005 and 2012, 2015, 2016.
Birds	
Continue with full count of all water associated birds bi-annually covering as much of the estuarine area as possible, (as part of the requirements of Ramsar). All birds should be identified to species level and the total number of each counted.	Ryan and Cooper, 1985; Williams, 1986; Simmons, 1994, 1995; Taylor *et al.,* 1999; Anderson *et al*., 2003. Nov 2012.
Additional to existing baseline	
Hydrology	
Improve on estimates for river inflow.	1993 – 1996.
Hydrodynamics and Macrophytes	
Lidar survey up to the 5 m MSL contour.	Once off.
Sediment	
Sediment core samples along the entire estuary (10 - 20 m deep).	Once off.
Sample suspended sediment load at Vioolsdrift.	Daily.
Invertebrates	
The Orange Estuary needs to be sampled quarterly over at least one year to account for the seasons.	Seasonal (i.e. quarterly).
Additional trip(s) may be required to gather data on the occurrence/recruitment and emigration of key that require a connection to the marine environment at specific times of the year.	
Fish	
The Orange Estuary needs to be sampled quarterly over at least one year to account for the seasons.	Seasonal (i.e. quarterly).
Given the evident links between the estuary and adjacent surfzone, it would also be advisable to sample the surf-zone with the seine-net, to at least 1 km either side of the mouth.	
Given the uncertainty as to the dominant food sources and the possible seasonal changes in them, a representative sample should be retained for stomach content analysis.	

15.2 DETAIL MONITORING STUDIES: ORANGE ESTUARY

This refers to studies (once-off) that are required to address identified gaps in the understanding of the system functioning.

Nutrient Assessment Programme: In the lower Orange River, a comparison between and the Vioolsdrift (D8H083Q01) and the Sir Ernest Oppenheimer Bridge (D8H012Q01) water quality stations indicate a significant increase in nutrient input below Vioolsdrift. As irrigated agriculture are predominantly concentrated in three areas along this stretch of the river, it is recommended that a few shallow boreholes be installed and monitored in the banks adjacent to these potential hotspots to try and identify the source and/or mechanism of the nutrients. Once the source has been identified, mitigation measures must be developed in consultation with the local famers and an agricultural specialist to reduce the input to the estuary.

Toxin Verification Programme in the Orange Estuary: No sampling was done for toxic substances (e.g. trace metals, hydrocarbons, herbicides and pesticides) in the Orange Estuary during this study. It is therefore recommended that sediment samples be collected and analysed for toxic substances (i.e. trace metals, petroleum hydrocarbons, herbicides and pesticides). To assist with the interpretation of results, samples should also be analysed for sediment grain size distribution and organic content. A grid of sediment sampling stations should be selected across the estuary, specifically targeting depositional areas (characterised by finer sediment grain sizes and/or higher organic content).

Impact of sustained low flows on water column (in-stream) habitat and fish: Detailed Topographical/Bathymetry surveys of the Orange Estuary at low flows are required to determine at what flow ranges the habitat become unsuitable for fish. The geomorphic survey should be conducted at the same time as biological surveys on fish, inverts and birds.

Ecological Water Requirements of the nearshore Orange Marine Environment: The flow requirements of the nearshore Orange Marine Environment - declared a South African Ecologically or Biologically Significant Marine Areas (EBSA) under the Conversion on Biodiversity Conservation - need to be assed to quantify the impact of the proposed Vioolsdrift dam development on the provision of sediments, organics, nutrients and freshwater fronts to the beaches and nearshore marine environment. This aspect needs to be formally addressed as part of the Classification.

15.3 ESTUARY BASELINE AND LONG-TERM MONITORING REQUIREMENTS OF THE SMALL WEST COAST ESTUARIES IN SUPPORT OF HIGHER LEVEL EWR STUDIES

Recommended minimum monitoring requirements to ascertain impacts of changes in freshwater flow to the estuary and any improvement or reductions therein are listed in Table 15.2.

Table 15.2 Recommended minimum requirements for long-term monitoring (Priority: Red = High; Orange = Medium, Yellow = Low, White = Not relevant)

Com-ponent	Monitoring action	Temporal scale (frequency and when)	Spatial scale (no. stations)	Buffels	Swart-lintjies	Spoeg	Groen	Sout
Hydrodynamics	Record estuary water levels.	Continuous	In main water body					
	Measure groundwater level.	Continuous	Near head of estuary					
	Satellite photographs of estuary (30x 30 m).	Every 3 years	Entire estuary					
Sediment dynamics	Bathymetric surveys: Series of cross-section profiles and a longitudinal profile collected at fixed 100-200 m intervals, but in more detail in the mouth. The vertical accuracy should be about 5 cm.	Every 3 years	Entire estuary					
	Set sediment grab samples (at cross section profiles) for analysis of PSD and origin (i.e. using microscopic observations).	Every 3 years (with invert sampling)	Entire estuary					
Water quality	Water quality (e.g. system variables (e.g. pH, oxygen, turbidity), nutrients and toxic substances) measurements in Groundwater entering the head of the estuary.	Monthly continuous	Close proximity to head of estuary					

Com-ponent	Monitoring action	Temporal scale (frequency and when)	Spatial scale (no. stations)	Buffels	Swart-lintjies	Spoeg	Groen	Sout
	Sewage volume and concentrations.	Monthly continuous	At source	Golf course			SAN-Park office	
	In situ salinity and temperature observations.	Continuous	In main water body (1 to 3 stations)					
	Longitudinal salinity and temperature profiles (in situ) collected over a spring and neap tide during high and low tide at: ▪ End of low flow season (i.e. period of maximum seawater intrusion). ▪ Peak of high flow season (i.e. period of maximum flushing by river water).	Every year at end of dry season	Entire estuary (3 - 5 stations)					
	Water quality measurements (i.e. system variables, and nutrients) taken along the length of the estuary (surface and bottom samples).	Seasonal surveys, every 3 years	Entire estuary (3-5 stations)					
	Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary, where considered an issue.	Every 6 years	Focus on sheltered, depositional areas					
	Water quality (e.g. system variables, nutrients and toxic substances) measurements on near-shore seawater.	Use available literature	Seawater adjacent to estuary mouth at salinity 35					
Microalgae	Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms and blue-green algae.	Summer survey every 3 years	Entire estuary					
	Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions using a recognised technique, e.g. High-performance liquid chromatography (HPLC).	Summer survey every 3 years	Entire estuary					
	Intertidal and subtidal benthic chlorophyll-a measurements.	Summer survey every 3 years	Entire estuary					
Macrophytes	Ground-truthed maps to document changes in macrophyte habitats over time. Document area covered by sensitive habitats i.e. submerged macrophytes.	Summer survey every 3 years	Entire estuary					
	Record number of macrophyte habitats, identification and total number of macrophyte species, number of rare or endangered species or those with limited populations documented during a field visit.	Summer survey every 3 years	Entire estuary					
	Note extent of macroalgal blooms, floating aquatic macrophytes and area occupied by invasive vegetation.	Summer survey every 3 years	Entire estuary					
	Take measurements of depth to water table and ground water salinity in reed beds.	Summer survey every 3 years	Upper reaches					

Com-ponent	Monitoring action	Temporal scale (frequency and when)	Spatial scale (no. stations)	Buffels	Swart-lintjies	Spoeg	Groen	Sout
Invertebrates	Record species and abundance of zooplankton, based on samples collected across the estuary.	Summer survey every 3 years	Entire estuary (3 - 5 stations)					*Pale mo* popul ation
	Record benthic invertebrate species and abundance, based on subtidal and intertidal grab samples at a series of stations up the estuary, and counts of hole densities.	Summer survey every 3 years	Entire estuary (3 - 5 stations)					
	Measures of sediment characteristics at each station.	Summer survey every 3 years	Entire estuary (3 - 5 stations)					
Fish	Record species and abundance of fish, based on seine net sampling.	Summer survey every 3 years	Entire estuary (3 - 5 stations)					
Birds	Undertake counts of all water associated birds, identified to species level.	Annual winter (Jul/Aug) and summer (Jan/Feb) surveys	Entire estuary					

Recommended baseline monitoring requirements to improve on the confidence of future EWR assessments are listed in Table 15.3.

Table 15.3 Recommended baseline monitoring requirements (Priority: Red = High; Orange = Medium, Yellow = Low, White = Not relevant)

Com-ponent	Monitoring action	Temporal scale (frequency and when)	Spatial scale (no. stations)	Buffels	Swart-lintjies	Spoeg	Groen	Sout
Hydrodynamics	Record estuary water levels.	Continuous	In main water body					
	Measure groundwater level.	Continuous	Near head of estuary					
	Satellite photographs of estuary (30x 30 m).	Once-off	Entire estuary					
Sediment dynamics	Bathymetric surveys: Series of cross-section profiles and a longitudinal profile collected at fixed 100 - 200 m intervals, but in more detail in the mouth. The vertical accuracy should be about 5 cm.	Once-off (or in the case of a flood)	Entire estuary					
	Set sediment grab samples (at cross section profiles) for analysis of PSD and origin (i.e. using microscopic observations).	Once-off (with invert sampling)	Entire estuary					
Water quality	Water quality (e.g. system variables (e.g. pH, oxygen, turbidity), nutrients and toxic substances) measurements in Groundwater entering the head of the estuary.	Breaching event, then quarterly for 2 years	Close proximity to head of estuary					
	Sewage volume and concentrations.	Breaching event, then quarterly for 2 years	At source	Golf course			SAN Park office	

Com-ponent	Monitoring action	Temporal scale (frequency and when)	Spatial scale (no. stations)	Buffels	Swart-lintjies	Spoeg	Groen	Sout
	In situ salinity and temperature observations.	Continuous	In main water body (1 to 3 stations)					
	Longitudinal salinity and temperature profiles (in situ) collected over a spring and neap tide during high and low tide at: ▪ End of low flow season (i.e. period of maximum seawater intrusion). ▪ Peak of high flow season (i.e. period of maximum flushing by river water).	Breaching event, then quarterly for 2 years	Entire estuary (3 - 5 stations)					
	Water quality measurements (i.e. system variables, and nutrients) taken along the length of the estuary (surface and bottom samples).	Breaching event, then quarterly for 2 years	Entire estuary (3 - 5 stations)					
	Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary, where considered an issue.	Breaching event, then quarterly for 2 years	Focus on sheltered, depositional areas					
	Water quality (e.g. system variables, nutrients and toxic substances) measurements on near-shore seawater.	Use available literature	Seawater adjacent to estuary mouth at salinity 35					
Microalgae	Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms and blue-green algae.	Breaching event, then quarterly for 2 years	Entire estuary					
	Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions using a recognised technique, e.g. HPLC.	Breaching event, then quarterly for 2 years	Entire estuary					
	Intertidal and subtidal benthic chlorophyll-a measurements.	Breaching event, then quarterly for 2 years	Entire estuary					
Macrophytes	Ground-truthed maps to document changes in macrophyte habitats over time. Document area covered by sensitive habitats i.e. submerged macrophytes.	Breaching event, then after 2 years	Entire estuary					
	Record number of macrophyte habitats, identification and total number of macrophyte species, number of rare or endangered species or those with limited populations documented during a field visit.	Breaching event, then after 2 years	Entire estuary					
	Note extent of macroalgal blooms, floating aquatic macrophytes and area occupied by invasive vegetation	Breaching event, then after 2 years	Entire estuary					
	Take measurements of depth to water table and ground water salinity in reed beds.	Breaching event, then after 2 years	Upper reaches					
Invertebrates	Record species and abundance of zooplankton, based on samples collected across the estuary	Breaching event, then quarterly for 2 years	Entire estuary (3 - 5 stations)					*Palemo* population

Com-ponent	Monitoring action	Temporal scale (frequency and when)	Spatial scale (no. stations)	Buffels	Swart-lintjies	Spoeg	Groen	Sout
	Record benthic invertebrate species and abundance, based on subtidal and intertidal grab samples at a series of stations up the estuary, and counts of hole densities.	Breaching event, then quarterly for 2 years	Entire estuary (3 - 5 stations)					
	Measures of sediment characteristics at each station.	Breaching event, then quarterly for 2 years	Entire estuary (3 - 5 stations)					
Fish	Record species and abundance of fish, based on seine net sampling.	Breaching event, then quarterly for 2 years	Entire estuary (3 - 5 stations)					
Birds	Undertake counts of all water associated birds, identified to species level.	Breaching event, then quarterly for 2 years	Entire estuary					

15.4 DETAIL MONITORING STUDIES: SMALL WEST COAST SYSTEMS

This refers to studies (once-off) that are required to address identified gaps in the understanding of the small estuaries functioning.

Salinity - Brine shrimp - Bird Dynamics Monitoring Programme: The Small West Coast estuaries play an important role as bird refuge areas. A critical food source for birds in this region is brine shrimp, which in turn is related to the occurrence of low and high salinities in the small systems, i.e. less than <50 PSU likely to be in in very low numbers, >150 PSU likely to be in cyst form. A dedicated study needs to be undertaken that focusses on bird abundance and brine shrimp abundance coupled with in situ salinity observations in these small systems.

The role of ground water in maintaining the salinity gradient of the Groen Estuary: Groundwater plays and important role in maintaining the springs that flow into the middle and upper reaches of the Groen Estuary (situated in the Namaqualand National Park). The springs, in turn, moderate the hyper salinity cycles that naturally occur in this system. The location of the springs needs to be mapped and their groundwater requirements established.

16 GROUNDWATER MONITORING

This report has been summarised from: (DWS, 2017c)
Department of Water and Sanitation, South Africa, July 2017. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Ecological specifications and monitoring report. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. DWS Report No: RDM/WMA06/00/CON/COMP/0217.

To determine water quality monitoring requirements, trace groundwater quality constituents in the Department of Water and Sanition ZQM database were analysed. Several chemical parameters which sometimes exceed potable standards were identified, these being Arsenic and Molybdendum.

To identify stressed areas in terms of water quantity, data on domestic groundwater use was collected from the All Towns strategy reports, and the Lower Orange ISP. Where no data was available from the All Towns studies, the ISP data was used. Schedule 1 water use was determined from the Census 2011 data water sources. The combined domestic water use from formal groundwater schemes and schedule 1 water users divided by total domestic water use determined the Groundwater Depenency. Livestock water use was obtained from GRAII and Irrigation, Mining and industrial water use from WARMS to obtain a total water use. The total water use relative to recharge is the stress index.

Several areas have been identified as being stressed in terms of high stress indices, declining water levels, and sole source dependency. Most of the priority catchments are located in the south, the Karoo sandstone and shale GRUs, which are the target areas for potential fracking (DWS, 2016c).

These GRUs are also classified as sole source aquifers for water supply, and highly dependent on groundwater with an already high stress index. Contamination or large abstractions from fracking or other activities could also cause significant deterioration in water supply. The specification of RQOs for these GRUs will require additional and stringent RQO attributes, which will need to be based on monitoring data.

Additional monitoring requirements for groundwater were identified based on the following key Indicators:

- Stressed catchments where groundwater use is a significant proportion of recharge, or where future use due to fracking and associated infrastructure, requires water use and water level monitoring.
- Good groundwater quality areas where hydraulic fracturing may occur.

The groundwater monitoring programme is provided in Table 16.1.

Table 16.1 Monitoring programme for groundwater resources

GRU	Catchment	Priority	Ground water dependency (%)	Stress index	Main stresses	Water level monitoring requirements	Water quality monitoring[1]
Bushmanland East	D53C	High	77	1.08	Regional water schemes	Ground water level monitoring is required in the vicinity of Kenhardt.	Cadmium
	D72C	Low	89	0.17	Regional water schemes	Some localised water level drops of 1 m have occurred in the vicinity of Marydale.	
Bushmanland West	D81B	Intermediate	6	1.02	Livestock	No long term water level monitoring exists to evaluate trends hence existing boreholes need to continue being monitored.	Arsenic
	D81C	Intermediate	37	0.74	Livestock	No long term water level monitoring exists to evaluate trends hence existing boreholes need to continue being monitored.	Arsenic
	D81D	Intermediate	35	0.96	Livestock	No long term water level monitoring exists and monitoring is required.	Arsenic
	D81E	Intermediate	28	1.35	Livestock	No long term water level monitoring exists and monitoring is required.	Arsenic
	D81F	High	61	3.80	Livestock	No long term water level monitoring exists and monitoring is required.	Arsenic
	D81G	Intermediate	3	1.02	Livestock	No long term water level monitoring exists and monitoring is required in the vicinity of Pofadder.	Arsenic
	D82A	Intermediate	69	5.63	Livestock	No long term water level monitoring exists and monitoring is required.	Arsenic
	D82B	Intermediate	40	2.15	Livestock	No long term water level monitoring exists and monitoring is required.	Arsenic
	D82C	Intermediate	9	2.03	Livestock	No long term water level monitoring exists and monitoring is required in the vicinity of Aggeneys.	Arsenic
	D82D	Intermediate	4	0.66	Livestock	No long term water level monitoring exists and monitoring is required.	Arsenic
Dwyka Tillite	D53G	Intermediate	29	0.64	Livestock mining Regional schemes	No long term water level monitoring exists and monitoring is required in the vicinity of Copperton.	
Carbonaceous Shale	D53F	Intermediate	51	1.47	Mining Industry	No long term water level monitoring exists and monitoring is required in the vicinity of the Commissioner's Pan Salt Works.	Arsenic

GRU	Catchment	Priority	Ground water dependency (%)	Stress index	Main stresses	Water level monitoring requirements	Water quality monitoring[1]
Ecca Sandstone and Shale West	D57A	High	92	0.86	Irrigation	A high stress index is related to irrigation usage in the (WARMS). The actual existence of this irrigation needs to be verified	
	D57C	High	98	0.75	Regional schemes	Brandvlei utilises a significant volume of groundwater, however, no monitoring data is available.	
Ecca Sandstone and Shale Central and Southwest	D54B	High	98	0.26	Irrigation Regional schemes	Significant water level declines are occurring near Carnarvon and monitoring should be extended.	Arsenic
	D54C	Intermediate	87	0.22	Regional schemes	Water level trends near Van Wyk's Vlei are uncertain and monitoring should continue.	
	D55L	High	99	0.56	Irrigation	Significant water use registration for irrigation exists near Williston. Most water level monitoring was stopped in 2003 and the few sporadic data after 2010exhibit uncertain trends.	
Ecca Sandstone and Shale East	D62G	Intermediate	95	0.05	Regional schemes	Water level data is sparse and of poor quality in the vicinity of Strydenburg, however, significant water level declines are evident.	Arsenic
	D62A	Low	98	0.06		Although the stress index is low, water levels are declining. Abstraction may be significantly higher than registered and should be monitored near Britstown.	Arsenic
Far Northwestern Coastal Hinterland	D82K	High	82	2.63	Regional schemes	Kuboes utilises a significant volume of groundwater, however, no monitoring data is available.	Arsenic
	F20D	High	55	2.78	Regional schemes	Port Nolloth utilises a significant volume of groundwater, however, very sparse monitoring data is available since 1990.	Arsenic
Ghaap Plateau (dolomitic)	C92B	Intermediate	52	0.06	Dolomites	Water level data is available only near Griekwastad in D71B. Monitoring should also be initiated in C92C between Cambell and Douglas.	Arsenic
	C92C	Intermediate	6	0.22			Arsenic
	D71A	Intermediate	61	0.02			Arsenic
	D71B	Intermediate	93	0.10			Arsenic
Karoo Sandstone and Shale West	D52C	Intermediate	92	0.74	Irrigation	A high stress index is related to irrigation usage in the WARMS. The actual existence of this irrigation needs to be verified.	Arsenic Molybdenum
	D55D	High	96	0.28	Irrigation Regional schemes	Significant water level declines are occurring near Loxton and monitoring should be extended.	Arsenic Molybdenum

GRU	Catchment	Priority	Ground water dependency (%)	Stress index	Main stresses	Water level monitoring requirements	Water quality monitoring[1]
	D55E	High	99	0.11	Regional schemes	Significant water level declines are occurring near Fraserburg and monitoring should be extended.	Arsenic Molybdenum
Karoo sandstone and Shale East	D61A	High	89	0.26	Irrigation Regional schemes	Significant water level declines are occurring near Richmond and monitoring should be extended.	Arsenic Molybdenum
	D61E	High	96	0.24	Regional schemes Irrigation	No long term historical data exists near Victoria West. Reliable data from only 1 borehole exists since 2009. The network needs to be extended.	Arsenic Molybdenum
	D62C	High	96	0.03	Irrigation Regional schemes	A suitable network exists however data since 2005 is sparse making monitoring and forecasting problematic.	Arsenic Molybdenum
	D62D	High	99	0.15	Regional schemes		Arsenic Molybdenum
Namaqualand East	F30D	High	55	1.8	Regional schemes	A significant groundwater use registration exists for Springbok, although the town is on surface water. This use needs to be verified. Groundwater level data is available only from 2014.	Arsenic
Namaqualand West	F30G	High	94	4.57	Mining	A high stress index is related to mining usage at Bontekoe Mining and De Beers Namaqualand in WARMs. The actual usage and its source irrigation needs to be verified. No water level data is available and monitoring is required.	Arsenic Cadmium
	F50F	Intermediate	96	0.28	Regional schemes	Significant usage for the cluster from Garies to Kamaggas occurs however, monitoring data does not show a decline in water levels. Monitoring should continue.	Arsenic Cadmium
Richtersveld	D82H	Intermediate	97	0.42	Livestock Regional schemes	Groundwater usage occurs for Eksteenfontein, however no monitoring data is available. Monitoring should be initiated.	
Karoo sandstone and Shale Southwest	D51A	High	>99	0.23	Irrigation Regional schemes	Significant abstraction occurs for Sutherland and a water level decline is evident in the two available boreholes. The network needs to be extended since the catchment is nearly 100% reliant on groundwater.	

1 A blank cell under monitoring requrements means no additional monitoring is required as no water quality problem exists in the availbale data and the host geology does not suggest any additional monitoring is required.

17 IMPLEMENTATION

This report has been summarised from: (DWS, 2017c)
Department of Water and Sanitation, South Africa, July 2017. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Ecological specifications and monitoring report. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. DWS Report No: RDM/WMA06/00/CON/COMP/0217.

17.1 BACKGROUND

"In the interim, there is still a need to influence decision-makers to amend the operating rules of dams, especially Vanderkloof, in order to simulate historical flow regimes, especially the sustained low winter flows required to close the mouth. A closer resemblance of future flow regimes at the estuary to historical patterns will result in the occasional flooding of the saltmarsh, opening and closing of the mouth and establishment of a larger area of mud-flats, all of which will result in additional feeding habitats for birds."

The above is an extract from the "Orange River Mouth RAMSAR Site Strategic Estuarine Management Plan" prepared by the Department of Environmental Affairs dated October 2015. It clearly states that a main intervention to improve the Estuary is linked to the operation of the system.

The current approach to manage and operate the Orange River Project (consisting of Gariep and Vanderkloof dams) is as follows:

1. Each year, prior to the annual operating analyses simulations, updated demands and projections are obtained from the existing users of the resource. These updated demand projections are included in the system simulation model in preparation for the annual analyses.
2. The observed dam storages on 1 May each year are obtained and also included as starting storages for all the major dams included in the model.
3. The system model is then used to carry out simulations, and an annual operating rule is prepared. The rule dictates three main operating conditions, namely:
   a. If surplus water is available in the system, it can be allocated as an additional discretionary allowance to Eskom for the purpose of Hydropower generation.
   b. If the storage in the system is sufficient to provide all users with their allocations at the required assurance levels, no restrictions will be required and users will receive their full allocation. When the storage in the system is low, restrictions might be required for the particular operating year. If restrictions are required, the extent of those restrictions amongst the various user sectors is determined from the results of modelling exercise.
   c. The release pattern for river releases from Vanderkloof and Gariep dams that should be used for the operating year based on user requirements and related monthly distribution of the demands over the year. Consideration is given to the distance between the Vanderkloof Dam and the most downstream users, and a lag time is built into the proposed releases, such that the water reaches the required point at the desired time. Releases from Gariep Dam follows the inverse monthly distribution of that determined from Vanderkloof Dam to enable a relative equal monthly generated hydro-power supply over the operating year.

One "demand" that is standard each and every year, and which has not been updated, nor modified since its original inclusion in the late 1990's, is known as the "Orange River Mouth Requirement". The demand is positioned downstream of all other users, and is supplied as a priority by the Orange River Project Dams in the model simulations. The total demand and the distribution pattern was first determined in the Orange River Development Project Replanning Study (DWAF, 1996). Very little was known at the time about the river mouth or river requirements, and it was considered the best solution with the limited data and information available at the time. The demand (pulling from the Orange River Project - ORP) is currently simulated as a constant annual (i.e. same total demand each year), with a varying monthly distribution. The demand consists of two components as indicated in Table 17.1 with units of million m^3:

Table 17.1 EWR for the Orange River obtained from the Orange River Replanning Study (ORRS)

Channel	Annual total	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920[1]	91.7	0.0	0.0	18.7	18.7	17.1	0.0	0.0	13.4	10.4	6.7	6.7	0.0
2142[2]	195.8	32.1	31.1	13.3	13.3	12.2	32.1	31.1	10.7	5.2	2.8	2.8	9.1

1 EWR components 1 and 2 combined represent the total EWR for maintenance at the river mouth.
2 EWR for drought situation (5%).

It has long been assumed that, though it is now understood that the current release for the environment is well below satisfactory, nothing can be done to modify it until the next scheme is built in the system. This would likely be a combination of Vioolsdrift Dam in the Lower Orange and Verbeeldingskraal Dam or other options in the Upper Orange with Polihali Dam in the Lesotho Highlands. However, what has changed in recent years is that, where these schemes were originally being considered for completion by 2019, they have now been pushed out and will likely only become operational by 2025. This is still eight years away.

Recent analyses as part of this study undertook to determine whether there was a possibility for an interim solution that could improve the current environmental release. A scenario was configured whereby the current ORRS “Orange River Mouth Requirement” was excluded from the simulation, and a modified environmental release was included. The release was based on the typical distribution required for the environment (i.e. following the natural flow pattern). The main objective of the analyses was that the environmental release would not result in an impact on yield of the system in any way, i.e. no other users of the system should be at a deficit as a result of including an improved environmental release.

The outcome of the analyses showed that it is in fact possible to modify the current release without impacting the system yield, and to a greater benefit of the environmental state in the Lower Orange River. It is proposed that an interim EWR, i.e. the Preliminary Reserve, be implemented in the system, prior to the eventual Reserve and the related Classification process, that will come online along with the new schemes.

The challenge now is to implement the interim Reserve. Further work is required in order to determine exactly how the variable EWR release pattern should look, and what will trigger the required releases.

17.2 PROPOSED IMPLEMENTATION METHODOLOGY

Very few practical examples exist in South Africa where a variable reserve release pattern is being released for, and is incorporated into the operation of a system. The Letaba system has a rudimentary process in order to improve flows into the Kruger National Park. While a similar process can be included in the Orange River system, it is anticipated that the operating procedure could be streamlined and improved on. The following steps would be required in order to undertake a study to implement the preliminary Reserve:

- **Step 1: Develop approach to determine an EWR release trigger which is usually natural flow, based on preceding weather conditions:** In order to determine what the EWR should be on a specified day, it is necessary to know what the natural flow would have been on that date, based on the preceding weather conditions (specifically rainfall) leading up to that date. A simplified approach should be developed in order to determine what the natural flow at the EWR sites should be, on any given day/month based on observed rainfall over a set time period. Existing calibrated rainfall runoff models can be used to determine the extent of the relationships that exist between rainfall and natural flow.
- **Step 2: Establishment of EWRs**. This has effectively been done as part of this study, whereby a Preliminary Reserve has been determined at EWR O5 (Sendelingsdrift).
- **Step 3: Develop Tool based on Step 1 approach:** This step should involve taking the information determined in step 1, and formalising it in a functional tool that will relate preceding observed rainfall to natural flow and then to the ecological requirement for a specified day.
- **Step 4: Produce Tool presentation techniques:** Once the EWR for a certain date has been determined, it should be compared with the observed actual flows at selected monitoring sites on a real-time basis. This step should develop the ability to do that, by building in the option to clearly present the real-time flows at the selected gauging points, and compare them graphically with what should be flowing, based on the set EWR. Alarm systems can be set up for occasions when the current flows remain lower or higher than the required flows for set time periods, prompting the end user of the tool to investigate the reasons for the differences.
- **Step 5: Establish operational links:** This step should develop a simple operational tool to use as a guide for releases that should be made at upstream dams in order to satisfy the EWR. EWR releases from the Vaal River system in support of the Orange River as well as spills from the Vaal River into the Orange need to be taken into account in this process. This is particularly important in the Orange River System due to the long lag times between dam releases and the flow reaching the lower EWR sites.

Figure 17.1 presents the suggested approach to implement the preliminary EWR. Further work on defining the approach and linking it to annual operations is however required.

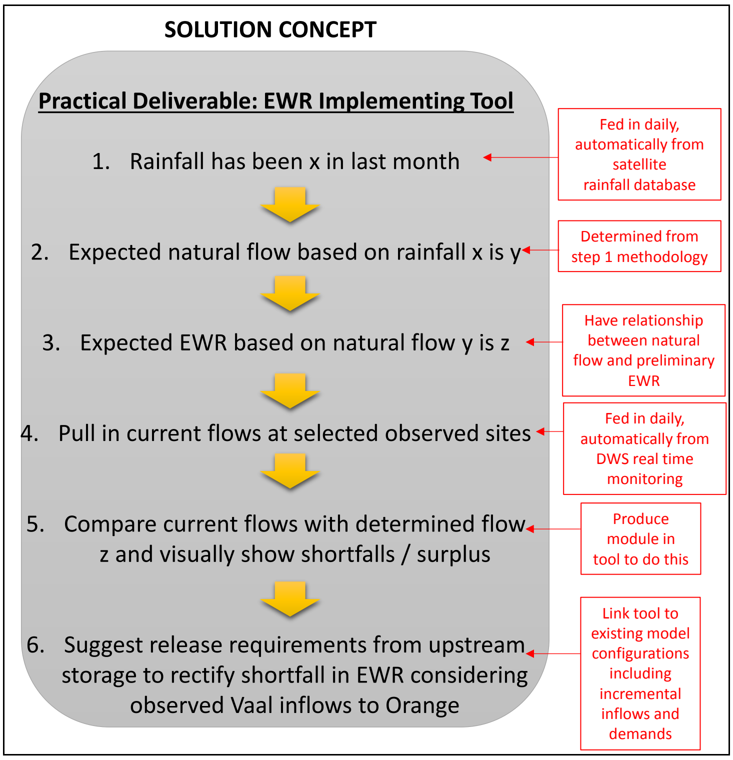


Figure 17.1 Suggested approach to implement the EWR

The implementation methodology is reliant on improved monitoring, especially of abstractions and return flows in the Lower Orange system, as well as inflows from the Vaal River system. The following flow gauges already exist on the DWS real time monitoring system and can be used as guides as to whether or not the observed flows are as per EWR requirements and to manage the EWR releases:

- C9R002: Spills from Bloemhof Dam.
- C9H024: Vaal at Schmidsdrift.
- D7H005: Upington.
- D7H014: Orange at Neusberg.
- D8H014: Orange at Blouputs.
- D8H008: Orange at Pella Mission.
- D8H015: Orange at Sendelingsdrif.
- D8H007: Orange at Brandkaros.

Careful consideration needs to take place relating the required EWR releases with the other existing users. Alternate approaches to operation may be required and solutions to potential problems addressed. For example, the hydropower releases for Eskom should be considered and made in the context of the other users, and especially the environment. Impacts of releasing additional hydropower for Eskom in naturally low flow months should be determined.

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19 APPENDIX A: COMMENTS REGISTER

Section	Report statement	Comments	Changes made?	Author comment
All editorial comments suggested by reviewers were incorporated in report.				
Executive summary		In the Executive Summary, under GROUNDWATER EWR, please include the 22% used for livestock watering in the 1st paragraph because the graph (**Fig 8.1**) which shows all the percentages is too far down in the main text.	Yes	
		Note the correction of Units in the BHNR Tables of the Executive Summary, Tables 9.2 and 9.3, i.e. *million/m³/a* - the correct one is ***million m³/a***.	Yes	
Chapter 8		Water level drops by a certain amount. The period of drop is necessary to ascertain how long it takes for such a decline, which helps in projecting future drops if nothing is done about it. This applies to all GRUs described in Chapter 8.	Yes	Time period of record was included.
		Consistency in expressing the Units for Recharge is crucial. In some cases it is expressed in mm only whilst in other cases it is expressed in mm/a. I suggest it is expressed as *mm/a* throughout the document. This applies to all GRUs described in Section 2.4 and Chapter 8 for example on page 2-9 under Namaqualand East, Namaqualand West, Western Kalahari *etc*.	Yes	Units changed.
		In the Tables of Section 8.3, I'd like to suggest that two Columns are added in order to depict i) Recharge and ii) Stress Index for each catchment. It is appreciated that these parameters are covered as ranges in the text above Tables, but for ease of reference they'd rather be on the Tables.	Yes	Columns added.
		Inside the Maps showing GRUs has two GRUs numbered 2. These are Figures 8.3, 8.4, (on pages 8-3 and 8-4) and in the Executive Summary. Please rectify (or clarify why).	No	The diagram is correct. The label GRU 2 is included twice as one Quaternary in the GRU is High priority, whereas the Quates to the NW and SE are moderate priority. The two disconnected moderate priority sections are labelled separately. See figure 8.2 for GRU delineation.
		In Section 8.3.2, it's not clear whether the reference to groundwater depth implies aquifer depth or groundwater level. Presumably it refers to groundwater levels when looking at the description of the rest of the GRUs. Can this please be clarified or rectified	Yes	The word groundwater level depth was added.
		Please rectify Sub-heading numbering after 8.3.15. Western Kalahari GRU is not numbered and then those below it are wrongly numbered.		Karim, I will do this once report is finalised.

Section	Report statement	Comments	Changes made?	Author comment
		A majority of GRUs and catchments have zero EWRs. Can it be briefly explained in the text what the implication is with regards to ecosystems of the WMA. - Does the non-existence of baseflow automatically translate to non-existence of EWR? Unless of course we are expressing '*Groundwater Contribution to Baseflow*' as '<u>*Groundwater EWR*</u>' in this document? - It seems the GW EWR values for two catchments (D51A and D73B) in this document are expressed as Baseflow in **Table 3.12 of the Groundwater EWR Report DWS, 2016c**; is it an accurate estimation for GW EWR?	Yes	Paragraph added in chapter 8
Chapter 9		Note and rectify the duplication of Paragraphs above Table 9.3.	Yes	
Whole document		The Department is called *Department of Water and Sanitation*, and not Department of Water Affairs and Sanitation. This is observed in places within the document, please rectify.	Yes	