COMPREHENSIVE RESERVE DETERMINATION

INTEGRATED VAAL RIVER SYSTEM

SURFACE WATER

MAIN INTEGRATION REPORT

TECHNICAL COMPONENT: LOWER VAAL

REPORT NO.: RDM/WMA10 C000/01/CON/0610

PROJECT NO.: 8829/1

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APPROVAL

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EXECUTIVE SUMMARY

Background

Chapter 3 of the National Water Act (NWA) (Act No. 36, 1998) provides for the protection of water resources of the country through the implementation of Resource Directed Measures (RDM), based on the guiding principles of sustainability and equity. In terms of the Act, before any authorization to utilise a particular water resource can be granted, it is necessary to determine the Reserve for the relevant ecological component of the resource that will be impacted by the proposed water use. The Reserve can be defined as, 'the quantity, quality and reliability of water needed to sustain both basic human needs and aquatic ecosystems.

The Chief Directorate: Resource Directed Measures (CD: RDM) is tasked with the responsibility of ensuring that the Reserve requirements, which have priority over other uses in terms of the Act, are determined before any new water uses are authorised. The Reserve requirements must be met, before the requirements for economic development or water uses are satisfied so as to ensure that the long-term integrity of ecosystems are not comprised or severely impacted upon'. As the Department of Water Affairs (DWA) is the custodian of the nation's water resources, it is their responsibility to ensure the adequate protection and effective management of these resources.

The CD: RDM initiated a Comprehensive Reserve Determination Study for the water resources of the Lower Vaal Water Management Area (WMA) that forms part of the overall comprehensive Reserve determination of the integrated Vaal River System. The purpose of this Reserve Determination Study is to determine the ecological and basic human needs water quantity and quality Reserve for the Middle Vaal at a comprehensive level of detail.

The Lower Vaal WMA forms part of the integrated Vaal River System, and falls within the C drainage region of South Africa. The Lower Vaal WMA is one of the three cascading WMAs in the Vaal River System catchment, which includes the drainage area of the Vaal River from its headwaters to the confluence of the Vaal and Orange Rivers.

The study area for the Comprehensive Reserve determination of the lower Vaal River is the Vaal catchment within the Lower Vaal and Upper Orange WMAs (part of WMA 10 and 13). These catchment areas form part of the integrated Vaal River System, as they fall within the C drainage region of South Africa. The Lower Vaal WMA is the last of the three cascading WMAs in the Vaal River System catchment, which includes the drainage area of the Vaal River from its headwaters to the confluence of the Vaal and Orange Rivers.

The Lower Vaal WMA is situated in the north-western part of the country and forms part of the Orange River watercourse. It covers a catchment area of 133 354 km^2, and includes parts of the Northern Cape and North-West Provinces, and a small part of the Free State Province. The Vaal River is the only major river in the WMA, as it flows in a westerly direction from Bloemhof Dam to the confluence with the Orange River. The largest part of the WMA falls within the catchment of the Molopo River, a tributary of the Orange River. The Molopo, Nossob and Kuruman rivers drain the remainder of the WMA but due to the very low rainfall in the WMA, these rivers are insignificant. The WMA consists of the D41 (excluding D41A), parts of D42C and D42D, parts of D73A and D73C, C31, C32, C33, C91, and C92 tertiary catchments. For the purpose of this study only the C drainage region is of relevance as it forms part of the Vaal River System, which includes the Harts River catchment and the Vaal River catchment. These two catchments as part of the Vaal River System cover a catchment area of 53 500km^2 within the Lower Vaal WMA. The C drainage region of the Lower WMA comprises four sub-catchments

The Modder/Riet system forms part of the upper Orange River catchment and consists of tertiary catchments C51 and C52. The Orange River confluences with the Vaal River near the downstream outlet of the Lower Vaal WMA.

Virtually all the surface flow of the Vaal River, the main source of water in the Lower Vaal WMA, originates from the Upper and Middle Vaal WMAs. Very little surface run-off originates within the WMA itself due to the low rainfall, flat topography and sandy soils. The groundwater resource is more substantial, supplying an estimated 128 million m^3/annum. The Vaal River is fed by the only tributary, the Harts River which drains a catchment area of 31 000km^2, with the Dry Harts being the major tributary of the Harts River joining it just downstream of Taung. The only lake and wetlands of note are at Barberspan in the Upper Harts River catchment which has been given Ramsar status as a wildlife conservation area.

The development of the surface water resources occurring in the WMA has reached its potential, however all water is not being fully utilised. The water in Taung Dam and Spitskop Dam are currently not utilised and further studies are required to determine best how to utilise the water contained in these dams.

The selected Ecological Water Requirement (EWR) sites are listed in Table A. The study area for the Comprehensive Reserve determination is the Lower Vaal and Upper Orange WMAs (part of WMA 10 and 13). These catchment areas form part of the integrated Vaal River System, as they fall within the C drainage region of South Africa. The Lower Vaal WMA is the last of the three cascading WMAs in the Vaal River System catchment, which includes the drainage area of the Vaal River from its headwaters to the confluence of the Vaal and Orange Rivers.

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The Modder/Riet system forms part of the upper Orange River catchment and consists of tertiary catchments C51 and C52. The Orange River confluences with the Vaal River near the downstream outlet of the Lower Vaal WMA. The C drainage region of the Lower WMA comprises four sub-catchments and the Upper Orange one catchment as listed in Table A.

Table A: Sub-catchments and related quaternary drainage regions within the C Drainage tertiary Catchment within the Lower Vaal WMA

PRIMARY CATCHMENT	SUB-CATCHMENT	QUARTENARY CATCHMENTS	AVERAGE GROSS AREA (km^2)
C	Dry Harts	C32A-D	10 205
	Harts	C31A-F	11 023
	Vaalharts	C33A-C	9843
	Vaal downstream Bloemhof	C91A-E, C92A-C	22 427
	Modder/Riet	C51A-M, C52A-L	34 795

Virtually all the surface flow of the Vaal River, the main source of water in the Lower Vaal WMA, originates from the Upper and Middle Vaal WMAs. Very little surface run-off originates within the WMA itself due to the low rainfall, flat topography and sandy soils. The groundwater resource is more substantial, supplying an estimated 128 million m^3/annum. The Vaal River is fed by the only tributary, the Harts River which drains a catchment area of 31 000km^2, with the Dry Harts being the major tributary of the Harts River joining it just downstream of Taung. The only lake and wetlands of note are at Barberspan in the Upper Harts River catchment which has been given Ramsar status as a wildlife conservation area.

The development of the surface water resources occurring in the WMA has reached its potential, however all water is not being fully utilised. The water in Taung Dam and Spitskop Dam are currently not utilised and further studies are required to determine best how to utilise the water contained in these dams.

The selected Ecological Water Requirement (EWR) sites 16 to 19 are listed in Table B.

Table B: Selected EWR sites for the Lower Vaal catchment

EWR Site number	EWR site name	River	EcoRegion (Level II)	Geomorphic zone	Altitude (m)	Quaternary catchment	Hydrological gauge
EWR16	Downstream Bloemhof Dam	Vaal	11.08; 29.02	E: Lower Foothills	1211	C91A	C9H021
EWR17	Lloyds weir on Harts River	Harts	29.02; 30.01	E: Lower Foothills	1114	C33C	C3H016
EWR18	Schmidtsdrift	Vaal	29.02; 30.01	E: Lower Foothills	1239	C92B	C9H024
EWR19	Lilydale Lodge	Riet	29.02	E: Lower Foothills	1107	C51L	C5H048

[1]: River Health Programme; [2]: Resource Unit 1.

In summary the Eco Status and Ecological Importance and Sensitivity for the Lower Vaal varied and this was due to water quality and flow changes. The difficulty in improving the REC is due to the Vaal River system being operated as a water supply scheme for irrigation and drinking water and not for ecological sustainability purposes. The Ecostatus results are summarised in Figure 1.

EWR 16			
Components	**PES**	**EIS**	**REC**
Hydrology	D	MODERATE	D
Physico-chemical	C		C
Geomorphology	D/E		D/E
Fish	D		D
Invertebrates	D		D
INSTREAM	D		D
Riparian vegetation	E/F		D*
ECOSTATUS	E		D

EWR 17			
Components	**PES**	**EIS**	**REC**
Hydrology	D	MODERATE	D
Physico-chemical	D/E		D/E
Geomoprhology	D		D
Fish	D		D
Invertebrates	C/D		C/D
INSTREAM	D		D
Riparian vegetation	D		D
ECOSTATUS	D		D

EWR 18			
Components	**PES**	**EIS**	**REC**
Hydrology	C	MODERATE	C
Physico-chemical	C		C
Geomorphology	C/D		C/D
Fish	C		C
Invertebrates	C/D		C/D
INSTREAM	C		C
Riparian vegetation	C		C
ECOSTATUS	C		C

EWR 19			
Components	**PES**	**EIS**	**REC**
Hydrology	D	HIGH	C
Physico-chemical	D		C
Geomorphology	C		C
Fish	C		B
Invertebrates	C		B
INSTREAM	C		B
Riparian vegetation	B		B
ECOSTATUS	C		B

Figure 1: Summary of PES, EIS and REC for the EWR sites in the Middle Vaal

The hydrology of the Lower Vaal WMA is impacted in the main stem of the Vaal by the Vaal Dam, Vaal Barrage (completed in 1919) and Bloemhof Dam. The flow regime in the main stem of the Vaal is impacted by the following:

- Vaal Dam storage
- Releases from Vaal Dam to dilute salts to 600 mg/L TDS (mainly in winter)
- Releases from Vaal Dam and Vaal River Barrage to supply the Vaal Hartz irrigation scheme (completed 1938)
- Interbasin transfers into the Vaal from Lesotho and Grootdraai Dam
- Vaal Hartz irrigation scheme transfer

This altered flow regime has resulted in increased winter base flows in the Lowere Vaal River and smaller floods being reduced in summer.

Due to this regulation having being implemented in varying degrees for 90 years the aquatic organisms have adapted and the river banks are stable.

In the Riet and Harts Rivers the hydrology has changed due to increase irrigation usage, upstream dams and urban requirements. These rivers have less flow in winter as well as summer due to these anthropogenic changes.

The objectives of this task were to recommend the magnitude, duration and timing of specific flows and flow patterns that are considered to be the most important for maintaining the abiotic (e.g. geomorphology) and biotic components (plants and animals) of each Resource Unit in a particular condition, or Ecological Category.

Data analysis focused on the relationships between discharge and habitat availability and key ecosystem processes. This process did not consider whether these flows could be supplied or managed, and impacts on users were not considered.

The natural MARs as provided by the hydrologist are given in Table C. The final flow requirements are expressed as a percentage of the natural MAR in Table D.

Table C: Natural and PD MARs of the EWR sites

Site	Virgin MAR	Present MAR
EWR 16	3242.50	1699.32
EWR 17	147.85	124.72
EWR 18	3347.19	1177.28
EWR 19	403.87	247.67

Table D: Summary of results as a percentage of the natural MAR

EWR Sites	EC	Maintenance Low Flows (% nMAR)	Drought Low Flows (% nMAR)	High Flows (% nMAR)	Long Term Mean (% nMAR)
EWR 16	E PES,REC	12.42	8.78	9.64	31.97
	D AEC UP				
EWR 17	D PES,REC	56.71	0.02	13.07	21.54
	D AEC UP				
EWR 18	C/D PES,REC	2.84	1.51	4.85	2.59
	D AEC DOWN				
EWR 19	D PES,REC	13.44	0.08	15.39	28.98
	D AEC UP				

Water quality

The Vaal River at Vaalharts weir (C9H008) display high salts (479 mg/ℓ) and an unacceptable high phosphate concentrations (0.117 mg/ℓ). The high nutrients stimulate algal and water hyacinths growth (DWAF, 2009a).

The water quality in the Harts River was extremely poor; 5/7 parameters were in the unacceptable range. The TDS concentration in the Harts at Delportshoop, Lloyds weir (C3H016) was unacceptable at 1 322 mg/ℓ and shows an increasing trend. The Harts River contributes significant amounts of salts to the lower Vaal River.

The water quality in the Vaal River at Schmidtsdrift (C9H024) was unacceptable because of the high salts (EC, 117 mS/m; ~820 mg TDS/ℓ) and high nutrients, especially high ammonia (0.147 mg/ℓ).

Irrigation and salinisation

Irrigation use about 82 % of the total water requirements in the WMA. Over 85 % of the requirements for irrigation are in the Harts sub-area, mainly at the Vaalharts irrigation scheme, with the balance being along the Vaal River. The Vaalharts irrigation scheme serves the purpose of beneficially utilising lower quality water discharged from the Upper Vaal water management area and thus prevents the accumulation of salinity in the lower reaches of the Lower Vaal WMA.

Water in the Harts River downstream of the Vaalharts irrigation scheme is of exceptional high salinity as a result of saline leachate from the irrigation fields, and needs to be carefully managed through blending with fresher water.

Because of salinisation problems experienced at the Vaalharts irrigation scheme an efficient subsurface drainage system was installed, resulting in large quantities of irrigation effluent being returned to the river and which could potentially be re-used downstream. The resultant balance at the downstream end of the water management area is reflected as a surplus for the Lower Vaal water management area, and not as a transfer to the Lower Orange water management area.

Water quality in the lower reaches of the Vaal River is also impacted upon by irrigation return flows from the Harts River as well as from the Riet/Modder River further downstream, necessitating further blending with low salinity water from the Orange River at the Douglas.

In arid and semi-arid regions irrigation tends to degrade soil and water quality through salt accumulation with devastating effects on some crops. A recent study in the Lower Vaal WMA showed that the addition of salts to the soils as a result of farming practices varied between 79 t/ha and 280 t/ha, with irrigation water being the major contributor of salt. Soils had been irrigated for periods of between 17 to 53 years. However, predictions showed that if the current practices are sustained for the next 50 years the osmotic potential of 6 soils will decline to below the threshold of -100 kPa for maize. In two of these soils the threshold of -280 kPa for wheat will also be exceeded. Hence salt-induced water stress could reduce the yield of maize and even wheat significantly in future if appropriate precautionary measures are not introduced.High dissolved salts concentrations in the Vaal River could be the tipping factor that may shift the algal composition in favour of undesirable highly toxic cyanobacterium species (notably *Cylindrospermopsis* sp.) that was already observed in the lower part of the Vaal River and Orange River.

Eutrophication and Algal blooms

Spitskop Dam is classified as an eutrophic system and toxic cyanobacterial blooms have been recorded. The occurrence of cyanobacterial species, *Cylindrospermopsis* sp., is a major concern because of the potent toxin produced by these algae and the difficulty to remove it from the water during water treatment process.

During 2000 the first major cyanobacterial outbreak in the Orange River downstream of the confluence of the Vaal and the Orange River was recorded. The findings of a study during this event indicated that the problem species (*Cylindrospermopsis* sp.) originated in the Spitskop Dam. During high flows the cyanobacterial species were transported downstream causing problems for all the treatment works that was designed to handle high turbidity in the supply waters and not cyanobacterial or algal blooms.

Water Transfers and hydrology

The bulk of the surface water found in the water management area is in the Vaal River, most of which is transferred along the river from the Upper Vaal water management area and via the Middle Vaal water management area, to the Lower Vaal water management area. Water is also transferred into the water management area at Douglas Weir, from the Upper Orange water management area, for water quality management purposes.

The only direct international obligation affecting the water resources of the Vaal River System is in the Lower Vaal WMA, in particular the Molopo River catchment.

The transfer of water between water management areas and arrangements with neighbouring countries resort under national control. The following reservations are made in the National Water Resource Strategy with respect to water transfers in to and out of the Lower Vaal water management area: Currently 500 Mm3/a is transferred from the Middle Vaal water management area to the Lower Vaal water management area. As an upper scenario this may increase to about 555 Mm^3/a during the period of projection – Reserved in the Middle Vaal WMA.

A reservation applies to the transfer of 18 Mm^3/a from the Upper Orange WMA to the Douglas Weir in the Lower Vaal WMA – Reserved in the Upper Orange WMA. The Lower Vaal WMA also forms part of the Vaal River System which extends over several water management areas. As water resource management in the Vaal River System impacts to some degree on water quantity and quality in all the inter-linked water management areas, management of water resources in the Vaal River System is to be controlled at a national level.

The purpose of Step 5 in the 8 step Reserve process is to predict the driver and biotic responses to each operational scenario, including natural and present day hydrology and derive the ecological categories for each EWR site. All information generated during steps 3 (ecoclassification) and step 4 (determination of Ecological Water Requirement) is used during this step.

The following steps were followed to determine the ecological consequences of the operational flow scenarios.

- The operational scenarios (DWA, 2010a) were modelled using the WRPM and a time series was provided for each scenario at each EWR site.
- The time series was converted to a flow duration table and both was provided to the physico chemical and geomorphology specialists.
- The impacts of these time series of the operational scenarios were analysed by the physico chemical and geomorphology specialists by completion of the Physico-chemical Assessment Index (PAI) and Geomorphology Assessment Index (GAI) models to predict the driver ecological category.
- The riparian vegetation specialist then assessed the response on the marginal and other riparian zones and supplied this information to the instream biotic specialists (macroinvertebrates and fish).
- Where required, the riparian vegetation specialist ran the Vegetation Response Assessment Index (VEGRAI) model to predict the ecological category for each operational scenario.

The following instream biotic assessment was then undertaken:

- Each time series was converted into a stress duration table and provided on a graph for the same months as evaluated during the EWR workshop.
- The requirements set for the low flow EWR scenarios for both fish and macroinvertebrates were copied onto these graphs.
- The operational scenarios were then compared to the EWRs set for the various ecological categories.
- If it was not obvious what the resulting category was, the stress and habitat implications for the operational scenario were investigated and the responses modelled in the Fish Response Assessment Index (FRAI) and Macro invertebrate response Assessment Index (MIRAI) to determine the ecological category.
- The VEGRAI, MIRAI and FRAI results were then used as input to the Ecostatus model to determine the resulting ecological category per operational scenario.

Table E provides a summary of the operational scenarios that were modelled using the WRPM.

Table E: Summary of the operational scenarios evaluated

Sc No	Dev Level	EWR Status	Scenario description	Reasoning
1	2008	Excluded	Base scenario representing the status quo.	This is a new PRESENT DAY. This scenario was not evaluated, but differences from the old PD were noted and reasoning was provided.

Sc No	Dev Level	EWR Status	Scenario description	Reasoning
4	2008	Included	Based on Scenario 1. EWR Scenario: With exception of EWR 4 and EWR 5, all EWRs in Vaal and one EWR in Thukela downstream of Driel Barrage were included.	Although EWRs are provided as a demand, it was still evaluated. One EWR site (e.g. in the Lower Vaal), could drive the requirements and result in unacceptable situations at EWR sites in the Upper Vaal (too much flow e.g.). NB: The EWR was included as a priority demand and this has a knock on effect on other users, and the operation rules of dams. This is relevant for all scenarios where dams are included.
5	2020	Excluded	Sc 1 representing the future 2020 development conditions excluding the EWRs. Includes VRESSAP pipeline from Vaal Dam to Eastern Sub-system. Includes proposed Polihali Dam and conveyance infrastructure. Includes proposed re-use of mine water. Includes projected possible transfer to the Crocodile catchment.	Key scenarios. Includes most likely future developments and illustrates resulting flows at EWR sites. NO EWRs were included as a demand in the system. Basically, this is the WHAT IF scenarios, i.e., what if we manage the system in this manner without providing EWRs – will the EcoStatus change and if so, how much.
6	2020	Included	Based on Sc 5. EWR Scenario: With exception of EWR 4 and EWR 5, all EWRs in Vaal and one EWR in Thukela downstream of Driel Barrage were included.	Combination of Sc 5 and Sc 4.
7	Full utilization (Future development scenario)	Excluded	Scenario representing the full utilization of available water. Based on current infrastructure. Includes VRESSAP pipeline from Vaal Dam to Eastern Sub-system.	This is also a future scenario, but brings in new developments apart from the VRESSAP pipeline. Full utilisation means that there is allocated water, or water available in dams, which have not been used yet.
8	Full utilization (Future development scenario)	Included	Based on Sc 7. EWR Scenario: With exception of EWR 4 and EWR 5, all EWRs in Vaal and one EWR in Thukela downstream of Driel Barrage were included.	Combination of Sc 7 and Sc 4.

Ecological and water quality consequences of the various operational scenarios were assessed and are described in the sections below. The ecological evaluation is based on an assessment of the impact on the status or ECs recommended for each component. Information on the water quality assessment as a key driver is provided below, followed by the overall assessment.

A summary of the scenario consequences are shown in Table F.

Table F: Scenario consequences

Main Stem	**Sc 1 PD REC**	**Sc 4**	**Sc 5**	**Sc 6**	**Sc 7**	**Sc 8**
16 Bloemhof	**E**	**E**	**E**	**E**	**E**	**E**
18 Schimdtsdrift	**C/D**	**C**	**C/D**	**C**	**C/D**	**C**
Tributaries						
17 Harts	**D**	**D**	**D**	**D**	**D**	**D**
19 Riet	**D**	**C**	**D**	**C**	**D**	**C**

A summary of ecological consequences per scenario are included for the main stem (Figure 2) and the tributaries (Figure 3), and an overview for the Lower Vaal EWR sites (Figure 4).

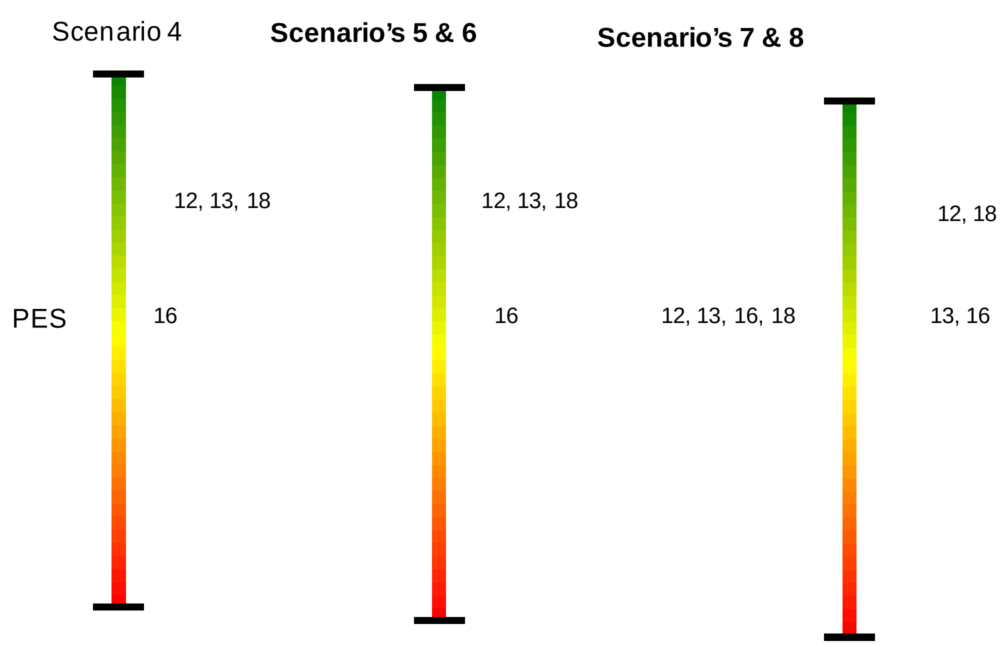

Figure 2: Summary of ecological consequences per scenario for the main stem of the Vaal EWR sites

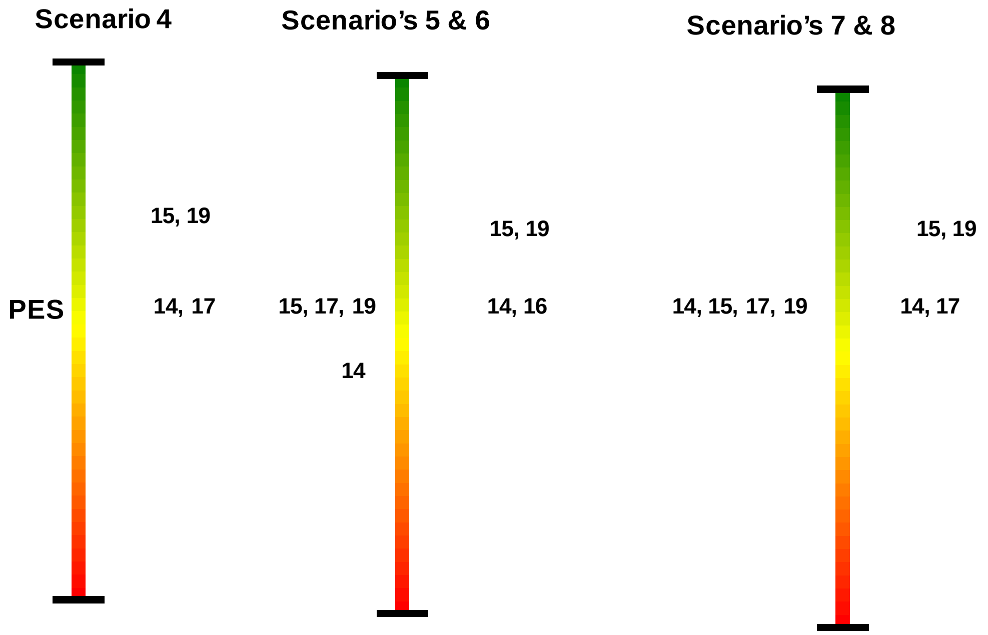

Figure 3: Summary of ecological consequences per scenario for the tributaries of the Vaal EWR sites

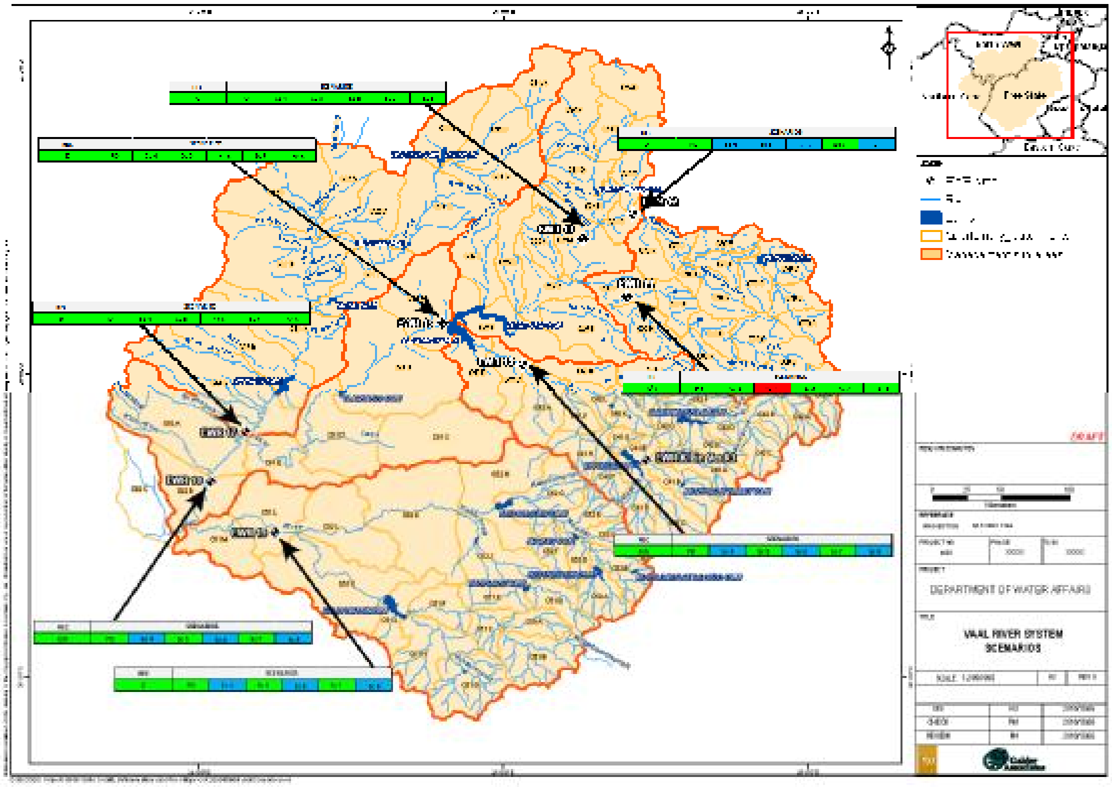

Figure 4: Summary of the Ecological Consequences for the Middle and LowerVaal Catchment scenario's.

Based on a similar approach used for the socio-economic impact assessment for the Upper Vaal WMA (as undertaken by Connningarth), the Middle and Lower Vaal WMAs were partitioned into defined economic zones. Several EWR sites were identified and establish along the Vaal River in the Upper, Middle and Lower Vaal WMAs within these economic zones in order to measure present day water use and to make predictions on future water use. These EWR sites were evaluated and identified according to criteria which included hydraulics, land use, regulation and accessibility. Eight EWR sites were then identified within the Middle and Lower Vaal WMAs and present day water use for various water users estimated. From the relevant socio-economic data collected for irrigated agriculture, mining and manufacturing and population within each WMA baseline economic indicators such Gross Domestic Product (GDP), employment and household income were generated for each economic zone using Water Multipliers. These baseline results were then adapted to account for water use (demand) at each of the eight EWR sites.

Although all eight scenarios were analysed as part of the overall study, Scenario 8 (which included the EWR) was assessed relative to Scenario 7 specifically for the socio-economic component of the Project. The remaining scenarios were used to assess the impact of alternative options for the inclusion of the EWRs.

Of the initial eight water allocation scenarios identified by the Project Team, the economic impacts of Scenarios 7 and 8 were modelled for several tributaries of the Vaal. Present day GDP and employment figures per EWR site were calculated using present day water abstraction at each EWR site and economic water multiplier for each economic zone within the Lower Vaal WMAs. The relevant economic zones were:

- Vaal River main-stem;
- Harts;
- Modder; and
- Riet.

Water use data were collected for various water users within the Lower Vaal WMA. Major water users within these WMAs are:

- Irrigated agriculture;
- Mining and manufacturing; and
- Domestic and/or household consumption

Relevant data were collected for each user category and used to estimate water use. These data were then modelled using the SAFRIM and WIM methodology (consistent with the Upper Vaal study) producing baseline economic impacts based on the economic zones identified. The baseline results indicated that irrigated agriculture had a significant economic impact in the Lower Vaal WMA providing R524 million directly to GDP and 7,403 employment opportunities.

Possible further research into this could entail a financial and economic analysis of irrigated agriculture along these tributaries based on water allocation or costs scenarios the aim of which could be to assess the impacts of increasing water cost to irrigators and assessing at what levels costs affect profitability. Necessary trade-offs that could be made could also be identified by such a study. The traffic diagram below (Figure 5) provides a graphic representation of the overall socio-economic impacts of Scenario 8 in the Lower Vaal WMAs.

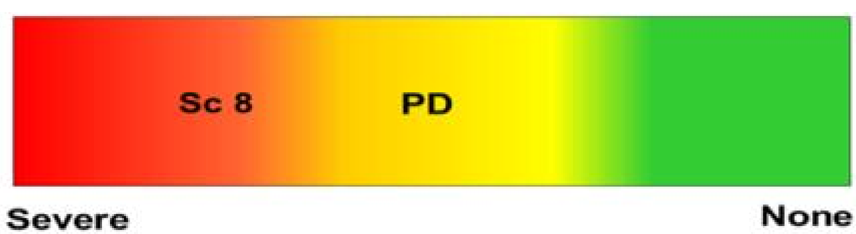

Figure 5: Traffic light diagram of overall socio-economic impacts of Scenarios 7 and 8 for Lower Vaal WMAs

The methodology used to assess the impacts on Ecosystems Goods and Services in this study was consistent with the approach used for the Upper Vaal WMA. Of the eight water allocation Scenarios identified, Scenarios 4, 5, 6, 7 and 8 were evaluated per EWR site. The approach investigated the impact of each Scenario on Fish, Riparian Vegetation, Recreation and Water Quality resources per EWR site. Overall it was found that by implementing the ER at each EWR site no negative impacts were found except for Scenario 5 at EWR site 14. These negative impacts were driven by impacts on fish species such as the, Smallmouth yellowfish (*Labeobarbus aeneus*), Orange-Vaal mudfish (*Labeo capensis*) and Moggel, (*Labeo umbratus*) and result from reduced flow levels leading to a decrease or disappearance of species from this reach. Scenario 5 cannot, therefore, be recommended as acceptable from an Ecosystems Goods and Services perspective based on these negative impacts. Scenario 6 had the highest overall score for each resource in both the Middle and Lower Vaal WMAs and on this basis must be recommended as the most acceptable Scenario from an Ecosystems Goods and Services perspective. The traffic diagram below (Figure 6) provides a graphic representation of the overall impacts of each Scenario on Ecosystems Goods and Services in the Lower Vaal WMAs.

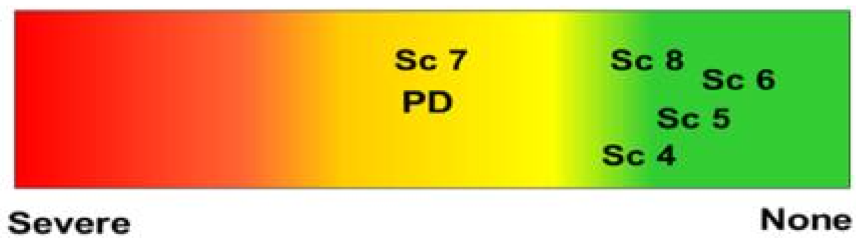

Figure 6: Traffic light diagram of overall Ecosystems Goods and Services impacts of Scenarios 4, 5, 6, 7 and 8 for Lower Vaal WMAs

The following final recommendations for the future management of the Lower Vaal (Table G) have been approved.

Table G: Final recommendations for the future management of the Lower Vaal

EWR site	Recommendation
16 Vaal (Bloemhof)	Sign off for instream REC=D as the current overall PES=E due to non-flow related impacts. Conditions to improve the Riparian Zone should be included.
17 Harts	Sign off for PES=REC=D
18 Vaal (Schmitsdrift)	Sign off for REC=C/D
19 Riet	Sign off for REC=D with a recommendation that the flow measurements at the gauging weir must be improved.

The final step in the Reserve process is to define the Ecological Specifications (Ecospecs) and monitoring requirements for the maintenance of the at each Ecological Water Requirement (EWR) site. The Ecospecs are intended to provide the quantifiable and enforceable descriptors of the quantity, quality and habitat and biotic integrity as they pertain to the ecological objectives for a particular water resource (in this case a particular river reach). These are the values of parameters (usually maximum concentrations) that should not be exceeded in order to meet the Ecological Category specified for the water resource.

The EcoSpecifications and Thresholds of Potential Concern (TPC's) for the maintenance of the ecological Reserve for each EWR site for components consisting of the drivers (geomorphology, physico-chemical variables and hydrology) and the response (riparian vegetation, fish and macroinvertebrates) were determined.

The TPCs are "triggers" that indicate management action is required, and the monitoring activities that should be undertaken in order to measure the Ecospecs and TPCs are also described.

Monitoring activities that should be undertaken in order to measure the Ecospecs and TPCs are indicated per EWR site. These monitoring programmes should be rolled out as part of the implementation of the Vaal River catchment Reserve study.

The derived Ecospecs for the maintenance of the Reserve for each EWR sites should not be exceeded in order to maintain the water driver and response components of the Recommended Ecological Category (REC).

Table H is a summary of the proposed monitoring frequency for the Ecological Reserve for the Middle Vaal EWR sites 16 to 19.

Table H: Summary of proposed monitoring frequency for the Ecological Reserve for the Lower Vaal.

Reserve component	**Monitoring Frequency**
Hydrology	Daily monitoring at closest DWA weir
Water Quality	Monthly, Quarterly (EC and Chlorophyll -a)
Geomorphology	• Every 2nd year: Daily hydrology and Fixed-point photography • Every 5 – 10 years: Bed material composition; Cross-sections and Aerial photographs
Fish	Monitoring should be conducted twice annually. If only once annually then the intermediate dry –wet season would be preferred.
Macroinvertebrates	Wet and dry season sampling
Riparian Vegetation	Monitoring should be conducted annually during the wet season (Spring to early Summer). Monitoring may be reduced to one survey every two to three years, however, any significant, change should precipitate immediate surveys which should be conducted annually for at least three years in order to monitor the change and determine whether it was

	a stochastic event or the beginning of a trend

It is important to note that the proposed Rapid Habitat Monitoring Programme (RHAM) has not been tested in the Middle Vaal. If this programme is to be implement then the suggested monitoring frequency in Table A would altered and the RHAM monitoring would be used a s screening approach. If the TPC are triggered then the proposed monitoring in Table G would then be initiated.

The use of RHAM should be a cost effective screening monitoring programme that could be used in Reserve monitoring. Furthermore the development of diatoms as biotic response indicators (Rapid Diatom Riverine Assessment Method (R-DRAM)) should be closely monitored and when there is sufficient scientific evidence this documented method should be included as an assessment tool for water quality Reserve studies. The R-DRAM serves as a water quality screening tool and indicates which physico-chemical variable(s) require further monitoring and more detailed data analyses. This method could be a cost effective addition to the ongoing water quality monitoring and an early warning link to aquatic ecological impacts. It is recommended that this method be implemented in the Vaal catchment.

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ABBREVIATIONS AND ACRYNOMS

BAEN	*Labeobarbus aeneus*
BBM	Building Block Methodology
BKIM	*Labeobarbus kimberleyensis*
CD: RDM	Chief Directorate: Resource Directed Measures
DRIFT	Downstream Response to Imposed Flow Transformation
DRM	Desktop Reserve Model
DWA	Department of Water Affairs (Name change 2009)
DWAF	Department of Water Affairs and Forestry
EC	Ecological Category
EIS	Ecological Importance and Sensitivity
EWR	Ecological Water Requirements
EWRM	Ecological Water Resource Monitoring
FCS	Fast over Coarse Substrate (Macroinvertebrate habitat)
FD	Fast deep fish habitat
FFHA	Fish Flow Habitat Assessment model
FI	Fast intermediate fish habitat
FS	Fast shallow fish habitat
FVS	Fast very Shallow fish habitat
HFSR	Habitat Flow Stressor Response
IHI	Index of Habitat Integrity
MAR	Mean Annual Runoff

MCM	Million Cubic Meters
NMAR	Natural Mean Annual Runoff
NWA	National Water Act
PD	Present Day
PES	Present Ecological State
REC	Recommended Ecological Category
PMAR	Present Mean Annual Runoff
QHI	Quick Habitat Integrity
RHAM	Rapid Habitat Assessment Method
REC	Recommended Ecological Category
RU	Resource Unit
SD	Slow deep fish habitat
SPATSIM	Spatial and Time Series Information Modelling
SCS	Slow over Coarse Substrate (Macroinvertebrate habitat)
SCI	Socio Cultural Importance
SS	Slow shallow fish habitat
Veg	Vegetation
VFCS	Very Fast over Coarse Substrate (Macroinvertebrate habitat)
WMA	Water Management Area
WWTW	Waste Water Treatment Works

GLOSSARY

DROUGHT FLOW	The minimum flow required facilitating the survival of the riverine ecosystem in a particular condition and over short, infrequent periods, when users are subject to water restrictions. Drought flows in the Vaal River will be defined as low-flows that occur less than x % of the time under natural conditions for each month.
ECOLOGICAL CATEGORY	A category indicating the potential management target for a river. Values range from Category A (unmodified, natural) to Category D (largely modified). This term replaces former terms used, namely: Ecological Reserve Category (ERC), Desired Future State (DFS) and Ecological Management Class (EMC). The reasons for these changes are explained in the proceedings of a workshop to clarify the terminology used in Reserve determinations (DWAF 2003). It should be noted that a distinction is made between Management Classes, which form part of the National Classification System, and Ecological Categories, which forms part of the Ecological Water Requirement assessment.
ECOSPECS	Clear and measurable specifications of ecological attributes (e.g. water quality, flow, biological integrity) that defines the Ecological Category. The purpose of Ecospecs is to establish clear goals relating to resource quality (Kleynhans 2003).
ECOSTATUS	An overall assessment of the Ecological Category (A-F), based on rule-based integration of specialist indices (water quality, fish, etc). EcoStatus refers to 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 and its capacity to provide a variety of goods and services" (Iversen *et al.* 2000, *In* IWR Environmental 2003).
ECOLOGICAL WATER REQUIREMENTS (EWR)	The flow patterns (magnitude, timing and duration) and water quality needed to maintain a riverine ecosystem in a particular condition. This term is used to refer to both the quantity and quality components.

INSTREAM FLOW REQUIREMENTS (IFR)	The flow patterns (magnitude, timing and duration) needed to maintain a riverine ecosystem in a particular condition. This term is used to refer to the quantity component only of Ecological Water Requirements.
MAINTENANCE FLOW	The flow required to meet the requirements of the riverine ecosystem at a particular site and maintain the resource base in a particular condition during "normal" climatic years. The distinction between "normal" and "drought" was based on an examination of monthly flow duration curves
PRESENT ECOLOGICAL STATE (PES)	The degree to which ecological conditions of an area have been modified from natural (reference) conditions. The measure is based on water quality variables, biotic indicators and habitat information collected 1 to 3 years prior to the assessment. Results are classified on a 6-poin scale, from Category A (*Largely Natural*) to Category F (*Critically Modified*).
REFERENCE CONDITION	Natural ecological conditions, prior to human development.
RESERVE	The quantity and quality of water required (a) to satisfy basic human needs by securing a basic water supply, as prescribed under the Water Services Act, 1997 (Act No. 108 of 1997), for people who are now or who will, in the reasonably near future, be (i) relying upon; (ii) taking water from; or (iii) being supplied from, the relevant water resource; and (b) to protect aquatic ecosystems under the National Water Act, 1998 (Act No. 36 of 1998) in order to secure ecologically sustainable development and use of the relevant water resource. The Reserve refers to the modified Ecological Water Requirement, where operational limitations, and stakeholder consultation are taken into account.
RESOURCE QUALITY OBJECTIVE	Quantitative and auditable statements about water quantity, water quality, habitat integrity and biotic integrity that specify the requirements (goals) needed to ensure a particular level of resource protection. This term takes into account the management *classes* and the requirements of other users. These components are not addressed in this project

RESOURCE UNIT	Stretches of river that are sufficiently ecologically distinct to warrant their own specification of Ecological Water Requirements, and that can be practically managed as a single unit.

1 INTRODUCTION

1.1 Background

Chapter 3 of the National Water Act (NWA) (Act No. 36, 1998) provides for the protection of water resources of the country through the implementation of Resource Directed Measures (RDM), based on the guiding principles of sustainability and equity. In terms of the Act, before any authorization to utilise a particular water resource can be granted, it is necessary to determine the Reserve for the relevant ecological component of the resource that will be impacted by the proposed water use. The Reserve can be defined as, 'the quantity, quality and reliability of water needed to sustain both basic human needs and aquatic ecosystems.

According to the Act all Reserve determinations that are currently determined and approved by the Department of Water Affairs (DWA) are preliminary Reserve determinations and the associated recommended class is a preliminary class (section 17(1)), until a system for the classifying of water resources has been prescribed.

The Chief Directorate: Resource Directed Measures (CD:RDM) is tasked with the responsibility of ensuring that the Reserve requirements, which have priority over other uses in terms of the Act, are determined before any new water uses are authorised. The Reserve requirements must be met, before the requirements for economic development or water uses are satisfied so as to ensure that the long-term integrity of ecosystems are not comprised or severely impacted upon'. As the Department of Water Affairs (DWA) is the custodian of the nation's water resources, it is their responsibility to ensure the adequate protection and effective management of these resources.

The CD: RDM initiated the Comprehensive Reserve Determination Study for selected water resources (rivers, wetlands and groundwater) in the Lower Vaal Water Management Area (WMA). The purpose of the Comprehensive Reserve Determination Study for the selected water resources of the Lower Vaal WMA is to determine the ecological and basic human needs water quantity and quality Reserve at an intermediate level of confidence. The final step in this process is to define the Ecological Specifications (Ecospecs) and monitoring requirements for the maintenance of the at each Ecological Water Requirement (EWR) site.

The results of the Comprehensive Reserve determination study will assist the DWA to make more informed decisions regarding the authorization of future water uses, operation and management of the system and the evaluation of the magnitude of the impacts of the present and proposed developments.

1.2 Purpose of this report

This report summarises the main components of the intermediate assessment of the Ecological Water Requirements (EWR) component of the Reserve that was commissioned by the CD: RDM. The study was conducted over a three-year period between August 2007 and October 2010. The study produced several reports, as indicated in the document index. This Main Report provides a brief overview of the study. For more details refer to the individual specialist reports.

1.3 Objective of study

The study objective was to determine an Ecological Reserve for the system which best meets the level of resource protection taking into account the legal, socio economic and sustainability goals/needs. A wetland and groundwater scoping assessment was also undertaken with the final product being a recommendation for what level of further study should be undertaken (if any).

An additional requirement of the study was the application of specialist and technical capacity building throughout the project with an emphasis on Historically Disadvantaged Individuals (HDIs).

1.4 Study area

The Lower Vaal WMA covers a catchment area of 133 354 km^2, and includes parts of the Northern Cape and North-West Provinces, and a small part of the Free State Province. It is situated in the north-western part of the country and forms part of the Orange River watercourse. The Vaal River is the only major river in the WMA, as it flows in a westerly direction from Bloemhof Dam to the confluence with the Orange River. The largest part of the WMA falls within the catchment of the Molopo River, a tributary of the Orange River. The Molopo, Nossob and Kuruman rivers drain the remainder of the WMA but due to the very low rainfall in the WMA, these rivers are episodic. The WMA consists of the D41 (excluding D41A), parts of D42C and D42D, parts of D73A and D73C, C31, C32, C33, C91, and C92 tertiary catchments. For the purpose of this study only the C drainage region is of relevance as it forms part of the Vaal River System, which includes the Harts River catchment and the Vaal River catchment. These two catchments as part of the Vaal River System cover a catchment area of 53 500km^2 within the Lower Vaal WMA. The C drainage region of the Lower WMA comprises four sub-catchments as listed in Table 1.

Table 1: Sub-catchments and related quaternary drainage regions of the C drainage primary catchment within the Lower Vaal WMA

PRIMARY CATCHMENT	SUB-CATCHMENT	QUARTENARY CATCHMENTS	AVERAGE GROSS AREA (Km^2)
C	Dry Harts	C32A-D	10 205
	Harts	C31A-F	11 023
	Vaalharts	C33A-C	9843
	Vaal downstream Bloemhof	C91A-E, C92A-C	22 427

The average temperature for the WMA is 16˚C. The rainfall is strongly seasonal occurring mainly in the summer months. Mean annual precipitation ranges between 100mm in the west and 500mm to the east of the WMA. Mean annual evaporation can reach as high as 2800 mm per year which is in excess of rainfall. The WMA has no climatic barriers and thus climate varies gradually according to the larger regional patterns, and is fairly uniform from east to west.

The WMA has relatively flat terrain with no distinct topographic features. As a result of the arid climate, vegetation over the WMA is sparse, consisting mainly of grassland and some thorn trees (notably the majestic camel thorns). The WMA is dominated by tropical bush and savannah with small areas of pure grassveld to the east.

Virtually all the surface flow of the Vaal River, the main source of water in the Lower Vaal WMA, originates from the Upper and Middle Vaal WMAs. Very little surface run-off originates within the WMA itself due to the low rainfall, flat topography and sandy soils. The groundwater resource is more substantial, supplying an estimated 128 million m^3/annum. The Vaal River is fed by the only tributary, the Harts River which drains a catchment area of 31 000km^2, with the Dry Harts being the major tributary of the Harts River, joining it just downstream of Taung. The only lake and wetlands of note are at Barberspan in the Upper Harts River catchment which has been given Ramsar status as a wildlife conservation area.

Large quantities of water are transferred from the Vaalharts weir on the Vaal River to supply the Vaalharts irrigation scheme in the Harts River catchment. The Vaalharts Irrigation scheme generates irrigation return flows which enter the Harts River upstream of Spitskop Dam. The return flows contribute salinity and nutrients to the Harts River.

The development of the surface water resources occurring in the WMA has reached its potential, however all water is not being fully utilised. The water in Taung Dam is currently not utilised. Studies are however currently underway to investigate the utilisation of these two dams, and if this happens this may impact on the ecosystems in these catchments and in downstream catchments which in some cases include ephemeral systems. There are several large dams that have been developed in the WMA. The main dams are listed in Table 2**.**

Table 2: Major Dams in the Lower Vaal WMA

Dam name	Quaternary catchment	River
Douglas Weir	C92B	Vaal
Spitskop	C33B	Harts
Taung Dam	C31F	Harts
Vaalharts Weir	C91B	Vaal
Wentzel	C31E	Harts

The Lower Vaal WMA is dependent on the Upper Vaal and Middle Vaal WMAs for supply of utilisable surface water resources, with over 90% of the water required being sourced through releases from the Upper Vaal WMA and from Bloemhof Dam. More than 50% of the yield from natural water resources in the tributary catchments within the WMA is supplied from groundwater.

Most of the water is used for urban, agricultural and mining purposes within the WMA. Water is also transferred into the WMA from the Lower Orange WMA into Douglas Weir.

The water quality of the rivers in the WMA has high seasonal turbidity levels and the Lower Vaal River has also high nutrient levels. The high TDS and nutrient levels are cumulative impacts of upstream agriculture and mining.

Current land use in the WMA, due to the arid climate is characterised by extensive livestock farming as the main activity and large scale dry land cultivation in the north eastern part of the WMA. Intensive irrigation (about 80% of water use) is practised at Vaalharts, as well as at locations along the Vaal River. The most significant urban area in the WMA is Kimberley to the South. Several towns as well as scattered rural settlements are found mainly in the central and eastern part of the WMA. Iron ore, diamonds and manganese are mined in the WMA. Small scale diamond mining is a common occurrence in and on the banks of the Lower Vaal River. Previous studies on the Lower Vaal (Heath, Moffet and Bannister 2004) have indicated tat the only impacts associated with the diamond mining is as follows:

- Habitat degradation (instream and riparian)
- Water quality (turbidity)
- Aesthetics (no rehabilitation)

These impacts and land use issues will be taken into account when the sites are selected.

The economy of the Lower Vaal WMA is relatively small, with the WMA generating about 2% of the Gross Domestic Product of South Africa (DWAF, 2003). The economy is still dominated by mining, however much of the beneficiation is done in other areas. Most of the economic activity is concentrated in Kimberley and at other major mining areas. Manufacturing activities in the WMA include cement and cheese factories and relate to the agriculture sectors as well as items for local consumption. The trade sector is concentrated in wholesale of primary products and related services to the community. No significant changes to the economy of the WMA are foreseen over the medium term. The agricultural and mining sectors in the region are strong and will continue to make an important contribution to the regional economy.

The Lower Vaal WMA also shows minimal potential for strong economic growth, and thus a low population growth is projected. Consequently, limited growth in water requirements is expected.

Selected Environmental Water Requirement (EWR) sites (EWR 12 – 15) are indicated in Table 3.

Table 3: Selected EWR sites for the Lower Vaal catchment

EWR Site number	EWR site name	River	National RHP[1] site	Coordinates		EcoRegion (Level II)	Geomorphic zone	Altitude (m)	RU[2]	Quaternary catchment	Hydrological gauge
				Latitude	Longitude						
EWR16	Downstream Bloemhof Dam	Vaal		S27.65541	E25.59564	11.08; 29.02	E: Lower Foothills	1211	MRU Vaal K	C91A	C9H021
EWR17	Lloyds weir on Harts River	Harts	C3HART-DELPO	S28.37694	E24.30305	29.02; 30.01	E: Lower Foothills	1114	MRU Harts C	C33C	C3H016
EWR18	Schmidtsdrift	Vaal	C9VAAL-SCHMI	S28.70480	E24.07601	29.02; 30.01	E: Lower Foothills	1239	MRU Vaal O	C92B	C9H024
EWR19	Lilydale Lodge	Riet		S29.03842	E24.50283	29.02	E: Lower Foothills	1107	MRU Riet D	C51L	C5H048

[1]: River Health Programme; [2]: Resource Unit

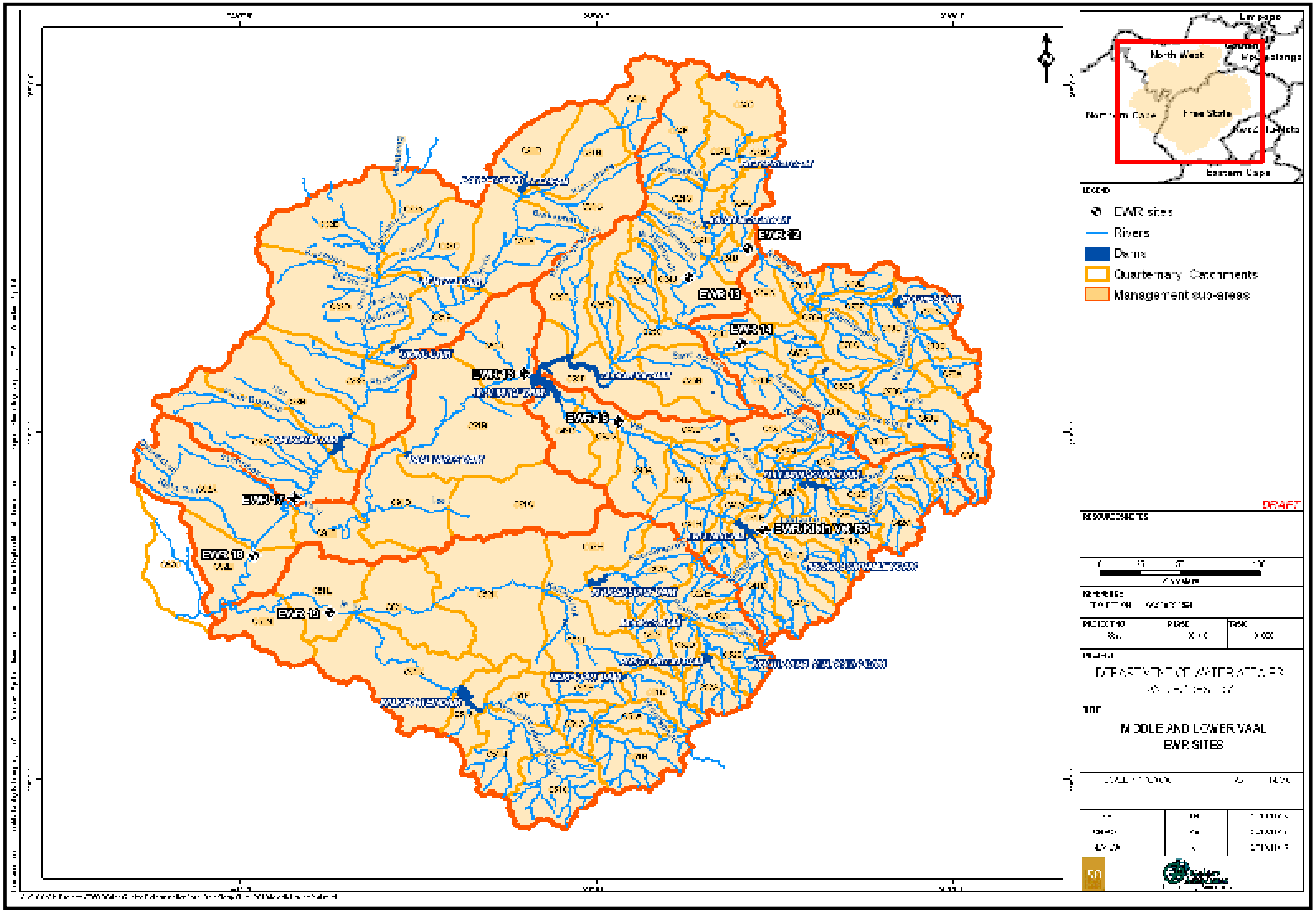


Figure 1: Resource Units and selected EWR sites for the Lower and Middle Vaal catchment

2 PROCESS

The generic eight step Ecological Reserve procedure is shown in Figure 2 (DWA, 2003) was followed in order to address the objectives:

- A set of Ecological Water Requirement (EWR) scenarios was generated to test through the application of a yield model. Each scenario represents a possible flow regime, intended to have specific outcomes linked to the Reserve. Scenarios specify how much water is required, where and when, and take cognisance of the likely water quality consequences.
- Based on the impacts of the EWR scenarios a set of flow scenarios, called Operational Scenarios, was generated and tested. These scenarios are realistic scenarios as impacts on users and constraints such as outlet sizes of dams are considered. Decision makers will select one of these scenarios as the Reserve.
- The likely impact of the Operational Scenarios on the available yield was determined.
- The likely impact of the Operational Scenarios on the aquatic ecology was determined.
- The likely economic impact of selected Operational Scenarios was determined.
- The likely impact of selected Operational Scenarios on the services provided by the riverine system was determined.

This process is consistent with the Resource Directed Measures (RDM) protocol. Best practice was followed, based on the most recent RDM developments. Dr’s Kleynhans and Jooste as well as Ms Thirion (all from DWAF-RQS, where consulted with throughout the project to ensure consistency in methods applicability as well as to make sure that the most recent methods were applied). All changes in RDM protocols, during the course of the study, were incorporated within the existing budget and the study programme was amended to take cognizance of new requirements.

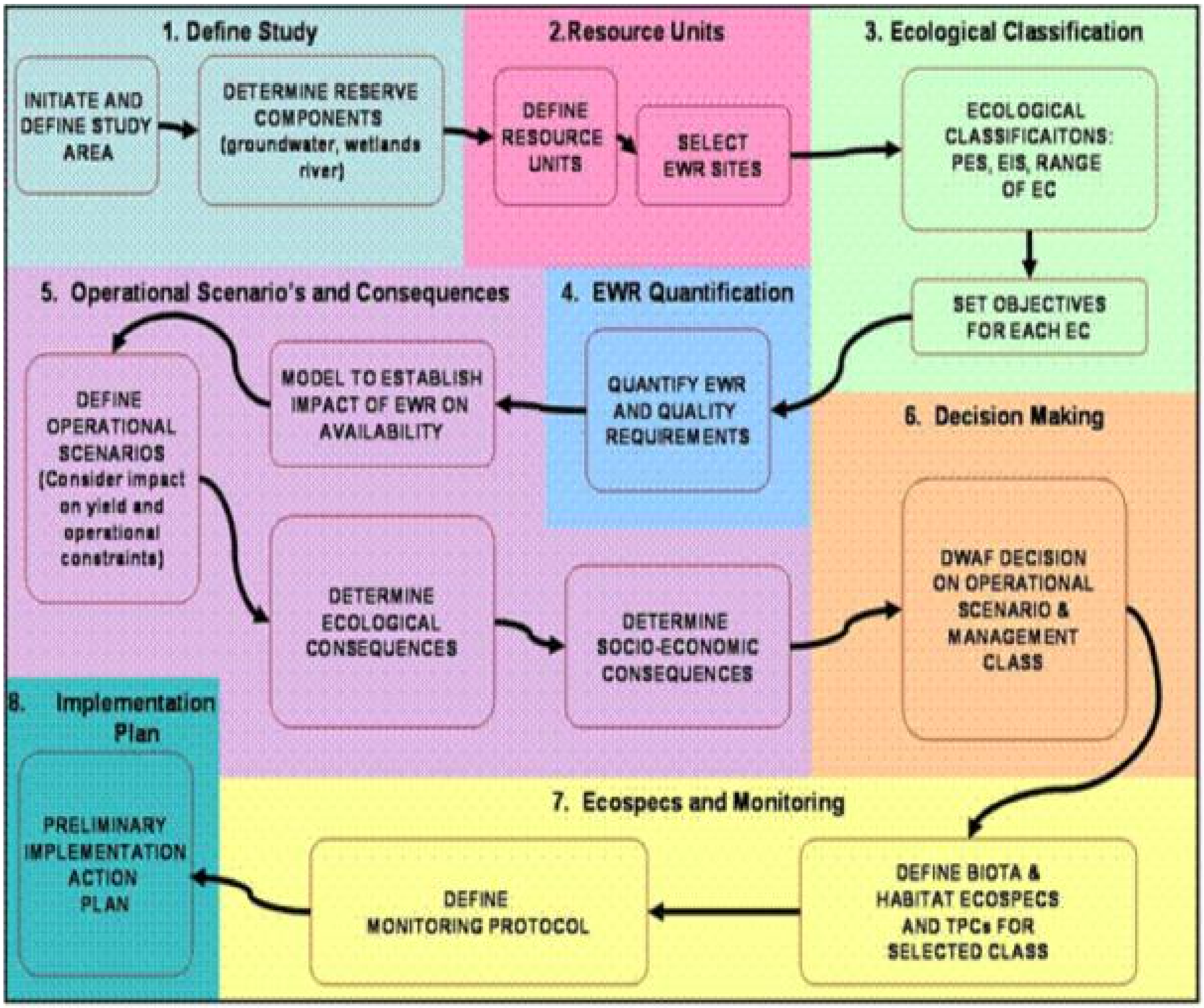


Figure 2: Generic procedure for the determination of the ecological Reserve

2.1 Level of detail of study

The study was designed to follow, as far as practically possible, a Comprehensive Ecological Reserve Determination approach to provide the highest confidence possible. The individual major components were addressed at different levels, depending on data availability and the importance of the component in the study area. For each, the present project status, the level of detail, and the specialist fields in which capacity building took place, are indicated.

The Wetland/Pans Assessment study was undertaken a desktop level of assessment.

The following separate studies were undertaken by other consulting teams and their findings used in this assessment:

- Groundwater assessment of the Vaal

- Department of Water Affairs (DWA), 2010. Resource Directed Measures: Comprehensive Reserve determination study for selected water resources in the Upper, Middle and Lower Vaal River Management Areas. Vaal River System Water Quality Report. Report no: RDM/ A000WMA3/01/CON/0408. Pretoria, South Africa.

- Water Resource Yield Model (overall model of the Vaal that was managed by WRP); and

- Conningarth modeled the overall Goods and Services for the Vaal Catchment to ensure a uniform approach to the study.

Table 4 indicates the level of study the Reserve components and the areas that capacity building was undertaken.

Table 4: Components/Tasks addressed within the study

Study components	Level	Capacity Building
Project Management		Project team members
Inception Report		Project team members
Resource Units	Comprehensive	Project team members
Wetland Scoping Report	Scoping/Desktop	Project team members
Socio-economic assessment		Project team members
Ecological Water Requirement scenarios (River quantity and quality)	Comprehensive	Hydrology, aquatic invertebrates, riparian vegetation, fish
Ecospecs and monitoring	Comprehensive	Hydrology, aquatic invertebrates, macro-invertebrates, vegetation, fish
Capacity building	Comprehensive	Regional Office training, project team members, CD RDM

2.2 Assumptions and limitations

Basic Human Needs: The Basic Human Needs component of the Reserve was assessed based on 1991 census data and verified extensively in 1994. The latest census data has not been disaggregated to quaternary catchment scale by DWA and thus could not be used.

Stakeholders: A stakeholder involvement programme was not included. The study team did however produce two background information documents, one to announce the study initiation and the second to notify stakeholders of the study results. The BIDs were distributed electronically to stakeholders databases in the catchment areas.

EWR Sites: EWR sites could not be selected in all Resource Units because of funding constraints (4 sites were selected in the Lower Vaal catchment).

Hydraulics: Confidence in flow assessments was low to medium due to the narrow range in observed data for hydraulic calibration purposes. This was due to the systems being highly regulated.

Hydrology: Natural and Present Day flows were generated by WRP and used as is in this study. Observed data used included in this assessment was of stations that would best represent flows at each of the sites, therefore proximity to the site as well as availability of data in long enough period for meaningful statistical at an overview level to be determined, determined station selection. However it should be noted that observed data has its own problems, with respect to capture, accuracy and reliability of the data. These are however problems that reduce the confidence in the observed data. In the absence of any other data that can be used to assess the current hydrological situation, set aside the simulated present day flows, the observed data is to a large extent useful. Careful consideration and knowledge of the system, climate and historical events such as big floods of 1987 enable for the informed use of the observed data. To a larger extent the observed data used in this assessment at the different sites agrees with the simulated present day flows, with highs and lows as would be expected when comparing simulated flows versus observed flows. The exception is station C5H016 and C9H010 which deviate very sharply for the present day flows and this is attributed to the fact that the high flows (i.e. very wet years) were not sufficiently captured. The hydrology assessment focused on the generation for flow duration curves, monthly flow distribution and rating of the confidence we have in the hydrology in relation to low flows, zero flows, moderate flows, high flows and seasonality changes in the flows.

The Water Resource Yield Model was used to assess the impact on yield of the recommended and alternative EWRs. A limitation of the model is that output is presented as monthly flows. This makes it difficult to distinguish between high and low flow components that were specified as EWR requirements during months where both low flows and high flows were specified.

Classification System. No classification system as required by the National Water Act exists for integrating the results of the ecological and socioeconomic consequences to decide on the Management Class.

Monitoring Plan. This report provides the basis for developing a monitoring plan, but it does not address monitoring requirements or implementation as this requires the development of operational rules, negotiation with and commitment by all relevant management agencies, and a comprehensive Decision Support System that allocates responsibilities, and specifies the actions that should be taken in the event of non-compliance. These aspects fell beyond the scope of this study.

3 DELINEATION

3.1 Background

The CD: RDM identified the Integrated Vaal River System, with the focus of this study, the Lower Vaal Water Management Area (WMA) as requiring a comprehensive Reserve assessment as to provide input to the Reconciliation studies and the integrated water quality management plan for the Vaal River studies undertaken by the National Water Resources Planning Directorate (D: NWRP) of the DWAF. These studies require higher levels of confidence in the Reserve determination results as is currently available. This will assist the DWAF to make informed decisions regarding the authorization of future water use and the magnitude of the impacts of the present and proposed developments.

A Desktop EcoClassification will serve as a scoping phase to investigate the WMA at a desktop level and at the scale of quaternary catchments and serves as the basis for most other tasks in the Reserve determination process. This scoping assessment provides an overview of the WMA and a better understanding when focussing on the EWR sites and the sections of rivers where comprehensive assessments will be undertaken. The output of the information also identifies areas of potential concern based on an integrated importance (combination of Ecological Importance and Sensitivity, Socio-Cultural Importance and Present Ecological State).

3.2 Approach

The objective of the EWR study is to provide information at two levels of detail, i.e. at scoping or desktop level, as well as a more detailed assessment. This report presents the results of the Desktop assessment of the EcoClassification process for each quaternary catchment. The term used for Ecological Classification "EcoClassification" (Kleynhans *et al*., 2005) refers to the determination and categorisation of the Present Ecological State (PES) - or health or integrity - of various biophysical attributes of rivers, compared with 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 from the reference condition. This provides the information needed to derive the desirable and attainable future ecological objectives for the river. The state of the river is described in terms of Ecological Categories (A to F).

The EcoClassification process also includes an assessment of Ecological Importance and Sensitivity (EIS), and Socio-Cultural Importance (SCI). These are described in terms of Low to Very High (EIS) and Minimal to Very High (SCI). All assessments include a confidence rating that may range from 1 (low confidence) to 5 (high confidence).

3.3 Ecological Importance and Sensitivity

The ecological importance of a river is an expression of its contribution to the maintenance of biological diversity and ecological functioning on local and wider scales. Ecological sensitivity (or fragility) refers to the system's ability to resist disturbance and its capability to recover from disturbance once it has occurred (resilience) (Resh *et al*., 1988; Milner, 1994).

Standard EIS models are used, irrespective of the level of assessment. The data which is used to populate the models vary, dependant on the level.

No areas of Very High EIS are present in the WMA. The few areas of high EIS are the following:

- C70G, C70H, C70J and C70K (Renoster River system) due to the presence of the endangered rock catfish (*Austroglanis sclateri*)

- C24B (Vaal River) due to the presence of the endangered rock catfish (*A. sclateri*).

- C25A (Klipspruit River) due to probable high species diversity, including rock catfish (*A. sclateri*) the site of the Wolvespruit Nature Reserve.

Most of the rest of the quaternary catchments were rated as moderate. The confidence of the evaluation ranged mostly from moderate to high with approximately 30% as low. No areas of Very High EIS are present in the WMA. The few areas of high EIS are the following:

- C91A and C91B (Vaal River) due to Sandveld Nature Reserve and Rob Ferreira Reserve, high species diversity, including *Labeobarbus kimberlyensis* and *A. sclateri*

- C31D (Barberspan/Leeupan)

- C92A (Vaal River after confluence with Harts River)

- C51A, C51B, C51C, C51D, C51E, and C51G (Riet River)

Most of the rest of the quaternary catchments were rated as moderate. The confidence of the evaluation ranged mostly from moderate to high with approximately 30% as low. A summary of the EIS is shown in Figure 3, and a summary of the integrated importance is shown in Figure 4.

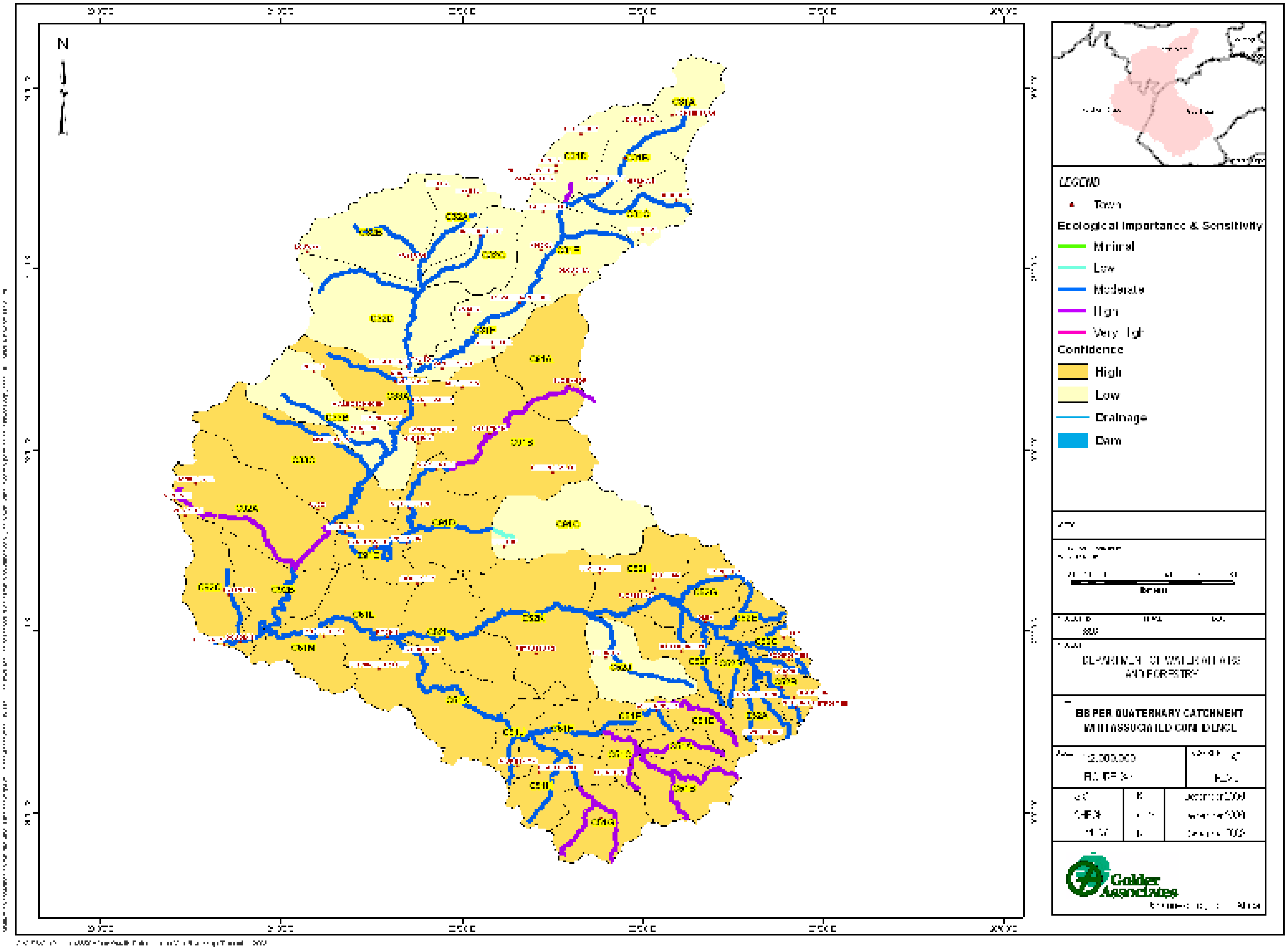


Figure 3: Summary of the Ecological Importance and Sensitivity (EIS) of the Lower Vaal Catchment

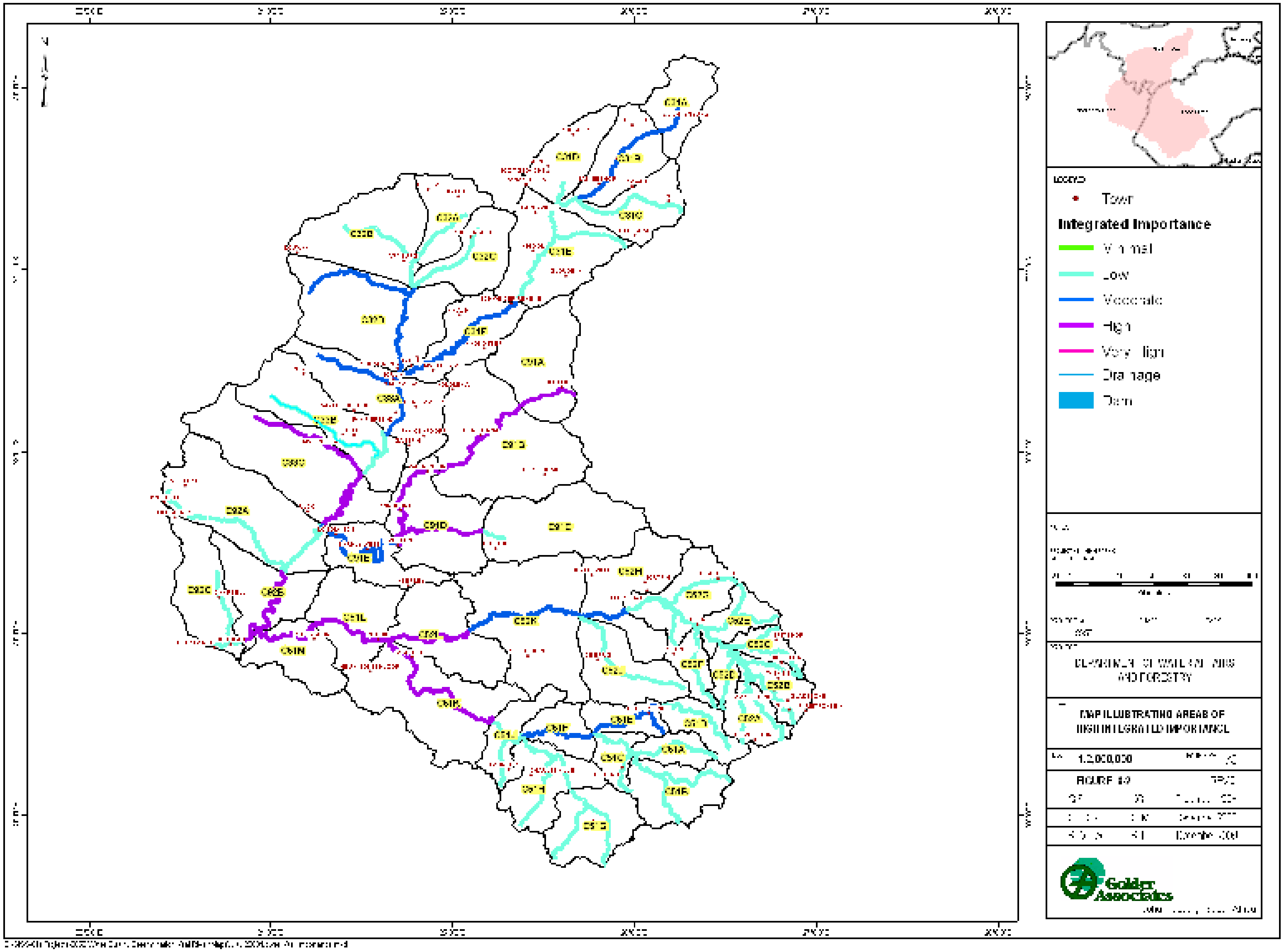


Figure 4: Summary of the integrated importance of the Lower Vaal Catchment

3.4 Socio-Cultural Importance

The SCI was determined from:

- A site visit that covered points along the river; and
- Extrapolation to sites not visited by reference to available literature, as well as to existing mapping.

The SCI was generated by scoring each quaternary, based on the following features:

- Ritual Use (e.g., ceremonial purposes, spiritual/religious activities.).
- Aesthetic Value.
- Resource Dependence (it refers to the goods and services delivered by the river system and peoples dependence on these components).
- Recreational Use.
- Historical/Cultural Value (e.g., places of historical battles, Bushman paintings etc).

Scores were then weighted to reflect the adjudged importance of each component relative to the other. The Resource Dependence component was given the highest weighting, because this component is designed to reflect the importance of a healthy riverine system to people who are often in the grips of poverty, and for whom the availability of such resources is a question of survival.

Areas dominated by relatively low population densities and given over to commercial farming enterprises tended to score relatively low in terms of SCI. An obvious exception is the recreational use of dams and the main stem of the Vaal River. Portions of the WMA with water related recreational activity scored slightly higher. Areas dominated by mining (mainly alluvial diamonds) and industrialisation also scored generally low in terms of SCI. It should be emphasised that low SCI score does not indicate low economic importance. A summary of the SCI is shown in Figure 5.

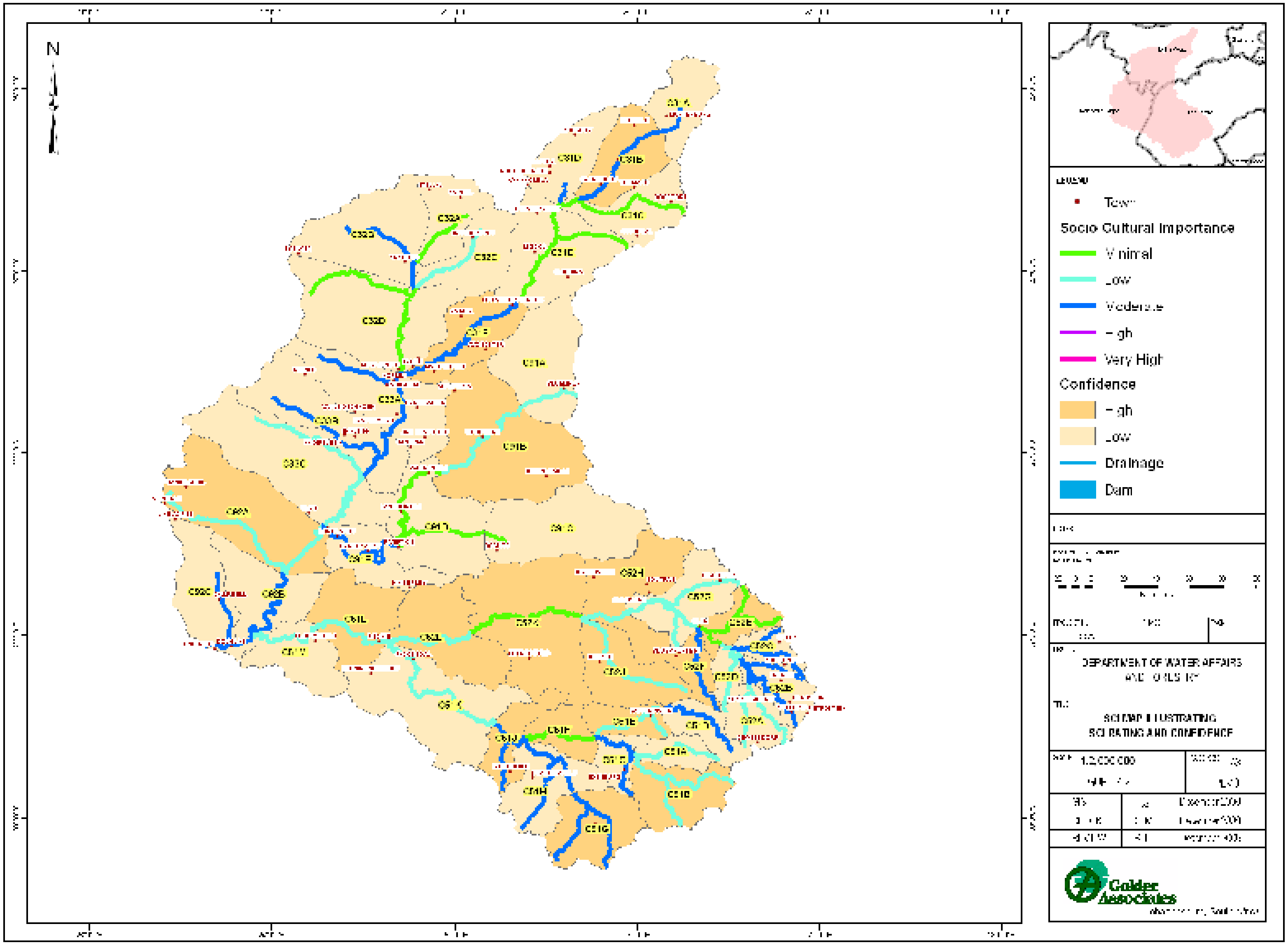


Figure 5: Summary of the Socio Cultural Importance (SCI) of the Lower Vaal Catchment

3.5 Present Ecological State

The PES of the river is expressed in terms of various components, i.e., **drivers** (Physico-chemical variables, geomorphology, hydrology) and **biological responses** (fish, riparian vegetation and aquatic invertebrates), as well as an integrated state, the EcoStatus.

A Desktop Level EcoStatus assessment was designed for use when assessments for planning purposes on large scale have to be undertaken. As the name indicates, this is done at desktop level, and is therefore based on available information and expert judgement. However, due to the lack of relevant information in some of the areas, a site visit was undertaken during this study to provide additional information.

The bulk of the rivers in the WMA are in a C, C/D and D category. Please note that this does not include all the smaller tributaries but only refer to the main rivers in the quaternaries. The rivers in a B category are the following:

- C91B: Vaal River at the Vaalharts weir
- C32B: Dry Harts River before the confluence with the Leeuspruit
- C33B and C33C: Harts River at Spitskop Dam and downstream of the dam.

This means that there are very few rivers in this large WMA which are potentially still in a good condition. The reason for this is the high utilisation of the catchment due to alluvial diamond mining, irrigation, interbasin transfers for irrigation (Vaal Harts) and the return flows of poor water quality from mainly irrigated areas. Water quality issues (salts and nutrients) are prevalent in many streams as well as increased flows, i.e. more than natural.

A summary of the PES is shown in Figure 6. A summary of the Ecological Water Requirement (EWR) hotspots is shown in Figure 7.

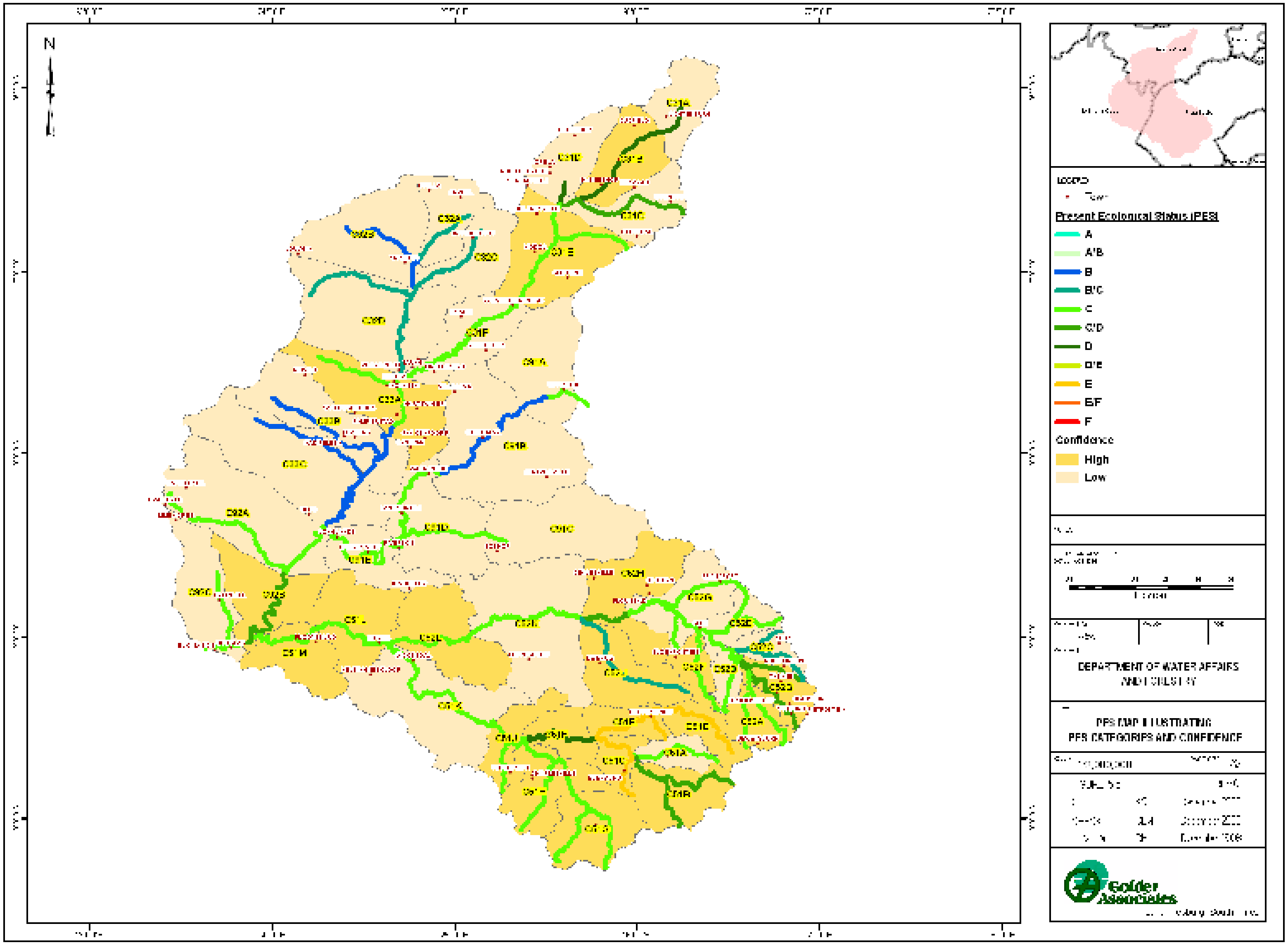


Figure 6: Summary of the Present Ecological Status (PES) of the Lower Vaal Catchment

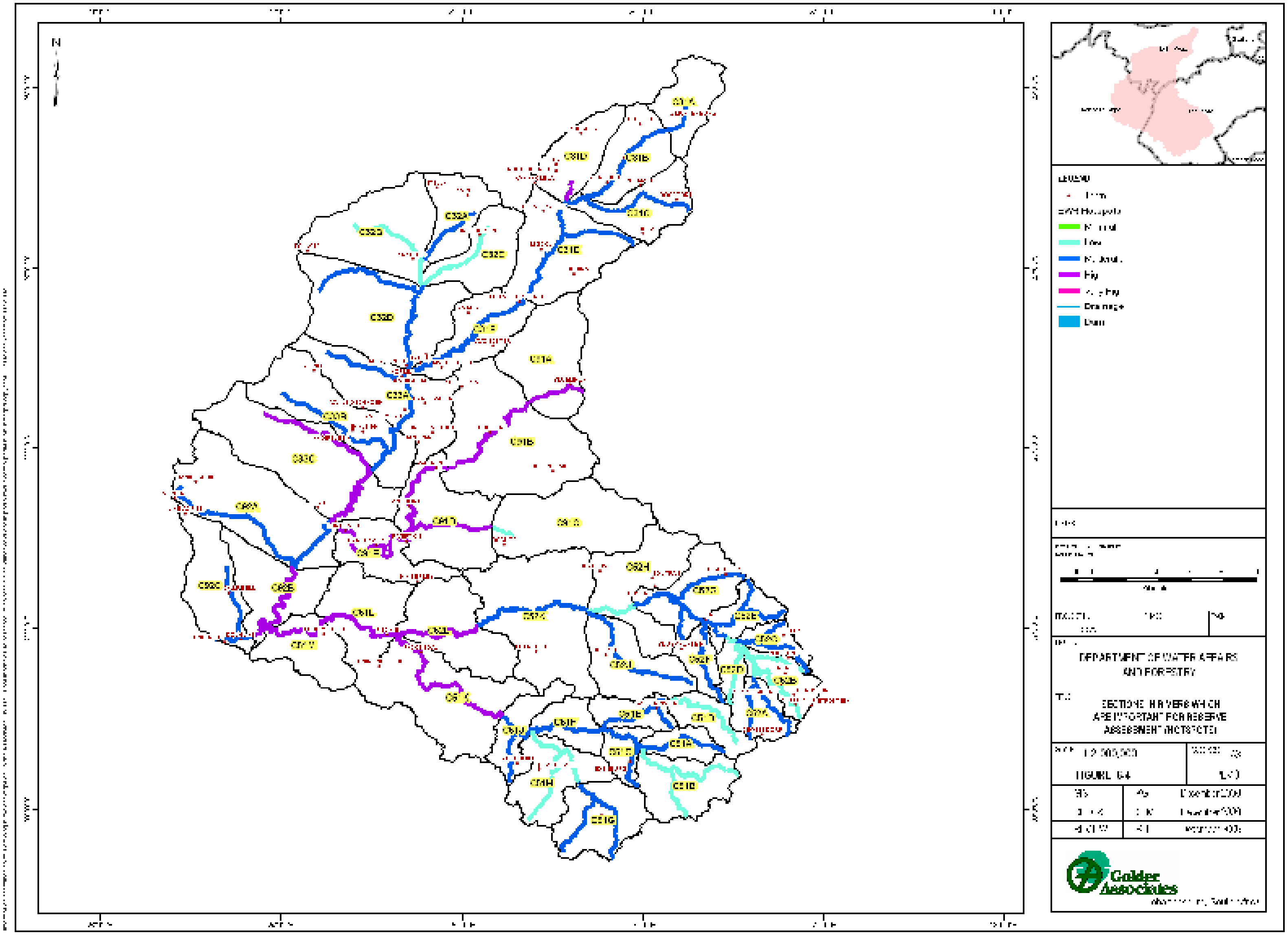


Figure 7: Summary of the Ecological Water Requirement (EWR) hotspots of the Lower Vaal Catchment

3.6 Recommendations

An evaluation has been undertaken comparing areas of Integrated Importance which consists of Ecological, Socio-Cultural and Present Ecological State, with an importance evaluation of Water Resource Use. All quaternary catchments with either a high (3) or very high (4) rating were identified and are illustrated in the map below. These quaternary catchments would require EWR of reasonably high confidence and detailed studies are therefore recommended. This information will play an important role in identifying the areas where EWR sites are to be selected.

4 RESOURCE UNITS

4.1 Background

The Chief Directorate: Resource Directed Measures (RDM) has initiated the Comprehensive Reserve Determination Study for the Integrated Vaal River System: Lower Vaal Water Management Area (WMA) surface water quantity. The purpose of the Comprehensive Reserve Determination Study for the water resources of the Lower Vaal WMA is to determine the ecological and basic human needs water quantity Reserve for the rivers and pans in the WMA.

The Reserve studies require higher levels of confidence in the results as is currently available. This will assist the Department of Water Affairs and Forestry (DWAF) to make informed decisions regarding the management and operation of the system, authorisation of future water use and the magnitude of the impacts of the present and proposed developments.

As part of the Reserve Determination process it is necessary to define the study area for the comprehensive assessment and to delineate key rivers of the study area into Resource Units (RU). Each RU represents a homogenous area which requires its own specification of the Reserve.

4.2 Delineation Approach

The process followed was that described in the updated Reserve manuals (Louw and Hughes, 2002).

Resource Units are required as it would not be appropriate to set the same numerical Reserve for the headwaters of a river as for the lowland reaches. The breakdown of a catchment into RUs for the purpose of determining the Reserve for rivers is therefore done primarily on a biophysical basis within the catchment and called Natural Resource Units (NRUs). Management requirements (DWAF, 1999, volume 3) also play a role in the delineation. Furthermore, the type of disturbance/impact on the river plays a role to select homogenous river reaches from a biophysical basis under present circumstances. These are called Management Resource Units (MRUs). MRUs can be further delineated in even smaller assessment units called Reserve Assessment Units (RAUs). It is preferable to select a EWR site within each MRU, and if possible, be selected within the RAU.

The following is considered for selection of MRUs:

- Geomorphological zones

- EcoRegions (Level II)
- Land cover
- System operation and presence of dams
- Water quality
- Local knowledge

4.3 Delineation Results

The results are displayed in Table 5.

Table 5: Management Resource Units and delineation per quaternary in the Lower Vaal

MRU	Delineation	Quaternary Catchment
VAAL RIVER		
MRU Vaal K	Outflow Bloemhof Dam to Vaalharts weir	C91A, C91B
MRU Vaal L	Vaalharts Barrage	C91B
MRU Vaal M	Vaalharts weir to Harts River confluence	C91D, C91E
MRU Vaal N	From Harts River confluence to Schmidtsdrift weir	C92A, C92B
MRU Vaal O	From Schmidtsdrift weir to Douglas Barrage	C92B, C92C
MRU Vaal P	Douglas Barrage	C92C
TRIBUTARIES		
HARTS RIVER		
MRU Harts A	From Origin of Dry Harts to confluence with Harts River	C32A, C32B, C32C, C32D
MRU Harts B	From origin of Harts River to Wentzel Dam	C31A, C31B, C31C,C31D, C31E
MRU Harts C	Wentzel Dam	C31E
MRU Harts D	From Wentzel Dam to Taung Dam	C31F
MRU Harts E	Taung Dam	C31F
MRU Harts F	From Taung Dam to irrigation canal	C31F, C33A
MRU Harts G	From irrigation canal to Spitskop Dam	C33A, C33B
MRU Harts H	Spitskop Dam	C33B, C33C
MRU Harts I	From Spitskop Dam to Vaal River confluence	C33C,C91E
****Note***: Barberspan is assessed in Wetland report		C31D
RIET RIVER		
MRU Riet A	From origin to Kalkfontein Dam	C51A, C51B, C51C, C51D, C51E, C51F, C51G, C51H
MRU Riet B	Kalkfontein Dam	C51J
MRU Riet C	From Kalkfontein Dam to confluence with Modder River	C51K
MRU Riet C.1	Origin of Modder River to Krugerdrif Dam	C52A, C52B, C52C, C52D, C52E, C52F, C52G
MRU Riet C.2	Krugerdrif Dam	C52G
MRU Riet C.3	From Krugerdrif Dam to confluence with Riet River	C52H, C52J, C52K, C52L
MRU Riet D	From confluence with Modder River to confluence with Vaal River	C51L, C51M

4.4 Ecological Water Requirement (EWR) Sites

The selection of EWR sites is guided by a number of considerations. The key considerations are:

- The suitability of the sites for accurate hydraulic modelling throughout the range of possible flows, especially low flows.
- Accessibility of the sites.
- An area or site that could be critical for ecosystem functioning. These are often represented by riffle units, where low flow conditions or the cessation of flow constitutes a break in the functioning of the river, and consequently, the biota dependant on this habitat and/or perennial flow are adversely affected. Pools are not considered critical habitats in perennial system since they are still able to function or at least maintain life during periods of no flow.

The rationale and assessment of the recommended EWR sites within the MRUs as identified in the study are detailed Table 6.

Table 6: Assessment of MRU and recommendations on EWR sites

MRUs	Assessment of Resource Unit	Recommendations on EWR site
VAAL RIVER		
MRU Vaal K	The unit is it just downstream Bloemhof Dam - it is important to understand the influences of the Upper and Middle Vaal WMAs. The river reach is considered a high priority as it forms the upper most reach of the Lower Vaal River. Importance of the MRU was rated as 3 thus it does warrant a selection of a comprehensive EWR site. Site is Easy to access. It is a single channel and has a gauging weir for flow records.	EWR site 5 just downstream Bloemhof Dam was selected. Site will account for influences from the Upper and Middle Vaal WMAs.
MRU Vaal L	Importance of this reach was rated as a 3, as the Bloemhof Dam releases asre required to maintain the integrity of the system. The Vaalharts weir captures major water quality impacts from the upper and middle Vaal catchments however much of the water is transferred to the Vaalharts irrigation scheme. An EWR site should be selected. Site is Easy to access. It is a single channel and has a gauging weir for flow records.	No EWR site was selected as there is little opportunity to change the operation of system (Vaalharts weir and irrigation scheme).
MRU Vaal M	Reach was rated as an importance of 3 as it was noted that the integrity of Vaal River downstream of Bloemhof Dam should be maintained (dependent of Bloemhof releases). There is also a need to keep environmental flows for yellow fish movement.	No EWR site selected due to operation rules of Bloemhof Dam and Vaalharts weir.
MRU Vaal N	Reach was rated as an importance of 1. Heavily impacted by Harts River (water quality – high TDS).	No EWR site was selected.
MRU Vaal O	Schmidtsdrift weir forms the upper delineation area of the reach. The lower level of the reach is inundated with Douglas Barrage water. Importance of this reach was rated as a 3 to ensure integrity of Vaal River is maintained. Site is Easy to access. It is a single channel and has a gauging weir for flow records.	EWR site 7 was selected (at Schmidtsdrift).
MRU Vaal P	RU comprises Douglas Barrage. Lowest end of Lower Vaal WMA and Vaal River System. Includes inflow from Riet River and transfer of water from Upper Orange River	No EWR site was selected.

MRUs	Assessment of Resource Unit	Recommendations on EWR site
	WMA (through pipeline). Water quality is impacted mainly from irrigation activities. Importance was rated as a 1.	
HARTS RIVER		
MRU Harts A	No major characteristic features, habitat and biota diversity or major operational influences occur in this MRU. The reach has a low priority rating (1).	No EWR site was selected.
MRU Harts B	No significant habitat and biota diversity. Priority rating was between 1 and 2 for these upper reaches of the Harts River.	No EWR site was selected.
MRU Harts C	Wentzel Dam forms the MRU. It forms an operational break in the system. The reach has a low priority rating. The Dam is not representative of site requirements.	No EWR site was selected.
MRU Harts D	The reach has a moderate priority rating. MRU is delineated by two dams. System is highly regulated. A EWR site is not proposed.	No EWR site was selected due to river not suitable – include that you did try and find a site for a rapid assessment
MRU Harts E	Taung dam is delineated as a unit. It forms an operational break in the system. The MRU has a moderate priority rating. The Dam is not representative of site requirements.	No EWR site was selected.
MRU Harts F	MRU has an increase in return flows from irrigation practices in the catchment areas. This reach did score a moderate priority rating (2). Includes many canal systems. Not suitable for an EWR site due to constant releases of irrigation return flows.	No EWR site was selected.
MRU Harts G	In this MRU the return flows have substantially changed the flow regime compared to natural conditions and has highly impacted the system in terms of water quality. Reach also includes many canal systems.	No EWR site was selected.
MRU Harts H	Spitskop dam is delineated as a unit. It forms an operational break in the system. The MRU has a low priority rating. The Dam is not representative of site requirements.	No EWR site was selected.
MRU Harts I	Reach scored a high priority rating in terms of maintaining the integrity of the Harts River. Most downstream reach on Harts River before confluence with the Vaal. Site is Easy to access. It is a single channel and has a gauging weir for flow records.	EWR site 6 selected at Lloyds weir.
RIET RIVER		
MRU Riet A	Upper most reach of the river. The Dam forms the lower delineation boundary of the unit. Region has a low priority rating.	No EWR site was selected.
MRU Riet B	Kalkfontein Dam is delineated as a resource unit. It forms an operational break in the system.	No EWR site was selected.
MRU Riet C	No significant changes in land use or operation. Reach was rated as a high priority rating (integrity of Riet River must be maintained).	No EWR site was selected as this MRU as it does include the influence of the Modder River.
MRU Riet C.1	Includes three Eco-regions in upper reaches of Modder River. No significant habitat or biota diversity. Region has a low priority rating.	No EWR site was selected.
MRU Riet C.2	Krugerdrif Dam is delineated as a resource unit. It forms an operational break in the system.	No EWR site was selected.
MRU Riet C.3	Area is impacted by return flows from the urban centres, bulk water users and irrigation. System is regulated by dam. Catchment area has a low to moderate priority	No EWR site was selected.

MRUs	Assessment of Resource Unit	Recommendations on EWR site
	rating.	
MRU Riet D	Reach has a high priority rating (3). Assessment requires the integrity of the Riet river to be maintained upstream of the confluence with the Vaal River. MRU should be considered for the selection of an EWR site. Single low flow channel and gauging weir for flow records is present.	EWR site 8 selected at Lilydale Lodge.

The site information and photographs of the selected EWR sites are shown in Table 7.

Table 7: Locality and characteristics of the Lower Vaal WMA EWR sites

Site information	EWR sites	Illustration
EWR nr and name	**EWR 16 Downstream Bloemhof Dam**	
River	Vaal	
National RHP site	No	
Decimal degrees:	S27.65541; E25.59564	
EcoRegion (Level II)	11.08; 29.02	
Geomorphic Zone	E: Lower Foothills	
Altitude (m)	1211	
RU	Vaal K	
Quaternary	C91A	
Hydrological gauge	C9H021	

Site information	EWR sites	Illustration
EWR nr and name	**EWR 17 Lloyds weir on Harts River**	
River	Harts	
National RHP site	C3HART-DELPO	
Decimal Degrees	S28.37694; E24.30305	
EcoRegion (Level II)	29.02; 30.01	
Geomorphic Zone	E: Lower Foothills	
Altitude (m)	1114	
RU	Harts C	
Quaternary	C33C	
Hydrological gauge	C3H016	
EWR nr and name	**EWR 18 Schmidtsdrift**	
River	Vaal	
National RHP site	C9VAAL-SCHMI	
Decimal Degrees	S28.70758; E24.07578	
EcoRegion (Level II)	29.02; 30.01	
Geomorphic Zone	E: Lower Foothills	
Altitude (m)	1239	
RU	Vaal O	
Quaternary	C92B	
Hydrological gauge	C9H024	

Site information	EWR sites	Illustration
EWR nr and name	**EWR 19 Lilydale lodge**	
River	Riet	
National RHP site	No	
Decimal Degrees	S29.0218.3; E24.3010.2	
EcoRegion(Level II)	29.02	
Geomorphic Zone	E: Lower Foothills	
Altitude (m)	1107	
RU	Riet D	
Quaternary	C51L	
Hydrological gauge	C5H048	

The sites selected are tabulated below (Table 8) and illustrated in the map with the MRUs (Figure 8).

Table 8: Summary of selected EWR sites for the Lower Vaal Catchment

EWR Site number	EWR site name	River	National RHP site	Coordinates	Ecoregion (Level II)	Geomorphic zone	Altitude (m)	RU	Quaternary catchment
EWR 16	Vaal River: Just downstream Bloemhof Dam	Vaal River		S27.65541 E25.59564	11.08, 29.02	E: Lower Foothills	1211	MRU Vaal K	C91A
EWR 17	Harts River: Lloyds weir	Harts River	C3HART-DELPO	S28.37694 E24.30305	29.02; 30.01	E: Lower Foothills	1114	MRU Harts C	C33C
EWR 18	Vaal River: Schmidtsdrift	Vaal River	C9VAAL-SCHMI	S28.70758 E24.07578	29.02; 30.01	E: Lower Foothills	1239	MRU Vaal O	C92B
EWR 19	Riet River: At Lilydale Lodge	Riet River		S29 02 18.3 E24 30 10.2	29.02	E: Lower Foothills	1107	MRU Riet D	C51L

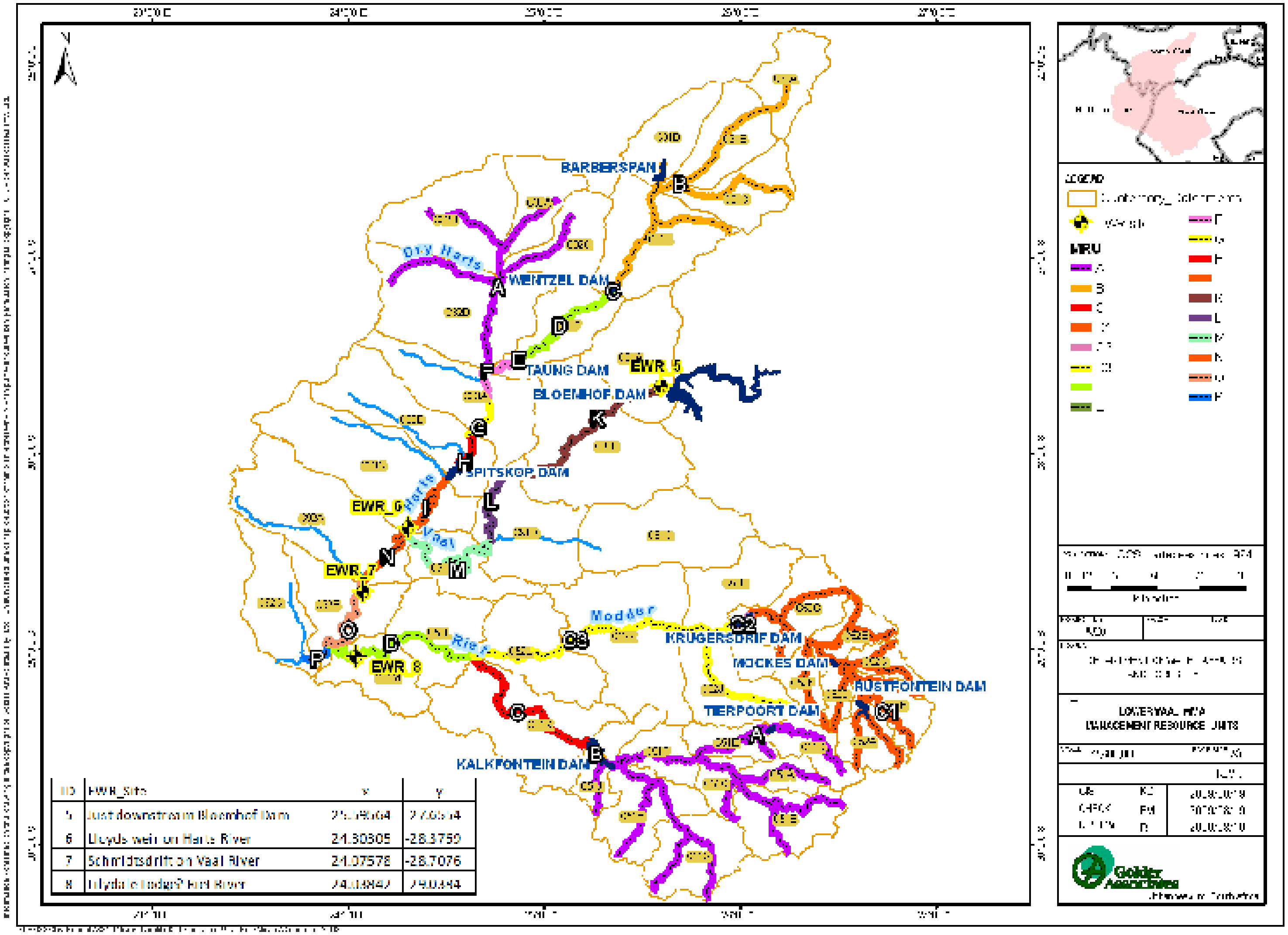


Figure 8: Summary of the Resource Units and the Ecological Water Requirement (EWR) sites

5 BASIC HUMAN NEEDS

5.1 Introduction

The National Water Act (Act No. 36 of 1998) (NWA) is founded on the principle that National Government has overall responsibility for and authority over water resource management for the benefit of the public without seriously affecting the functioning of the water resource systems. In order to achieve this objective, Chapter 3 of the NWA provides for the protection of water resources through the implementation of resource directed measures (RDM). As part of the RDM, a Reserve has to be determined for a significant water resource, as means to ensure a desired level of protection.

In this the CD:RDM has initiated the Comprehensive Reserve Determination Study for the Integrated Vaal River System: Lower Vaal Water Management Area (WMA) surface water quantity (technical component). The purpose of the Comprehensive Reserve Determination Study for the water resources of the Lower Vaal WMA is to determine the ecological and basic human needs water quantity Reserve for the rivers and pans in the WMA at the highest possible level of confidence given data, budget and time constraints.

As part of the Reserve Determination process it is necessary that the Basic Human Needs (BHNR) requirements is determined to understand the likely direct users of the surface water resources of the catchment so these uses are quantified and accounted for in the Reserve. This task is therefore focused on understanding and determining for the water resources in Lower Vaal WMA the BHNR component.

The Reserve is defined in terms of the National Water Act, Act No. 36 of 1998 as: “The quantity and quality of water required to satisfy basic human needs and to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource”.

In terms of the above definition the Reserve comprises two distinct components viz.:

- The Basic Human needs (BHNR), and
- The Ecological Reserve.

The focus of this task is to determine the BHNR for the Lower Vaal WMA.

The BHNR provides for the essential needs of individuals served by the water resource in question and includes water for drinking, food preparation and for personal hygiene. A life-line amount of 25 litres per person per day has been adopted for the BHNR by DWAF which is aligned to the Reconstruction and Development Programme (RDP) targets of Government of 25 litres per person per day, as well as the World Health Organisation minimum standards.

5.2 Approach

The process followed in determining the BHNR for the Lower Vaal WMA and Modder Riet catchment was as per that specified by the CD: RDM. The BHNR was analysed using the following factors:

- The population of those living within the catchment (per quaternary);
- The per capita requirements (litres/day) of the total population based on the life line amount of 25 litres per person per day; and
- The mean annual runoff (MAR) of the catchment areas in question.

In terms of the above factors the following applied terms of the Lower Vaal WMA and Modder Riet catchment.

5.2.1 Population

The basic human needs Reserve was calculated from population water requirements provided by Chief Directorate: Water Services, Directorate: Community Water Planning. The population figures used were based on the 1991 census and extensive field verification project initiated in 1994. The total population of the quaternary catchment was used to calculate the basic human needs Reserve at the outlet of the quaternary catchment. Population figures were not available for all quaternary catchments. This was either due to lack of information or the area not being populated.

Although the population figures from the 2001 National census are available, these figures are only available at a municipal demarcation boundary level. The DWAF has not yet disaggregated the population figures to quaternary catchment boundary level as per personal communication of the Sub-directorate Systems Analysis.

The Water Services National Information System database (DWAF website, 2008) also provides an estimated growth in population per province. This estimate is based on Census 2001 and updated with the DWAF, National Water Services project progress and project implementation from October 2001 to March 2007. The average annual growth in population for Northern Cape Province is 0.57%, for North West Province is 0.52% and for the Free State Province is 0.60% growth. This projected growth was used as estimates for the population growth in Lower Vaal WMA and Upper Orange up to 2020.

5.2.2 Per capita requirements

The next step in the analysis is to multiply total population figures by possible BHNR water quantity targets. As such, from the population figures available a BHNR can be a calculated. It should be noted that there is no "official" BHNR figure. The RDP target (Target 1), of 25 litres per person per day is conventionally is used by DWAF as the basic human need requirement (DWAF, 1994).

5.2.3 Percentage of Mean Annual Runoff

The final step of the process is to determine what percentage of virgin Mean Annual Runoff (MAR) BHNR comprises. While the virgin MAR is preferred in the case of the Lower Vaal and Modder Riet catchment, the virgin MAR for each quaternary catchment was not available as the system hydrology has not been determined to quaternary catchment level. The hydrology has been grouped into blocks and it was not possible to disaggregate it to quaternary catchment level. The gross MAR per quaternary catchment was thus used (WRC, 1994).

5.3 The Results

The BHNR calculated for the Lower Vaal WMA is presented below in Table 9. The results of the analysis are also presented in Figure 9 and Figure 10.

Table 9: BHNR required for Lower Vaal

QUATERNARY CATCHMENT	TOTAL POPULATION	Annual % Growth	Population 2020	Per Capita need (litres/day)	Per Capita need (MCM/ Annum): Current	Per Capita need (MCM/ Annum): 2020	Gross MAR	%MAR
C91B	35,570	0.6	41,556	25	0.32	0.38	17.3	1.88
C91C	14,440	0.6	16,870	25	0.13	0.15	13.1	1.01
C91D	30,285	0.6	35,381	25	0.28	0.32	8	3.45
C91E	240,350	0.57	278,627	25	2.19	2.54	3.5	62.66
C31A	38,940	0.52	44,562	25	0.36	0.41	15	2.37
C31B	5,790	0.52	6,626	25	0.05	0.06	14.1	0.37
C31C	1,140	0.52	1,305	25	0.01	0.01	15.1	0.07
C31D	41,877	0.52	47,923	25	0.38	0.44	9.1	4.2
C31E	6,910	0.52	7,908	25	0.06	0.07	23.1	0.27
C31F	87,030	0.52	99,594	25	0.79	0.91	10.2	7.79

QUATERNARY CATCHMENT	TOTAL POPULATION	Annual % Growth	Population 2020	Per Capita need (litres/day)	Per Capita need (MCM/ Annum): Current	Per Capita need (MCM/ Annum): 2020	Gross MAR	%MAR
C32A	1,330	0.52	1,522	25	0.01	0.01	11.5	0.11
C32B	28,310	0.52	32,397	25	0.26	0.30	21.2	1.22
C32C	30	0.52	34	25	0	0.00	15	0
C32D	54,830	0.52	62,746	25	0.5	0.57	30.9	1.62
C33A	79,013	0.52	90,420	25	0.72	0.83	24.4	2.95
C33B	24,372	0.57	28,253	25	0.22	0.26	22	1.01
C33C	3,400	0.57	3,941	25	0.03	0.04	25.1	0.12
C92A	11,895	0.57	13,789	25	0.11	0.13	30.7	0.35
C92B		0.57					11.1	
C92C	15,738	0.57	18,244	25	0.14	0.17	10.2	1.41
C51A	4,365	0.6	5,100	25	0.04	0.05	18.9	0.21
C51B		0.6					43.4	
C51C	7,783	0.6	9,093	25	0.07	0.08	12.7	0.56
C51D		0.6					27	
C51E		0.6					17	
C51F		0.6					12.7	
C51G	7,535	0.6	8,803	25	0.07	0.08	34.8	0.2

QUATERNARY CATCHMENT	TOTAL POPULATION	Annual % Growth	Population 2020	Per Capita need (litres/day)	Per Capita need (MCM/ Annum): Current	Per Capita need (MCM/ Annum): 2020	Gross MAR	%MAR
C51H	13,412	0.6	15,669	25	0.12	0.14	31.7	0.39
C51J	5,130	0.6	5,993	25	0.05	0.05	17.3	0.27
C51K	23,012	0.6	26,884	25	0.21	0.25	8.9	2.36
C51L	9,787	0.57	11,346	25	0.09	0.10	5	1.79
C51M	93	0.57	108	25	0	0.00	2.7	0.03
C52A	9,773	0.6	11,418	25	0.09	0.10	27.9	0.32
C52B	360,903	0.6	421,636	25	3.29	3.85	36.9	8.92
C52C	6,378	0.6	7,451	25	0.06	0.07	18.6	0.31
C52D		0.6					13.1	
C52E		0.6					20	
C52F	360,775	0.6	421,487	25	3.29	3.85	16.3	20.2
C52G	19,900	0.6	23,249	25	0.18	0.21	43.9	0.41
C52H	13,250	0.6	15,480	25	0.12	0.14	10.9	1.11
C52K	10,031	0.6	11,719	25	0.09	0.11	13.1	0.7

MCM: million cubic metres, MAR: mean annual runoff

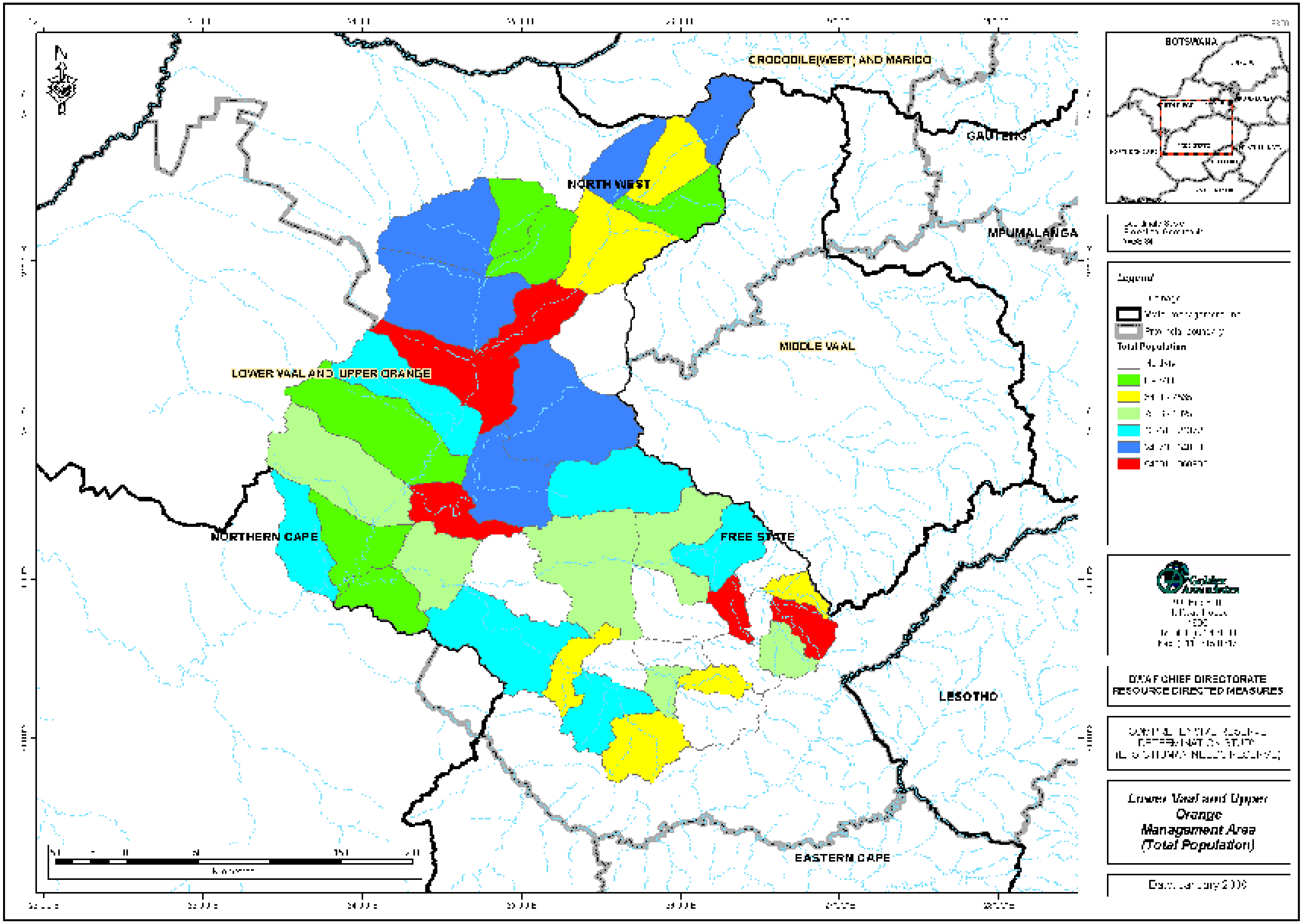


Figure 9: Population distribution within quaternary catchments in the Lower Vaal WMA

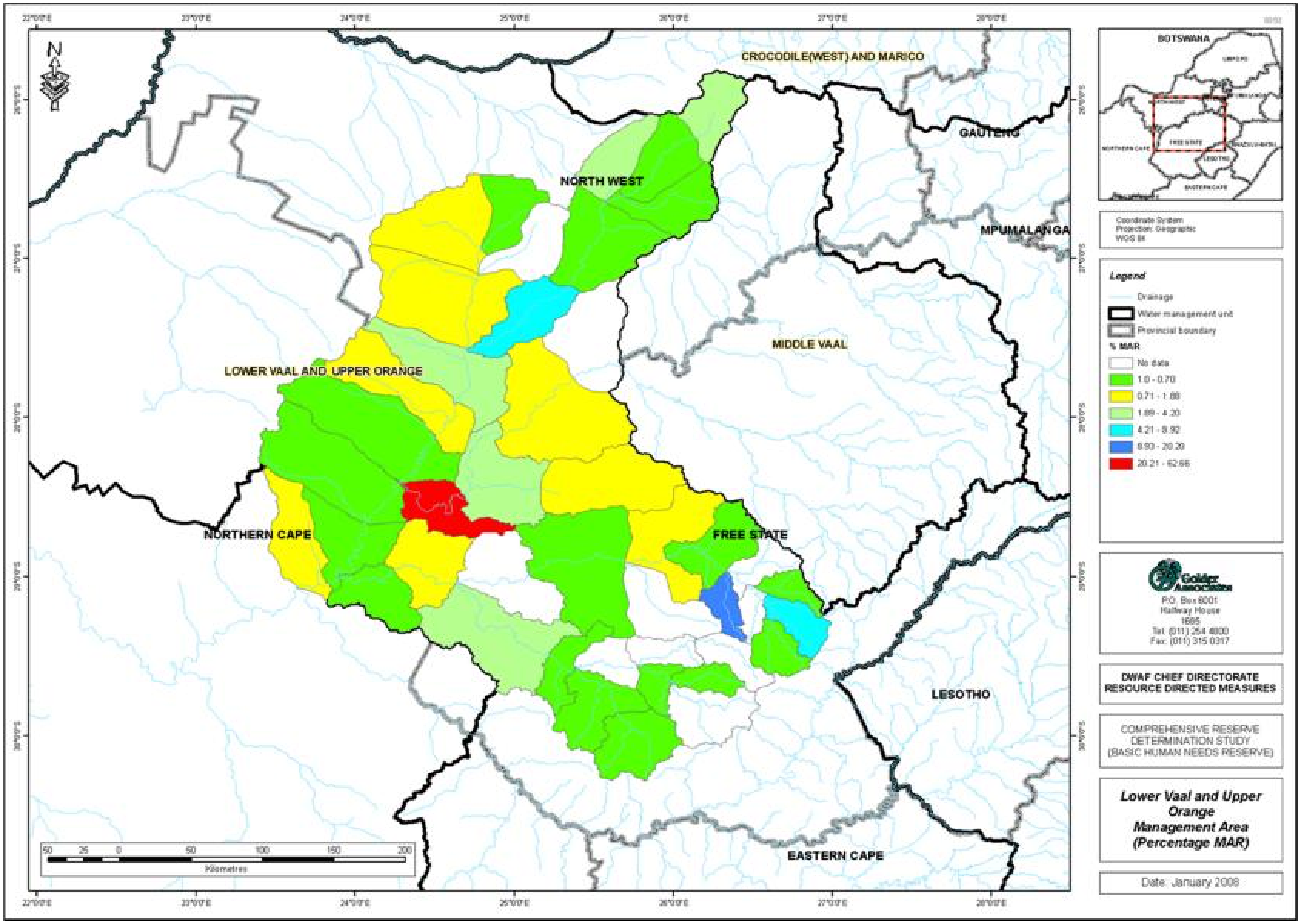


Figure 10: % MAR the BHNRR comprises per quaternary catchment in the Lower Vaal WMA

6 PANS/WETLAND SCOPE

6.1 Desktop Methodology

To locate wetlands and pans, data from the National Spatial Biodiversity Assessment (NSBA) and the South African National Biodiversity Institute (SANBI) was used. Data from the National Land Cover 2000 (NLC 2000) was used as a tool to guide wetland and pan identification and on screen delineation.

The DWAF Rivers shape file was then overlaid with the Wetland Probability shape file (NLC2000). All the wetlands that intersect with rivers were removed from the Wetland Probability shape file. To do this a 100m buffer was generated around rivers and all wetlands within this buffer or intersected with the buffer were removed from the Wetland Probability shape file. Thus the wetlands that fell within river channels and their surroundings were excluded. These areas will be addressed by the monitoring points in the river.

Environmental Impact Studies on some of the wetlands provided valuable information, especially those related to dolomitic eyes in the study area. Ramsar status information (Ramsar, 1975) and Important Bird Areas (Barnes, 1998) information was very useful in providing biodiversity data. After GIS buffer analysis the wetland size, biodiversity as well as desktop information was used to prioritize the wetlands to a list of 22 wetlands and pans. The 22 wetlands and pans were described and discussed in a workshop attended by wetland specialists, officials of the Department of Environmental Affairs and Tourism and the Department of Water Affairs and Forestry held during 14 November 2007 in Parys.

Site knowledge was used to add wetlands and pans or remove wetlands and pans from the list until a shortlist of priority wetlands for further study and investigation was produced. This list will be proposed in this document for further investigation.

6.2 Classifying the wetlands

Wetlands and pans are described in terms of their position in the landscape, and the classification was done according to its hydro-geomorphic setting (Kotze, Marneweck, Batchelor, Lindley & Collins, 2004).

Due to the course nature of this research, the lack of substantial data and very little ground truthing opportunity, a detailed classification was not viable. A general description of the wetlands and pans that can be expected in the catchments is based on a rough delineation and assessment exercise. By making use of the scoring system in Wetland-Assess the generic expected goods and services of the wetland types are described and discussed.

6.3 Current status of the wetlands

Since no baseline information on the status of these wetlands and pans is available, a generic attempt in assessing the current status or integrity of the wetlands was done. Basic principles of the Present Ecological Status (PES) were used to give guidance in this regard (WRC, 2008). Further, the procedure for determination of Resource Directed Measures for Wetland Ecosystems (DWAF, 1999) provided the basic criteria followed.

Land use activities in and around the different types of wetlands was used to make assumptions from and to supplement findings.

6.4 Requirements for wetland Reserve determination in the Middle and Lower Vaal River Catchments

The Department of Water Affairs and Forestry (DWAF) is the custodian of all South Africa's water resources, including wetlands. Wetland Reserve (environmental flow determination) studies are increasingly required to be undertaken by or on behalf of DWAF (Wet-priorities).

Wetlands and pans need to be prioritized, especially those that provide essential goods and services (directly or indirectly) to the area. Other aspects that will contribute towards prioritizing of wetland systems for this purpose would be:

- Wetlands with high conservation values;
- Wetlands functional attributes (goods and services);
- Wetlands that are ecologically important;
- Present health and integrity of wetlands (threats); and
- Representative wetlands of the area.

6.5 Results

6.5.1 Wetland Types and distribution

For this report a wetland is an area of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt (Ewart-Smith, Ollis, Day and Malan. 2006).

Palustrine wetlands do occur in the study area and refers to non-tidal wetlands dominated by emergent plants (e.g. reeds), shrubs or trees and includes a variety of systems commonly described as marsh, floodplain, vlei or seep (Ewart-Smith, *et al.* 2006).

A total of 347 699 palustrine wetlands and pans were identified in the Middle and Lower Vaal Catchment areas (Figure 11). All six palustrine wetland types occur in the study area: floodplain, valley bottom with a channel, valley bottom without a channel, hill slope seepage feeding a watercourse, hillslope seepage not feeding a watercourse and depressions that includes pans. This classification is based on their hydro-geomorphic setting (Kotze, et al, 2004).

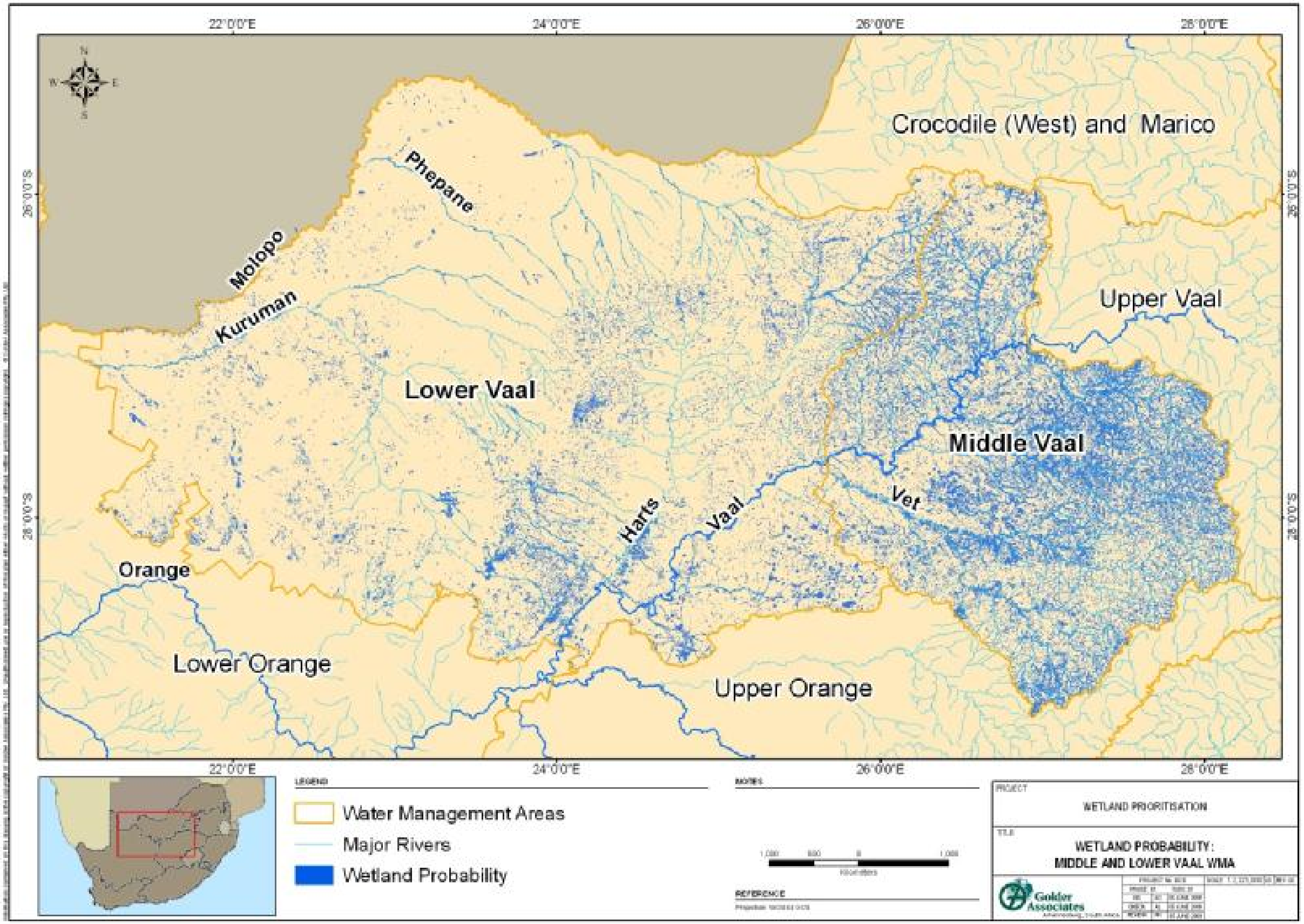


Figure 11: Map indicating wetlands and pans occurring in the Middle and Lower Vaal river catchments

6.5.2 Floodplains

Floodplain systems like the Harts River occur in the study area (Figure 12).

Figure 12: The Harts River floodplain wetland system close to the Barberspan Bird Sanctuary.

6.5.3 Pans

Pans are fairly widespread in the study area, although they occur in clumps in some areas (Figure 11). Most pans in the study area are inundated ephemerally and irregularly. The most ubiquitous wetlands seem to be endorheic pans. The term endorheic refers to the closed (no outlet) nature of the drainage system of pans. These are characterized by saline deposits on their floors, and many have been mined for salt in the past. Pans in the study area tend to be large, dry, floodplain-like features, elongated along river courses (McCartney, Cairncross, Huizenga & Batchelor, 2007).

There is some pattern to the distribution of pans. Some occur in clumps and some is arranged in a linear fashion coinciding with the fossil courses of dry rivers, e.g. Barberspan, along the ancestral path of the Harts River (Allan, Seaman & Kaletja, 1996). This feature indicates their ancient origin. Typically their shape is circular to oval, and where two or more pans have spread and combined, they form characteristically kidney-shaped or lobed wetlands, e. g. Barberspan. They are shallow, even when fully inundated, and usually less than about three meters deep. Barberspan is the largest pan exceeding 1000 ha and are considered as major and striking feature of the local landscape with Leeupan just upstream thereof (Figure 13)

Figure 13: Leeupan occurring adjacent to Barberspan.

Almost all the pans identified are associated with shale, organic sedimentary rock and andesite, trachyte, phonolite lithologies.

6.5.4 Dolomitic Eye Systems

The eye systems occurring in the study area, such as the Kuruman Eye (Figure 14) and the Ventersdorp Eye, can according to the National Wetland Classification System for South Africa, based on the Cowardin system of the United States of America (Cowardin, Carter, Golet & LaRoe, 1979), be classified as Palustrine Persistent Emergent Wetlands. According to the Ramsar Classification System these eyes are non-forested peatlands. This type of wetland is dominated by emergent plant species, which normally remain standing at least until the beginning of the next growing season (Cowardin *et al*. 1979).

Figure 14: The Kuruman Eye dolomitic spring feeding into a reed and water lily dominated wetland downstream

The dominance and abundance of emergent plant species such as *Phragmites australis* support this classification. At a finer level of classification, these wetlands can also be classified as valley-bottom fens. The dominance of reeds may be a recent directional change in the structure and composition of the wetland that may have been caused by increased sediments and/or changes in the available nutrients in the ground or surface water entering these wetlands (Engelbrecht & Linström, 2007).

Superficially, the eye systems appear to be similar to other wetlands occurring on the Highveld grasslands. However, it is unique in that it is influenced by karst landforms and fed by perennial dolomitic springs, which supply a constant source of groundwater into the wetland system downstream. These wetlands are hydraulically isolated from most of the main river channels it feeds into and is not influenced by any flood events in the rivers.

6.6 Likely ecosystem services provided by the Pans and wetlands

6.6.1 Pans and Depressions

By their physical presence and shape, and the vegetation they support, pans may act as sediment traps. Pans can be very productive and it may be because they provide abundant supplies of both nutrients and water in a stable environment.

Pans also provide important habitat for the life cycles of a significant number of species. The pans edge, characterized by emergent plants including sedges, grasses and herbaceous species that is usually <1m tall and the shallow open water (<1.5 m) containing floating or submerged aquatic plants, provides an area of highest biodiversity in an otherwise species poor habitat, dominated by reeds. The above-mentioned area provides a refuge for a variety of species such as fish, small mammals, and birds. This is a benefit of the pan in terms of biodiversity protection.

Pans are also important stopover sites for waterfowl, with over 320 recorded species including Palearctic species, Red Knot *Calidris canutus* and Black Godwit *Limosa limosa* visiting the Barberspan. Species present include all indigenous waterfowl species except the Tropical Dwarf Goose *Nettapus auritus*. Barberspan is the only locality in South Africa where the Pintail *Anas acuta* has been recorded. Some waterfowl species breed in the wetland.

Pans have aesthetic significance as a landscape component. While these pans are an aesthetically pleasing landscape feature in the area, they do not appear to be perceived as having any particular value by the overall community. Biodiversity in the form of water birds does attract birdwatchers. This may become important to planners and entrepreneurs to attract tourists. A camping and picnic site, a trail and bird hides have been established on and around some pans. Pans are popular angling sites and recreational areas in the study area.

6.6.2 Dolomitic eye systems

Wetland benefits are those functions, products, attributes and services provided by the ecosystem that have a value to humans in terms of worth, merit, quality and importance. These benefits may be derived from outputs that can be consumed directly, indirect uses that arise from the attributes or functions occurring within the ecosystem, or possible future direct outputs or indirect uses.

6.6.3 Wetland Benefits

These wetlands, in this case the dolomitic eye systems; contribute towards the bigger ecosystem services by means of the following wetland functions:

- Water supply
- Flow regulation
- Erosion control
- Sediment and nutrient removal and/or retention

- Maintenance of Biodiversity Significant For Conservation
- Socio-cultural significance
- Carbon Sink
- Good representative example of a specific class of wetland

The Wet-EcoServices (Kotze et al, 2006) assessment tool was used to indicate the most likely ecosystem services of a dolomitic eye system (Figure 15). Dolomitic eye wetlands (this includes the eye and the peat/reed valley bottom area downstream) contribute in particular towards ecosystem services such as streamflow regulation, nitrate removal, erosion control, carbon storage, and the maintenance of biodiversity.

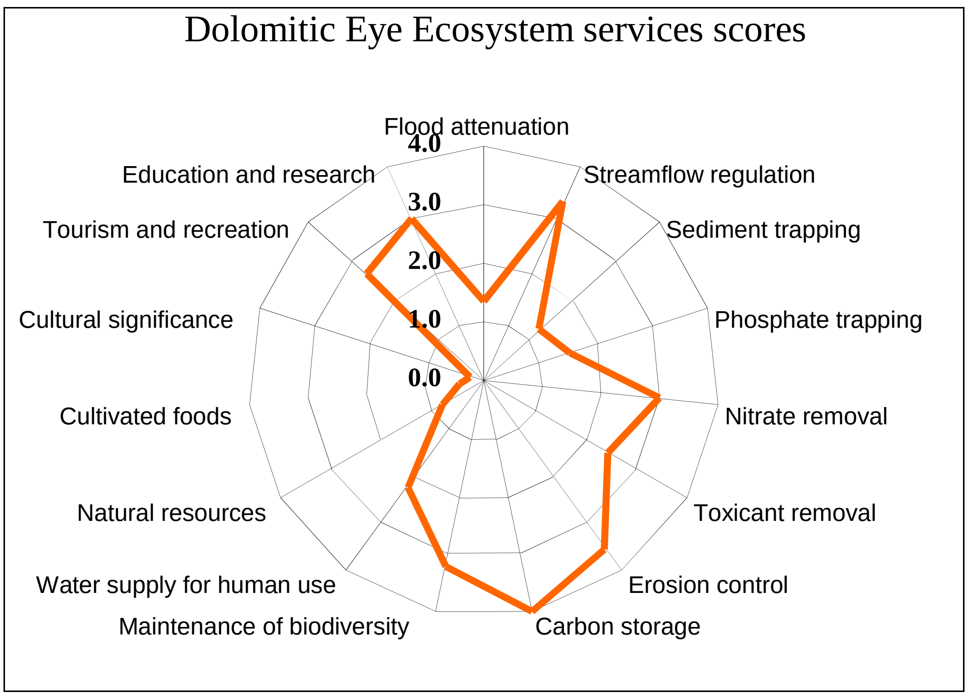


Figure 15: Wetland ecosystem services scores most likely performed by dolomitic eyes in the Lower Vaal River Catchment

6.7 Threats to the Pans and wetlands

Several anthropogenic threats to Pan Ecosystems and their associated biota have been identified and in some cases quantified.

6.7.1 Agricultural developments

A major threat to endorheic pans comes from agricultural development. Many pans in crop farming regions are surrounded by fields that often encroach onto the periphery of these wetlands and even impinge into the actual basins of smaller, well vegetated pans. Such pans are subjected to contamination and eutrophication by pesticides and fertilizers. The endorheic nature of pans exacerbates this problem and toxic substances concentrate in their basins. Poisons in particular pose a serious threat to wildlife. Ploughing, overgrazing and excessive trampling b livestock damages the shore vegetation, increase wind erosion and leads to the siltation of pan basins. Many pans are dammed or excavated to provide a water supply for livestock. The construction of fence lines across pan basins to control livestock movements is ubiquitous and these structures are a danger to flying water birds that frequently collide with or are becoming entangled in them.

6.7.2 Water pollution

The release of untreated sewage into aquatic systems has got detrimental effects on biota downstream thereof and especially in pans because of its endorheic nature. This is a major problem since raw sewage is being dumped into river systems in the study area. Barberspan especially is at risk because the Harts River is diverted to flow into the pan. This can result in the pan to become a sewage settling pond.

6.7.3 Urbanization

Factors associated with urbanization, such as recreational and residential developments, are encroaching rapidly on my pans. Such developments directly disturb wildlife and lead to excessive littering. In urban areas, pans provide convenient sites for municipal dumps. Rubble is frequently dumped in pan basins to provide a foundation for constructions. Farm dumps in pan located in rural areas, however, are usually insignificant. In many rural areas homesteads are frequently built close to pans and this increases littering and disturbance to wildlife.

6.7.4 Road-building operations

Another major threat, particularly in the central Highveld, is road construction. Pan are frequently seen as ‘lines of least resistance’ by road planners.

6.8 Reference conditions of the wetlands

6.8.1 Dolomitic springs with associated wetland habitat downstream

These wetlands most likely developed under very constant flow conditions provided by dolomitic springs in and around the wetland. Rainfall events in the catchments of these wetlands contribute little to the available water in the systems. Flood conditions in these systems are also an unlikely event, except maybe during extreme rainfall events (Engelbrecht & Linstrom, 2007).

Unregulated wetland fires occur and layers of ash occur in the upper portions of the peat indicating recent desiccation. Fences and grazing have a minor impact on these wetlands. Adjacent agricultural activities and roads in and around the wetland have increased the presence of invasive exotic plant species. Some invasive species do occur in some of these peat wetlands, especially in the disturbed areas on the perimeter.

Although most of these wetlands are still in a very good condition, these wetlands are presently dominated by an almost monotypic stand of reeds. Available information suggests that this may be the result of recent directional change from a more diverse wetland with a mosaic of vegetation patches to an almost uniform reed dominated wetland.

Because of stable hydrological conditions and a history of anthropogenic disturbance in and adjacent to these wetlands, directional changes from floristically more diverse systems towards an almost monotypic reed dominated system may have occurred. However, several habitat types and vegetation communities still occur in these systems, such as:

- Active channels with some floating leafed, short emergent vegetation and small pockets of open water. The common reed (*Phragmites australis*) can dominate the vegetation in this habitat and it can contain patches of species such as *Typha capensis, Juncus effusus* and *Juncus punctorius.* The alien invasive watercress *(Rorippa nasturtium-aqauticum)* can also occur in this habitat type.

- The permanently wet habitat type consists mainly of tall emergent species dominated by the common reed *Phragmites australis.* This habitat type is mostly underlain with clayey course.

- A narrow but ecologically extremely important transitional grass-sedge dominated transitional zone occurs between wetland and terrestrial habitats.

- A grass-sedge wetland area occurs containing a mixture of wetland grass, sedges and other facultative hydrophytic species. The buttercup *Ranunculus multifidus* and *Ranunculus meyeri* can be common in this habitat type.

- Seepage areas can occur along the margin of these wetlands with the presence of both seasonally and temporary wet zones. Within these, semi-circular monospecific stands of Cottonwool grass *Imperata cylindrica* can be common.

- Natural open water habitat largely associated with dolomitic springs in the wetland. A characteristic deposit of white sulphur reducing bacteria normally occur in the substrate of the eyes.

- Typical riparian species associated with rocky habitat occurs around the eyes.

- Terrestrial habitat occurs adjacent to the wetland area.

6.8.2 Pans

Pans and depressions are of ecological importance as part of the broader landscape of arid regions and of further ecological interest within the pans themselves for their own biota, specifically during the periods that they hold water, and because of the briefness of those periods and the limited availability of water. Hydrological variability is a predominant feature affecting the ecology of pans. The physical and chemical properties of the substrata and water of pans therefore varies seasonally and regionally. Furthermore, within each inundation considerable changes in the physical and chemical properties of the pans also take place (Allan, Seaman & Kaletja, 1996).

The Barberspan Pan (Figure 16) is used to identify some reference conditions that will be applicable to some of the other important pans as well:

Figure 16: Visual of Barberspan that is connected with the Harts River (Google, 2007)

Overview of the Barberspan site

The reserve is 3118 ha in extent, of which about 2 000 ha is water. The pan is connected with the Harts River via a channel and is the largest of a series of depressions along this channel. The pan itself is about 600m wide and 1 550m long. It is a natural, shallow, alkaline lake which is perennial. Other pans in the vicinity are non-perennial. It is one of the few permanent natural water bodies on the western Highveld and provides food and shelter during the dry months for large numbers of waterfowl. Migrating aquatic species use the pan as an important stopover.

Almost 300 species of birds have been recorded here, about one-fifth being migrants. A research station was established during 1952 for the ringing and study of waterfowl but is no longer operational.

Approximately 40 000 birds of 190 species were ringed annually for study of their distribution and migration.

Physical Features: Barberspan is the largest of a series of pans on the fossil bed of the Harts River. The reserve is underlain by amygdaloidal lava of the Ventersdorp System (age 2 100 million years). This is covered by surface limestone (age 100 million years) and classified as vlei or pan limestone according to origin. The quality varies from pure limestone to calcrete. It is hard and massive on the surface but softer and granular beneath the crust. There are no known economic deposits of any minerals. The depth varies from 5m to 9,5m flooding an area of 1 000 ha to 1 700ha. The storage capacity varies according to depth from $0.033 \times 10^6 m^3 – 0.096 \times 10^6 m^3$.

Conservation: The whole of the pan is protected as a Provincial nature reserve proclaimed in 1954 and is therefore State controlled. It was proposed that funds be raised to purchase the farms compromising the nearby Leeupan which is a natural extension of Barberspan. This is however unlikely. The possibility of a conservancy should be investigated. However, a major problem is the farmers negative attitude towards conservation as much of the land forming the reserve was in fact expropriated from them.

The pan is already a designated Ramsar Site and was listed during 1975. The pan qualifies as a wetland of international importance according to the Ramsar Convention of 1971. In order to be listed as such, Barberspan needs to comply with certain specifications, such as:

- It is an example of a specific type of wetland which is rare or unusual in the biogeographical area.
- It maintains a large number of threatened plants and/or animals.
- It is of special value for the maintenance of the ecological diversity of the region.
- It is of special value as habitat to plants and animals in a critical part of their life cycles.
- It maintains large numbers of individuals of specific groups of water birds which indicate the value, productivity and diversity of the wetland.

Threats: Threats are mainly external with pressure on the system arising from agricultural activities. The main threat is agricultural pollutants such as fertilizers, pesticides and herbicides. Littering by anglers is also a problem. Quarrying occurred previously and should be prohibited in the future.

Social and cultural values: Social and cultural values are extremely subjective concepts. The main value of the area lies in the pan itself. The conservation value of the site is perceived to be exceptionally high and may be of national and even sub-continental importance.

Signs of previous human occupation of the area have been discovered. Primitive implements made of lava dating mostly to the Early Stone Age (50 000 years B.P.) and Middle Stone Age (10 - 40 000 years B.P.) have been found in quarries and on pebble outcrops. As yet no major cultural historic or archaeological finds have been made. However, the remains of General Smuts's house are present which may be of interest to some.

The area is used mainly for research on birds and angling. The pan is also a popular angling resort and recreational area in the Western Transvaal.

6.9 Present ecological state and ecological importance and sensitivity of the pans and wetlands

Pans have received little attention and this applies in particular to pans associated with the study area. As a result little research or conservation effort has been focused on these ecosystems and there has been an underestimation of their conservation value, despite their unique nature. Their importance, which extends far beyond their value as wildlife refuges, and the vulnerability of these ecosystems motivate strongly for the detailed study and protection of these resources.

Groundwater dependent ecosystems, like dolomitic eyes, are facing increasing pressure from consumptive uses for agriculture, mining, urban and commercial developments. Collectively, anthropogenic changes in the groundwater regime pose a significant, but largely unknown threat to groundwater dependent ecosystems.

6.10 Priority wetland and pans that require reserve assessments

Wetlands identified were classified and listed according to size, IBA status, Ramsar criteria consideration, uniqueness in the study area and threats. The wetland polygons in the study area were sorted by size and the largest were investigated and assessed on Google Earth (Google, 2007). Aspects that can possible influence the wetland functionality and integrity was identified. A cross reference was then made between the larger wetlands found on GIS with those received via correspondence from specialists. From the above process a list of ~21 wetlands was generated. The identified wetlands were presented at a workshop with the specialist whereby the proposed list of 21 wetlands was discussed and adapted to 9 wetlands according the specialists' experience in the field (Table 10, and Figure 17).

Table 10: Priority Wetlands and Pans identified in the Lower Vaal River Catchments

Catchment Area	Priority Wetlands	Reasons	Location (GPS)
Lower Vaal	Barberspan	Ramsar Site & Important Bird Sanctuary.	Lat -26.58111 Lon 25.58929
	Harts River Floodplain	Unique feature and birdlife.	Lat -26.71755 Lon 25.53948

	Heuning Vlei	Unique birdlife.	Lat -26.31345 Lon 23.14362
	Kamferpan	Lesser flamingo breeding site.	Lat -28.67388 Lon 24.76290
	SA Lombard NR	Important Floodplain system.	Lat -27.59514 Lon 25.47673
	Kuruman Eye	Dolomitic Eye and peatland.	Lat -27.46166 Lon 23.43061

6.11 Conservation and management recommendations

Much remains to be done concerning the conservation of pans and wetlands. The entire network of pans requires conservation, so that there is always some suitable habitat available to act as refuge for the species adapted to these ecosystems somewhere within their ranges. Management strategies aimed at land in private ownership, is as important as land acquisition for formal nature reserves. However, some of the larger, and perhaps a suite of representative, pans should be given formal conservation protection if for no other reasons than for their tourism and education potential. Consideration should be given to including many of the more important pans in the formal nature reserve system, including municipal reserves. It is important that pans set aside as reserves in the latter areas are managed as nature areas and not as city parks with their attendant planting of alien trees and lawns, uncontrolled disturbance.

Legislation and its effective enforcement should be considered to halt the wanton environmental degradation of pans and other wetlands in the study area. The education of landowners and other parties who impact on these systems, as to full value of wetland habitats has been sorely neglected. For example, trampling by livestock transforms well-vegetated pan shorelines to open mud. Vegetated shorelines provide important feeding and/or breeding site for many birds, and probably other organisms. Landowners could be persuaded to permanently fence off large areas of shoreline so as to promote diversity of habitats and, for example, bird species. This would be especially valuable n creating breeding habitat for ducks.

Systematic and representative monitoring projects need to be established to maintain a constant watch over the environmental health of pans. Such monitoring needs to be pro-active and identify threats from developments while these are still in the early planning stages.

A particularly topical issue at present is the problem of aerial spraying of problem seedeater flocks with avicedes. Large flock of these species frequently roost in pan reed beds, especially in the Barberspan area, and the potential exists for a major ecological disaster to non-target species should any of these sites be sprayed. Such operations should be banned at pans and indeed at any wetland sites.

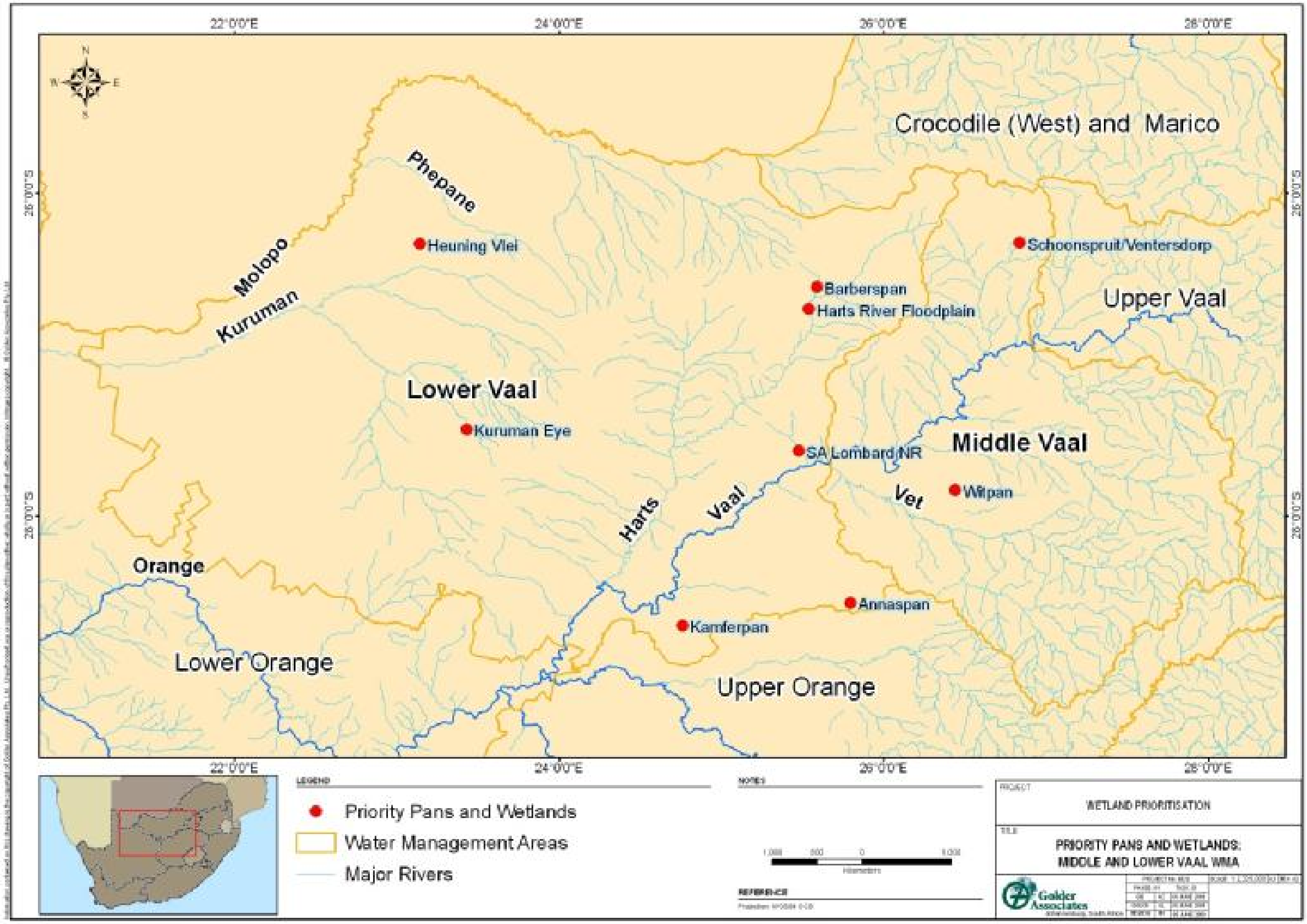


Figure 17: Priority Pans and Wetlands in the study area

Basic management actions should be taken to project pans and wetlands in the study area, such as:

- Correct burning regimes of pan shores should be implemented to promote its vitality. This will remove moribund and/or unacceptable grass material; and to eradicate and/or prevent the encroachment of undesirable plants.

- Many wetlands have been degraded by invasive exotic vegetation. Given the high hydrological/functional importance of these pans and wetlands, an urgent rehabilitation programme should be investigated in cooperation with Working for Wetlands.

- Buffer zones between pans/wetlands and roads, agricultural activities, developments, mining activities, etc. This will protect the water resources and promote the integrity of these systems.

- Investigate the laying out of roads in and around pans/wetlands. If possible, roads should be closed and rehabilitated in pan/wetland areas.

6.12 Way forward

Very little information with regards to wetlands in the Lower and Lower Vaal River catchments exists. Be it a wetland inventory or baseline data or general information. Further studies with regards to completing a wetland inventory are necessary and should include the verification of the existence of wetlands in some areas and to at least indicate the priority wetlands. Thus infield verification will be necessary.

Infield verification should also include Ecological Integrity and Sensitivity (EIS) Category assessments and Wetland Habitat Integrity (PES) assessment where applicable; this information will add value to future Ecological Reserve assessments.

Candidate wetland sites for determining an Ecological Reserve should occur in an area where impacts on the aquifer is high and the aquifer is vulnerable to drought (Marneweck, 2006). Impacts can be in the form of draining channels, water abstraction, mining activities, wrong burning regimes, etc. The level of determining the Reserve is still to be determined. However, given the groundwater component of the dolomitic eye systems, some of the valley bottom systems, endorheic pan, etc. would require further refinement of existing Reserve determination methods.

7 HYDROLOGY

7.1 Introduction

The location of the EWR sites (EWR16 to EWR 19), the quaternary catchment boundaries, rivers and major urban areas of Gauteng are shown in Figure 18. Sites EWR16 and EWR18 are on the Vaal River, site EWR 17 on the Harts River, site EWR19 on the Riet River.

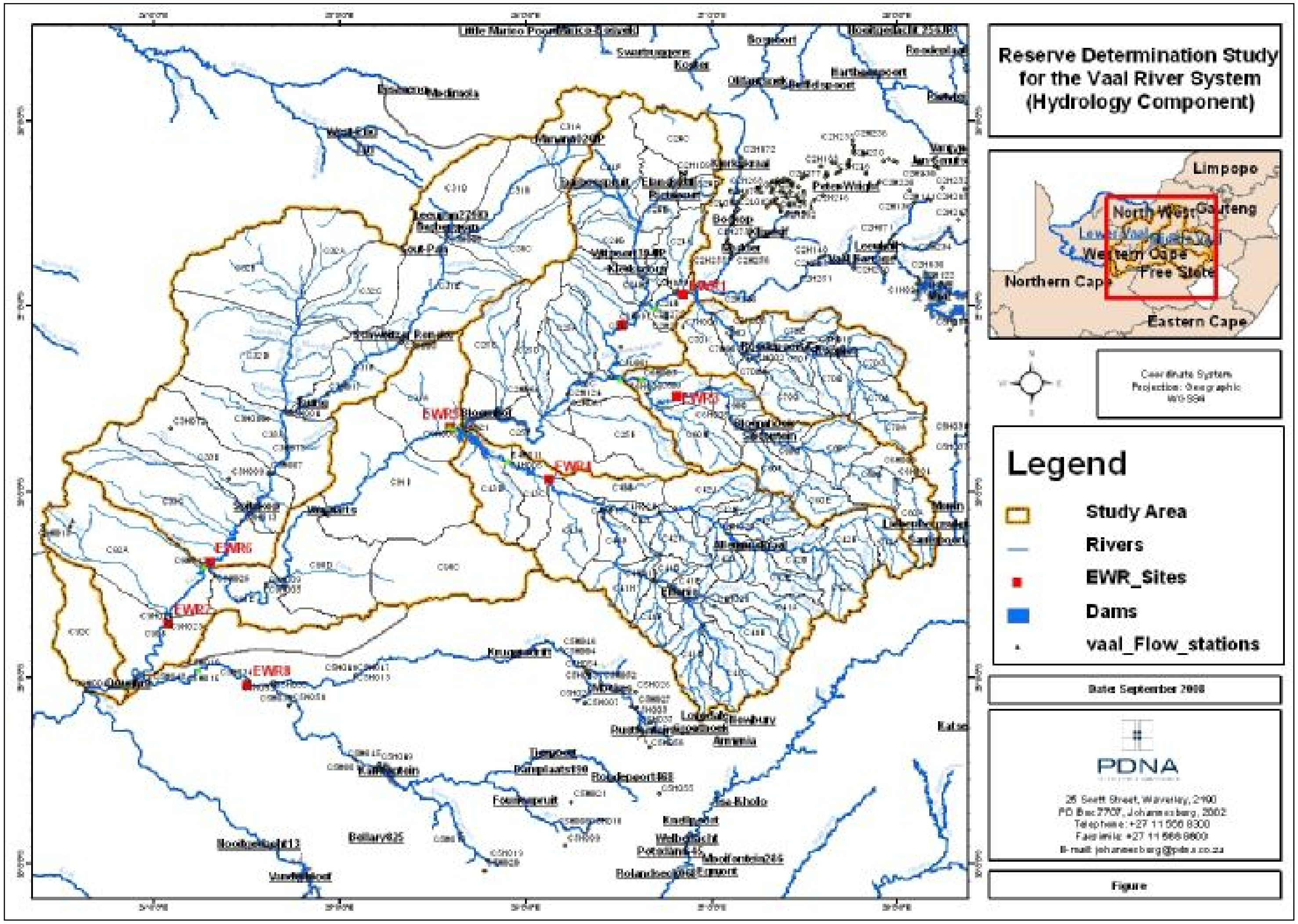


Figure 18: EWR sites and quaternary catchments

7.2 Approach

During the data collection phase of the project, any existing hydrology for the catchment was collected, with particular emphasis on hydrological data that has been used in previous yield modelling on the catchment.

The data was evaluated by the PSP and recommendations made to the client should any further hydrology be required to be developed for the project.

Both simulated naturalised and present day hydrological data was presented at the level of monthly flows. Daily flow conditions will be represented by observed data where recorded. Observed daily flow data (using DWAF rating curves) from selected flow gauging stations will be used where available. Where necessary simulated 'naturalised" daily flow data, using observed daily flow records from reliable gauging stations will be used.

Disaggregation of the catchment at the proposed EWR sites was carried out and hydrological modelling for the various EWR sites and the catchment as a whole will be performed using the models specified in the DWAF "Guidelines for Decision Support Models for Water Use Evaluation". If an adequate amount of reliable daily streamflow data is available, a daily rainfall-runoff model will be calibrated and used. If unavailable, then monthly modelling will be applied.

The spatial and time-series distribution of flows was studied and will take into account flow volumes, timing, flow patterns, flow levels, seasonal and inter-annual flow variability together with flood and drought cycles. Current flow regimes as well as naturalised flows, to represent the virgin hydrology of the catchment, will be studied. The hydrologist will prepare monthly base flows as well as the frequency and size of "freshes", average annual floods, drought and other high flow events, together with their frequency, in as much detail as possible, to represent what has been naturally experienced in the flow reach.

During the specialist workshops the hydrologist presented the time series of flow regimes to assist the other specialists in making decisions about the ecological water requirements and ensuring that they do not set flows that are unrealistic from the point of view of what would be expected to occur in the river under natural conditions.

The outcome of the specialist workshops was the required flows for various scenarios and will include:

- Maintenance low flows expressed in m^3 s-1
- Maintenance high flow events defined as peak flows in m^3 s-1 and durations in days
- Drought low flows expressed in m^3 s-1
- Drought high flow events defined as peak flows in m^3 s-1 and durations in days
- Flood events defined as peak flows in m^3 s-1 and durations in days

The monthly hydrology from the systems model (was supplied by WRP.) for each EWR site (present and naturalised flows) will be used and will be set up in SPATSIM. No additional systems modelling will be undertaken by this study.

This information was relayed to the water resources analysts (systems modellers), who will determine what the impacts that these requirements have on the yield of the catchment.

The Scenario Planning phase was designed to resolve any disparities between the EWR and the required yield and could involve reassessment of the workshop results, redefinition of the EWR assurance rules, a change in management class or considerations and proposals relating to the water supply schemes in the catchment.

Data to be provided:

- cumulative variance of total runoff MAR for each site
- seasonal distribution of simulated monthly naturalised and present day flows at each EWR Site
- whisker-box plots of "virgin" daily averages at each EWR Site
- monthly flow duration curves for “virgin" daily averages at each EWR Site
- flood frequency curves based on annual maxima for each EWR Site
- simulated naturalised monthly flows at selected gauging stations
- simulated present day flows at selected gauging stations

From the above, for the selected critical periods and in conjunction with the specialists requirements, flow-duration curves, exceedance diagrams and flow-stress data will be generated at each of the sites.

7.3 Results

The highest and lowest low flow months selected as the key months are February (wet) and August (dry). The key assurance percentages selected for which stress requirements had to be set were for:

- 95%: Representing droughts for both wet and dry months. This would represent 5% on the stress duration graphs.
- 45%: Representing maintenance flows for both wet and dry months. This would represent 55% on the stress duration graphs.
- Any additional points which had specific significance in terms of flow or stress requirements.

The level of confidence in the hydrology data varied and in many cases the present day data and observed data was used in case of each other.

7.3.1 HAI for EWR16 – Just downstream Bloemhof Dam

The site is located downstream of Bloemhof Dam which was constructed in 19...It is also located close to DWAF gauging weir C9H006 (108 652 km^2 – data for 1937 to 1970) and C9H021 (108 652 km^2 – data for 1970 to 2008). The estimates of HAI based on the simulated data are provided in Table 11. There is a sufficiently long record of observed flows and even though the weir changed in 1970 the data is consistent. The observed flows are seen to be higher than the present day flows when high flows are considered. The seasonality at the site has not been impacted and that is consistent even with the observed flows as shown in Figure 19.

Table 11: HAI details for site EWR16

HYDROLOGY DRIVER ASSESSMENT INDEX		
HYDROLOGY METRICS	RATING	CONFIDENCE
LOW FLOWS	0.00	4.00
ZERO FLOW DURATION	0.00	3.00
SEASONALITY	0.00	4.00
MODERATE EVENTS	5.00	3.00
EVENT HYDROLOGY(HIGH FLOWS-FLOODS)	5.00	3.00

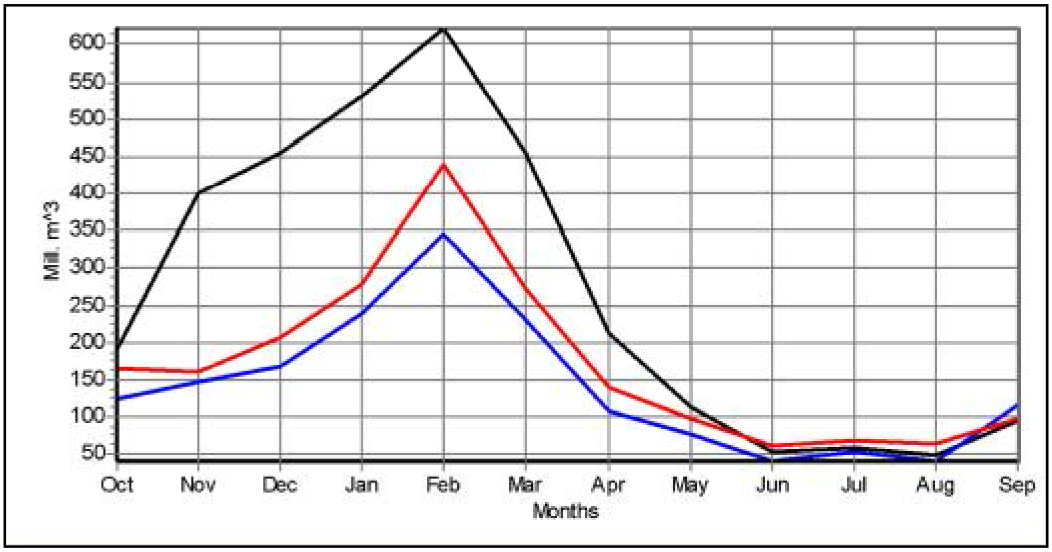


Figure 19: Seasonal distributions (data 1920 to 1994 for Natural and Present Day, 1937 to 1970 for Observed) for site EWR16 (Black = Natural, Blue = Present Day, Red = Observed).

7.3.2 HAI for EWR17 – Lloyds weir on Harts River

There is a DWAF gauging station just downstream of this site, C3H016 (29 370 km² – data for 1994 to 2007). There is a remarkable consistency between the present day and observed flow as seen in Figure 20. Table 12 provides the best estimates of HAI based on these data.

Table 12: HAI details for Site EWR17

HYDROLOGY DRIVER ASSESSMENT INDEX		
HYDROLOGY METRICS	RATING	CONFIDENCE
LOW FLOWS	5.00	4.00
ZERO FLOW DURATION	0.00	3.00
SEASONALITY	0.00	4.00
MODERATE EVENTS	4.00	3.00
EVENT HYDROLOGY(HIGH FLOWS-FLOODS)	4.00	3.00

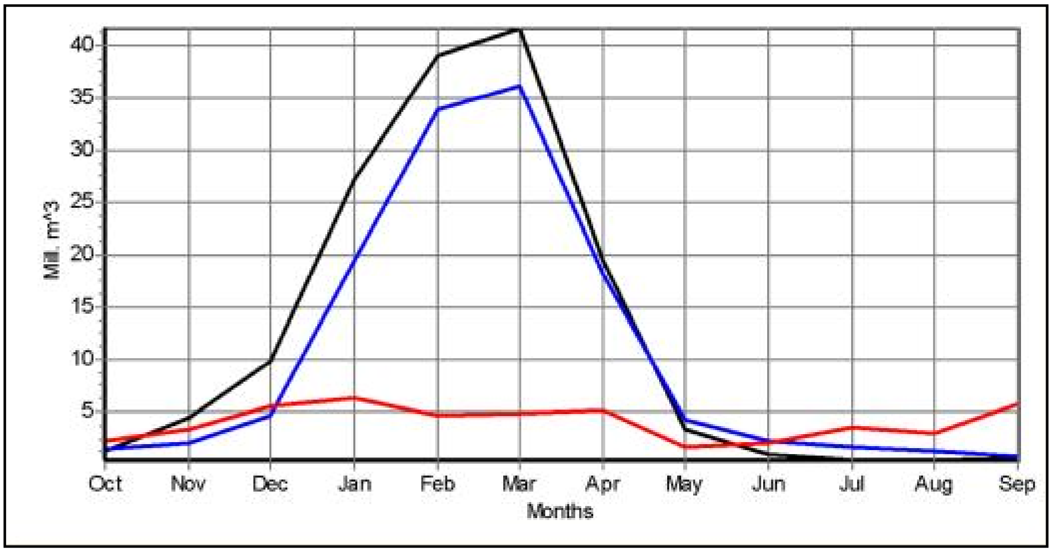


Figure 20: Seasonal distributions (data 1920 to 1994 for Natural and Present Day, 1974 to 2007 for Observed) for site EWR17 (Black = Natural, Blue = Present Day, Red = Observed).

7.3.3 HAI for EWR18 – Schmidtsdrift on Vaal River

The HAI values given in Table 13 and indicate a heavily impacted site with increased runoff, particularly in winter (dry) months. Observed data are available at C9H010 (153 093 km² data from 1974 to 2007) The seasonality rating is set at 0 as observed in Figure 21, which shows no shift in the seasonality of the flows.

Table 13: HAI details for Site EWR18

HYDROLOGY DRIVER ASSESSMENT INDEX		
HYDROLOGY METRICS	RATING	CONFIDENCE
LOW FLOWS	5.00	4.00
ZERO FLOW DURATION	0.00	3.00
SEASONALITY	0.00	4.00
MODERATE EVENTS	5.00	3.00
EVENT HYDROLOGY(HIGH FLOWS-FLOODS)	5.00	3.00

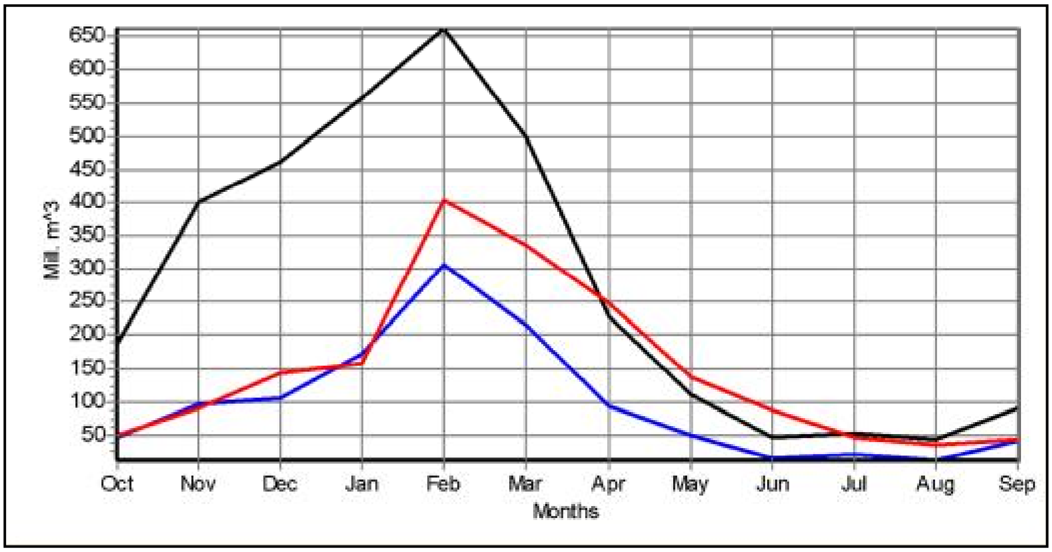


Figure 21: Seasonal distributions (data 1920 to 1994 for Natural and Present Day, 1974 to 2007 for Observed) for site EWR7 (Black = Natural, Blue = Present Day).

7.3.4 HAI for EWR19 – Lilydale Lodge? Riet River

There is a gauging station downstream of the site, C5H016 (33351 km² - data from 1953 to 1999), which indicates a substantial reduction in flows at the site when compared to the present day flows. The observed record is relatively long, however the reliability of the record has not been verified and major peaks show by the present day flow seem not to have been picked up in the observed flows. The estimates of HAI based on the simulated data are provided in Table 14. As observes in Figure 22 there is no indication of a seasonality shift at the site.

Table 14: HAI details for Site EWR19

HYDROLOGY DRIVER ASSESSMENT INDEX		
HYDROLOGY METRICS	**RATING**	**CONFIDENCE**
LOW FLOWS	1.00	4.00
ZERO FLOW DURATION	0.00	3.00
SEASONALITY	0.00	4.00
MODERATE EVENTS	4.00	3.00
EVENT HYDROLOGY(HIGH FLOWS-FLOODS)	5.00	3.00

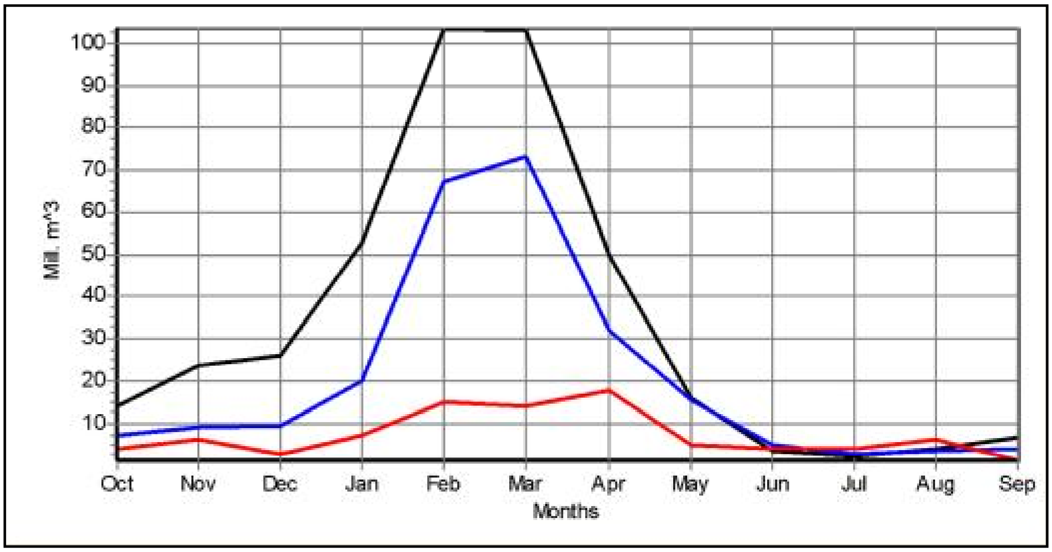


Figure 22: Seasonal distributions (data 1920 to 1995 for Natural and Present Day, 1953 to 1999 for Observed) for site EWR19 (Black = Natural, Blue = Present Day, Red = Observed).

7.3.5 Natural and Present Day flow summary of the EWR sites

The natural MARs as provided by PDNA (Volume 2) are given in Table 15. The final flow requirements are expressed as a percentage of the natural MAR in Table 15.

Table 15: Natural and PD MARs of the EWR sites

Site	Virgin MAR	Present MAR
EWR 16	3242.50	1699.32
EWR 17	147.85	124.72
EWR 18	3347.19	1177.28
EWR 19	403.87	247.67

8 GEOMORPHOLOGY

8.1 Introduction

The availability of hydrological data enabled potential bed material transport (PBMT) modelling to be undertaken at the EWR (Environmental Water Requirement) sites. This modelling usually greatly improves the confidence of flow requirements for geomorphology in bedload dominated rivers, as the results can be used in conjunction with the more traditional methods of using sedimentary and morphological cues to determine EWR requirements for bed and channel maintenance.

8.2 Approach

Flow requirements for the maintenance of channel form, or geomorphology, can generally be determined using one, or a combination, of two possible approaches. The first relies on specialist knowledge and experience to identify alluvial morphological cues at the site and within the reach which are associated with regular flooding return frequencies (such as active, seasonal and ephemeral paired benches and terraces). The second approach uses the catchment hydrology and site-specific hydraulic characteristics to model the long term potential sediment movement within the river to identify so-called geomorphologically effective discharges. These are ranges of flows which are responsible for a disproportionately large amount of the long term sediment transport (geomorphic work) which is happening at the site.

8.2.1 Morphological Cues

The rivers in this study area are very low energy systems. Low shear stresses; even at high flood flows; mean that under natural conditions the ability of the river to flush sediments and scour the bed is very limited. The system is however relatively sediment poor (hence the bedrock bases and lack of mobile larger sediment components), and yields of bedload from the catchment are dampened by the low slopes. These low energy characteristics explain why, even with the highly altered flow regime and grossly elevated baseflows, the islands in these lower reaches have remained relatively stable. This is due to the limited capacity of the river to erode.

The limited availability of bedload; reduction in flood flows; trapping of sediment in the numerous dams and weirs along the main stem and tributaries and high degree of physical anthropogenic bank disturbance (particularly at our EWR sites which have been usually selected at or very close to bridge crossings) means that morphological cues (benches and terraces correlated with significant flood return intervals) are consequently poorly developed or absent.

8.2.2 Sediment Transport Modelling

The form (morphology) of a river channel is dependent on the interaction between the supply of sediment from its catchment, and the ability, or capacity, of that section of the river to transport the sediment it is supplied with. The ability of the river to move sediment is referred to as its sediment transport capacity. Sediment supply and sediment transport capacity interact such that:

- where sediment supply is less than the sediment transport capacity, there is an excess of erosive energy, resulting in net erosion, causing the river channel to erode its bed/banks and incise; but

- where sediment supply is greater than sediment transport capacity, there is an excess of sediment, resulting in net deposition and the development of an aggrading river/floodplain environment.

The interactions described above are generally considered over very long timescales. The Elefantes and Limpopo Rivers in Mozambique are primarily alluvial river systems, meaning that, in the very long term (hundreds to thousands of years), sediment supply is greater than the transport capacity of the river channel.

Over shorter timescales, which are of more interest to river managers (years and decades in southern Africa), studies in southern African rivers have demonstrated that rivers experience periods of metastability or quasistability interrupted by periods of rapid change (Rountree *et al*, 2001; Rountree and Rogers, 2004; Parsons *et al*, 2006). During these timescales, it is the discharge of water and sediment supply that determines channel form. Where changes in these driving factors occur, the channel form will adjust in sympathy with the imposed change. This is of significance as the channel form provides the physical habitat for riverine biota.

Where key sediments are required to be moved or flushed, entrainement velocities required to achieve movement of the key sediments can be derived from the hydraulic data.

8.2.3 Geomorphologically Effective Flows

Geomorphologically effective flows are those discharges that, over the longer term, are responsible for transporting disproportionately larger proportions of the sediment load (relative to their duration). These are essentially the flows that do the most “work” in determining the sediment transport capacity of the channel, and therefore influencing its form.

The calculation of these flows is essentially the sediment transport potential of a particular flow event, multiplied by its duration, which yields its potential contribution to the sediment transport of the system in the long term. The theoretical position taken in these methods is that two sets of discharges are significant in maintaining channel form in southern African rivers:

- a set of gemorphologically effective discharges in the 5-0.1% range on the 1-day daily flow duration curve, which transport a disproportionately large volume of the sediment in the longer term, and

- larger ‘re-set’ flood events such as the flood events of 2000, which can reshape the channel and remove vegetation from the banks and floodplain.

The theoretical basis for these assumptions is presented in Dollar & Rowntree (2003). These methodologies have been used in various ecological flow determination studies in South Africa (e.g. on the Thukela, Elands, Letaba, Waterval and Inkomati Rivers) and Mozambique (e.g. the lower Zambezi River). Whilst it is possible to manage flows in the 5 to 0.1% range of the flow duration curve, the large “re-set” events are not manageable events. The focus of flow requirement assessments is therefore focussed on the 5 to 0.1% range of flows.

The methods employed to determine geomorphologically effective flows for each of the sites are described below. The observed daily flows from nearby gauges, together with the regional slope, rating curves (provided by the hydraulician) and sediment characteristics for the site or reach were used to model potential bed material transport at each site under the recent (over the observed flow record) flow conditions, using Yang’s (Yang, 1973) total load equations to determine the effectiveness of discharges. This modelling technique assumes:

- The bed material sampled at the site is representative of the supply of bed material to the channel (hence potential bed material load as opposed to bed load);

- Bed material sampling can be averaged at each EWR site and used to represent the cross-section;

- The supply of bed material to each EWR site is based on the existing bed material and its size distribution, and is available for transport at all discharges; and that
- Average conditions can be used.

A full, detailed description of the technique can be found in Dollar & Rowntree (2003).

Although the Vaal is not strongly bedload system, maintenance of the bed habitats is important for biota. In this study we focussed on the mobile component of the bed material at each site (since many sites are located on atypical bedrock riffle areas, and most of the large boulders and cobbles are likely to be ***in situ*** weathered material rather than fluvially transported sediment, as evidenced by the angular nature of these larger rocks). This approach was adopted for sites where reliable hydrological (flow) records existed.

8.3 Results

8.3.1 Flood motivations for EWR 16

Although the site is located immediately below a large dam (and thus no sediments are moving through from the upstream reach), the flows set for this site are to maintain the reach. Thus whilst large floods may cause erosion in the sections immediately below the dam; the flows are set to manage the geomorphology of the larger reach.

FLOODS		**GEOMORPHOLOGICAL MOTIVATIONS**	**FREQUENCY**		
Class	**Size (daily avg)**		**PES**	**REC**	**AEC**
IV	500	Effective discharge for fines (>50%) and important for gravel activation and movement.	1:3	1:2	
Confidence:		**Comments**			
2		Flows for geomorphology are set using the results from Potential Bed Material Transport (PBMT) modelling only. High flow hydraulics are reliable for the site, and a long gauge record of observed flows was used to undertake the modelling. No morphological cues exist at the site to verify the effective flow classes identified through the PBMT modelling. Additional uncertainty is introduced because the dam immediately upstream cuts off all bed sediment supply from the upstream catchment, and thus for a section downstream, erosion of the bed and banks will continue until the sediment load is increased through tributary and bed/bank erosion inputs.			

8.3.2 Flood motivations for EWR 17

The site is located on the lower Harts River, but is in the backup zone of the Vaal River. High flow hydraulics are not reliable due to the backup effects of the Vaal; and similarly the sediment characteristics at the site are not representative of the upper reach. Flows for geomorphology have been set using assumed sediment characteristics of reaches upstream of the site, but confidence is extremely low because the hydraulics of these upstream areas are not known.

FLOODS		GEOMORPHOLOGICAL MOTIVATIONS	FREQUENCY		
Class	Size (daily avg)		PES	REC	AEC
I	2	One of the important discharge classes for movement of fines through the channel.	3	4	
II	10	An important discharge class for the movement of fines from the bed of the channel.	2	2	
Confidence:		Comments			
1		VERY low confidence in the flows estimated to maintain and /or improve the geomorphological condition of the site and reach due to - Poor condition of the site, lack of morphological cues or representivity; - Unreliable high flow hydraulics due to backup impacts; and - The unreliable hydrology from the nearest gauge due to the drowning out of the weir during even small (5m3/s) floods.			

8.3.3 Flood motivations for EWR 18

The site is located at the downstream end of the Vaal, and the site is characterised by very low energy conditions (very slow velocities).

FLOODS		GEOMORPHOLOGICAL MOTIVATIONS	FREQUENCY		
Class	Size (daily avg)		PES	REC	AEC
III	120	This flow class would flush out some of the fines from the channel and clean substrates for instream biota.	1:1	1:1	1:1
IV	560	This flow class is the effective discharge for the fines and small gravels at this site, responsible for more than 60% of PBMT over the long term. These	1:3	1:2	1:3

		occasional floods would thus activate the bed of the channel.			
Confidence:		**Comments**			
2		The reliability of the hydrology used to conduct the PBMT is uncertain. A comparison of the two nearest flow gauges shows large discrepancies in flows and especially in the flood sizes and frequencies.			

8.3.4 Flood motivations for EWR 19

The site is located in a steep bedrock gorge section of the river. Most of the bed of the active channel is exposed bedrock (i.e. sediment free), and there is thus is little available sediment in the active channel due to the high energy of the site. The intention for the flows for geomorphology are to maintain the potential energy of the site to keep transporting sediment through the reach and thus prevent excessive sedimentation of the active channels and pools. The very large floods may enable some overtopping an inundation/recharge

FLOODS		**GEOMORPHOLOGICAL MOTIVATIONS**	**FREQUENCY**		
Class	**Size (daily avg)**		**PES**	**AEC up**	**AEC down**
I	2	These frequent small floods will flush out the fines from the active channel. This is the effective discharge class for fines at this site, responsible for 30 to 40% of the PBMT of fines.	5	6	3
III	20	These small floods will flush fines and small gravels from the bed of the active channel, as well as inundate and activate the lower bench at the site.	1	1	1:2
IV	100	These floods will flush scour the active channel bed, removing accumulated sediment from this bedrock reach. This flow class will also inundate the upper bench and activate the seasonal channel at the site.	1:2	1:2	1:3
V	230	These floods will flush scour the active channel bed and lower banks, removing accumulated sediment fines and gravels from this bedrock reach, as well as activating the cobbles in the reach.	1:5 +	1:5 +	1:5 +
Confidence:		**Comments**			
3.5		Some morphological cues are present at the site, and these correlated in many cases with the important flow classes identified through the PBMT modelling. This corroboration of results from two different approaches increased the confidence of the results.			

9 HYDRAULICS

9.1 Introduction

Assessment of the ecological Reserve for rivers required the determination of Environmental Water Requirements (EWR) for protection of aquatic ecosystems. EWR tend to quantify the water needs of the various biotic components in terms of relations between flow magnitude and timing. These relations include the frequency, duration, timing and rate of change of flows, and the specification of flows for the ecological Reserve aims to replicate important aspects of the natural hydrological regime (Hirschowitz et al, 2007).

The results of hydraulic analyses and modelling form the essential link between the way in which the hydrologists, engineers and water managers express the flow of water in the river in terms of flow rate, and the way in which river ecologists express the water requirements of the river ecosystem itself in terms of variables like the flow depth and flow velocity (Birkhead, 2002).

The role of hydraulics and the procedure for generating hydraulic information has been documented for different levels of Reserve determinations (Department of Water Affairs and Forestry, 1999). A procedure for using standard hydraulic information as the basis for quantifying hydraulic habitat has been described by Jordanova et al., 2004. Further development regarding the use of hydraulic information for prediction the abundance and composition of hydraulic habitats has been carried out (Hirschowitz et al, 2007). Habitat-Flow (HABFLO) simulation software has been developed to provide a working model that automates the prediction of habitat-type abundance and composition for fish and macroinvertebrates (Hirschowitz et al, 2007). The model has been used for prediction of hydraulic habitats for fish and macroinvertebrates.

9.2 Approach

The product of the hydraulics work comprises series of relationships between flow rate, and flow depth, flow velocity, wetted perimeter and flow area (Tharme, R.E. & King J.M, 1998). These relationships have to be determined for EWRs cross-sections at each selected site. In order to satisfactorily characterise the hydraulic relationships for Reserve determination study, field data, including discharge, water stage, and slope have to be collected for a range of flows over the hydrological season. Through the hydraulic modelling, using measured cross-sectional and flow data relationships (discharge and flow depth), biologically useful parameters (wetted perimeter, flow area and flow velocity) will be developed. These relationships will be presented graphically and in a tabulated format. The methodology of generating hydraulic information for determining the water quantity component of the Comprehensive Ecological Reserve is based on the RDM for Protection of Water Resources: River Ecosystems, Appendix R 17 (Birkhead, A.L. 2001).

9.3 Results

Surveyed EWR cross-sectional profile for each EWR site is shown in Figure 23 to Figure 26.

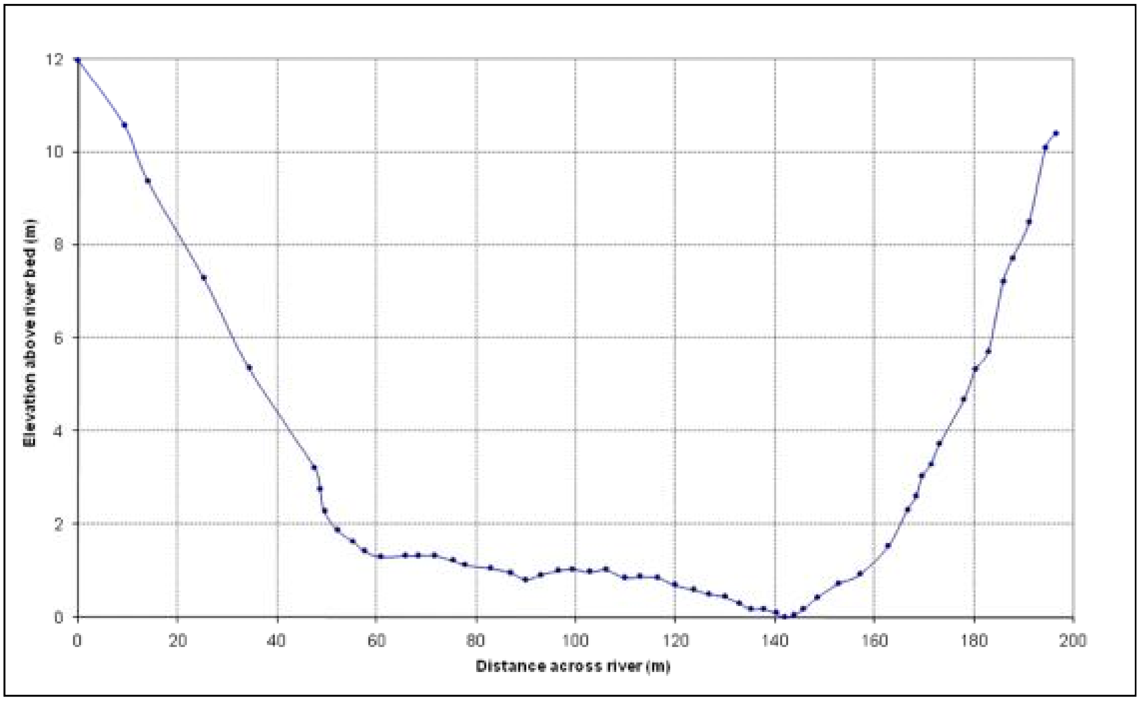


Figure 23: Cross-sectional profile for EWR 16 on the Vaal River.

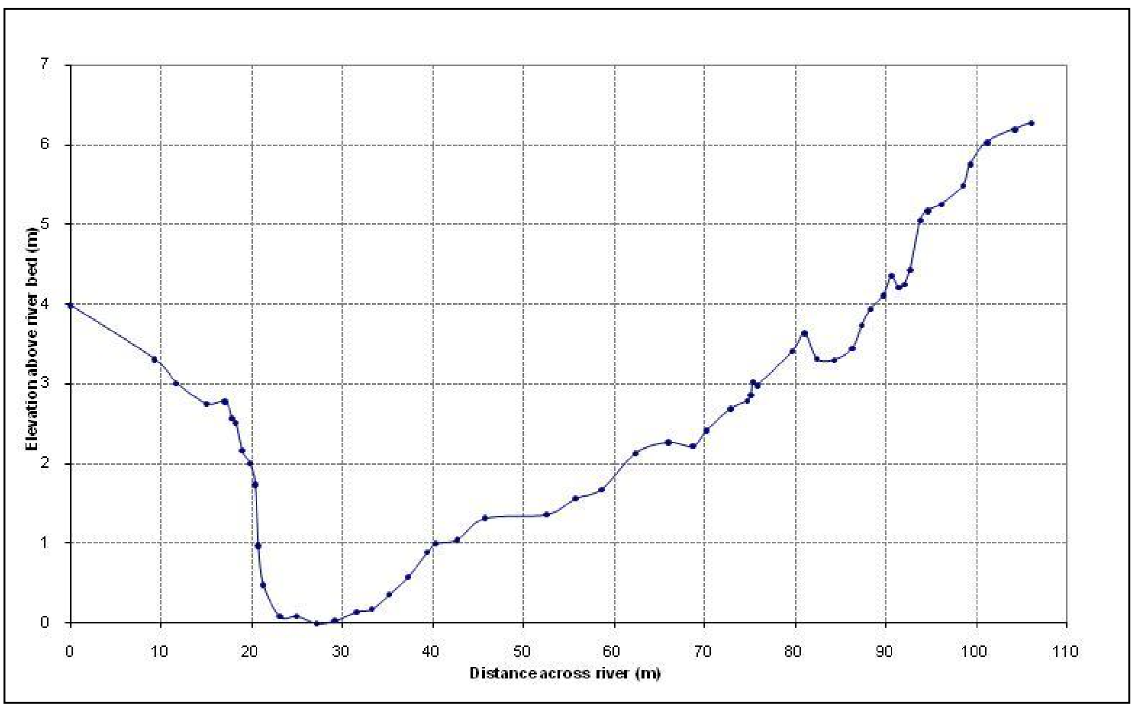


Figure 24: Cross-sectional profile for EWR 17 on the Harts River

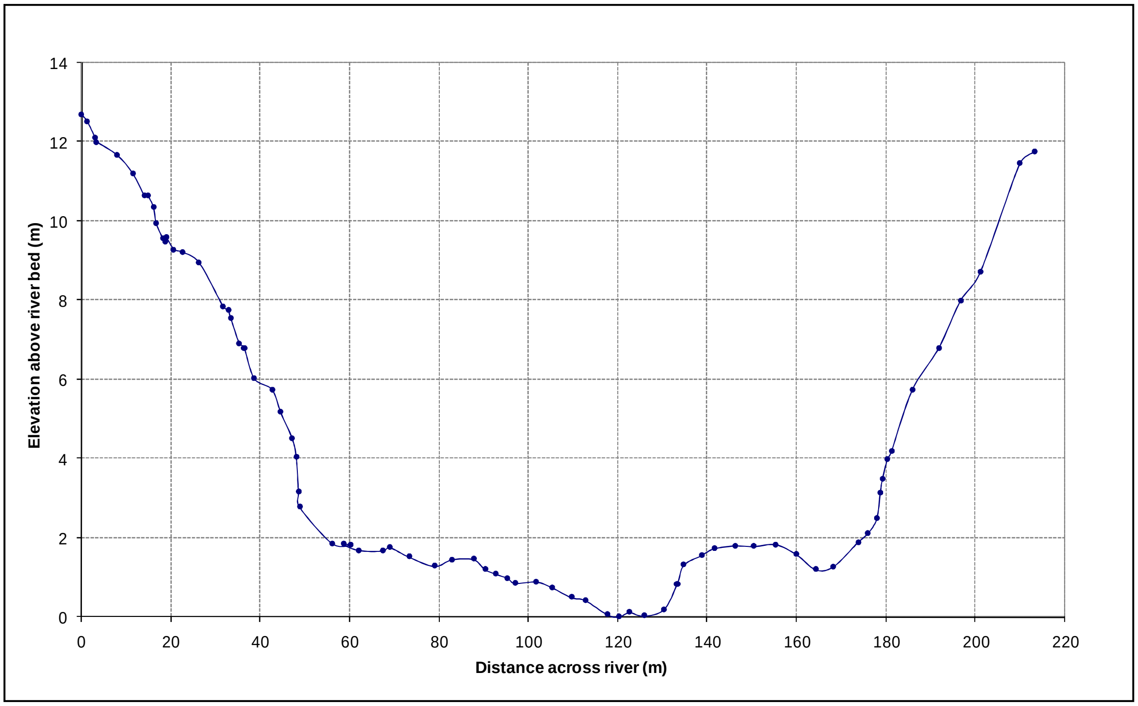


Figure 25: Cross-sectional profile for EWR 18 on the Vaal River

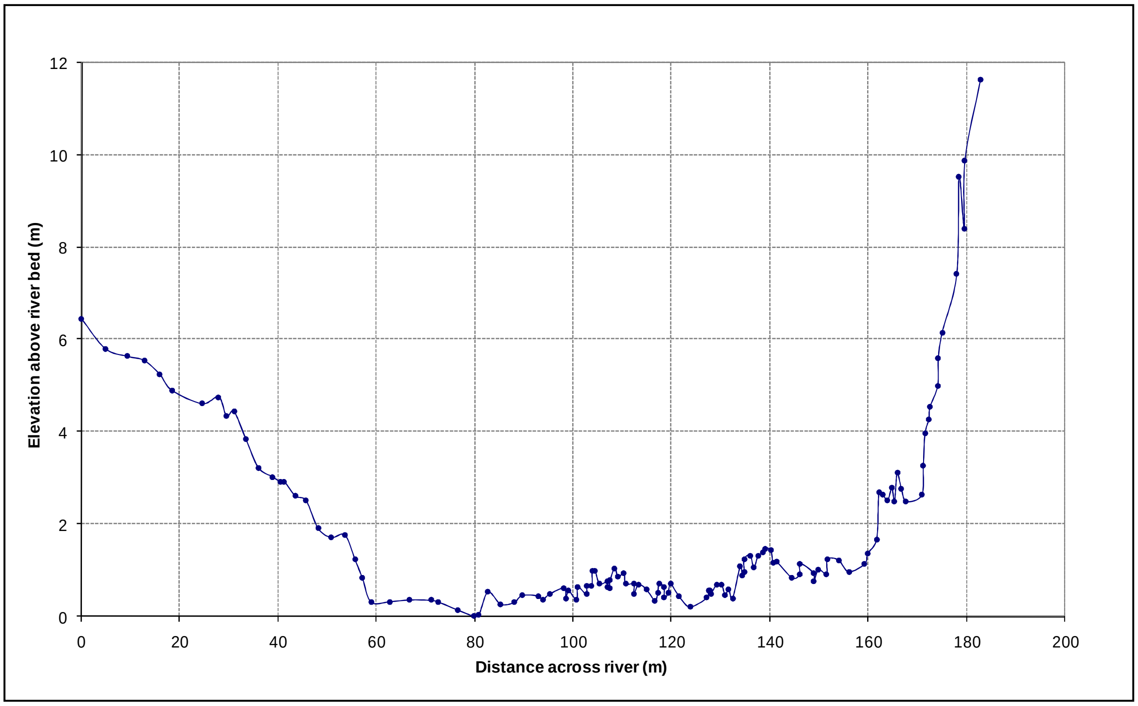


Figure 26: Cross-sectional profile for EWR 19 on the Riet River

9.3.1 Hydraulic data collected

The stage-discharge data collected at the EWR sites together with the dates when the data were collected are provided in Table 16.

Table 16: Hydraulic data collected at EWR sites

River	Site no.	Date	Discharge Q (m^3/s)	Max. flow depth, y (m)
Vaal	EWR 16	26.09.2007	40.89	2.94
		25.08.2008	55.03	2.99
Harts	EWR 17	28.09.2007	1.13	1.05
		25.08.2008	0.89	0.96
Vaal	EWR 18	20.06.2008	4.99	3.14
		26.08.2008	2.11	3.00
Riet	EWR 19	27.09.2007	5.26	0.84
		24.06.2008	4.20	0.77
		26.08.2008	2.55	0.67

10 ECOLOGICAL CLASSIFICATION

10.1 Overview and objectives

EcoClassification (the term used for Ecological Classification) 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/close to natural, reference condition. The purpose of EcoClassification is to gain insights 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 but attainable future ecological objectives for the river. The EcoClassification process also supports a scenario-based approach where a range of ecological endpoints (Ecological Categories) has to be considered. For each of these, a flow (EWR) scenario must be described.

EcoClassification must not be confused with the Classification System as indicated in the National Water Act. The Classification System considers a range of different issues in Integrated Water Resources Management in the process of determining the class of a river, one of which is ecological.

10.2 Method

The following process was applied to each Resource Unit:

- **Reference Conditions**: Reference conditions were described for the main ecological drivers (hydrology, geomorphology and water quality) and ecological responses (riparian vegetation, aquatic invertebrate and fish).
- **Present Ecological State:** The Present Ecological States (PES) for each of the drivers and the responses were assessed, and the results integrated into an overall assessment of PES, referred to as the EcoStatus.

- **Changes in PES**: An assessment was made as to whether the PES is stable under current development conditions, or whether it is changing.
- **Causes and Origins**. The causes and origins for the PES were identified, and specified as flow or non-flow related.
- **Ecological Importance and Sensitivity**: The Ecological Importance and Sensitivity (EIS) of the biota and habitats were assessed.
- **Recommended Ecological Category (REC)**: A realistic Ecological Category was recommended for each component as well as for the overall EcoStatus, based on a consideration of the PES and EIS,
- **Alternative Categories**: Alternative categories, "up" and "down", were identified, where appropriate.

The results of the EcoClassification process were expressed in terms of Ecological Categories (ECs) ranging from Category A (Natural) to Category F (Critically Modified) (Figure 27). The categories represent a range along a continuum, so boundary categories (i.e. Category B/C) represent a condition at the border between Categories B and C. The six-point classification system (A to F) will be converted into a descriptive terminology when applied to Management Classes, which are the output of the Classification System procedures, as referred to in the National Water Act (Act 36 of 1998). The flow diagram, Figure 28, (adapted from DWAF, 2001) illustrates the process.

The results of the process, *i.e.* the PES and EC are provided as different river categories ranging from A (near natural) to F (critically modified). These will be converted to a descriptive terminology (still to be determined, but illustrated as Good, Fair, Poor etc.) when applied to Management Classes that are the output of the Classification System procedures (as referred to in the National Water Act, Act 36 of 1998, which is currently being developed). The interface between ECs and management Classes are provided in Figure 27.

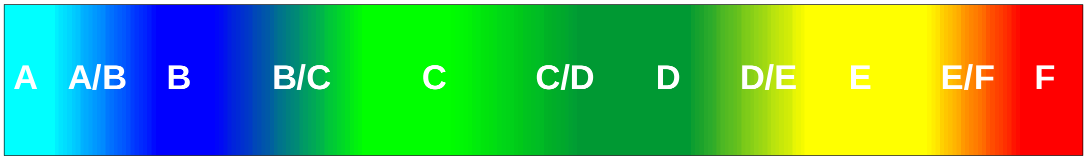


Figure 27: Illustration of the distribution of Ecological Categories (A to F) on a continuum and the relationship with Management Classes

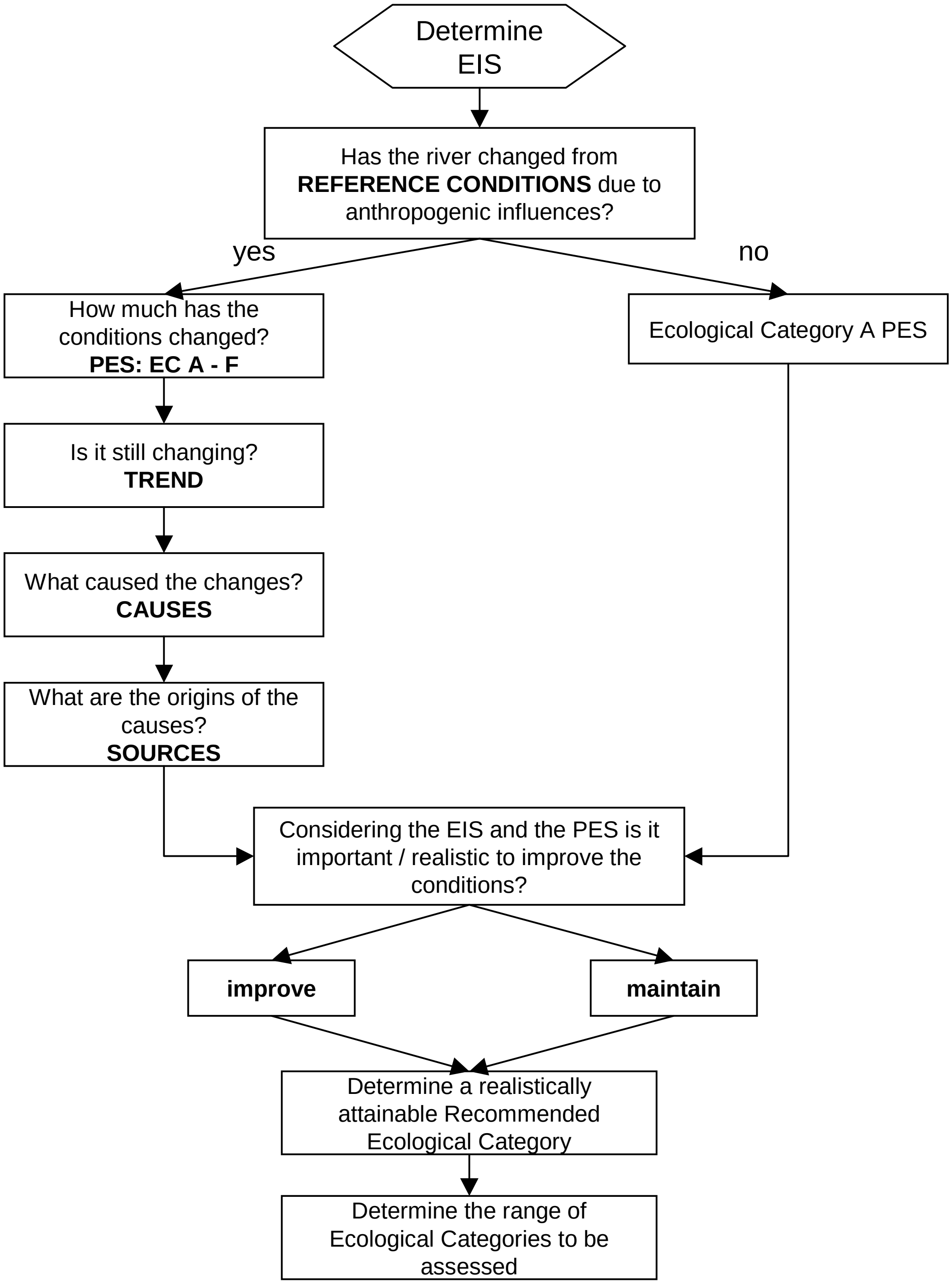


Figure 28: Flow diagram illustrating the information generated to determine the range of ECs for which EWRs will be determined

The range of Ecological Categories (ECs) for which flow scenarios were provided are guided by the rules as shown in Table 17. This must be seen as guidelines to determine a realistic range of ECs, which can be addressed within the scenario-approach.

Table 17: Guidelines for the range of Ecological Categories (ECs) to be addressed

PES	Alternative EC	
	Increase (Up)	Decrease (Down)
A	N/A	N/A
A/B	N/A	B/C
B	N/A	C
B/C	B	C/D
C	B	D
C/D	B/C	D
D	C	N/A
D/E	D	N/A
E	D	N/A
E/F	D	N/A
F	D	N/A

10.3 Results of the ecological classification process

In summary the Eco Status and Ecological Importance and Sensitivity for the Lower Vaal varied and this was due to water quality and flow changes (

EWR 16			
Components	PES	EIS	REC
Hydrology	D	MODERATE	D
Physico-chemical	C		C
Geomorphology	D/E		D/E
Fish	D		D
Invertebrates	D		D
INSTREAM	D		D
Riparian vegetation	E/F		D
ECOSTATUS	E		D

EWR 17			
Components	PES	EIS	REC
Hydrology	D	MODERATE	D
Physico-chemical	D/E		D/E
Geomorphology	D		D
Fish	D		D
Invertebrates	C/D		C/D
INSTREAM	D		D
Riparian vegetation	D		D
ECOSTATUS	D		D

Figure 29). The difficulty in improving the REC is due to the Vaal River system being operated as a water supply scheme for irrigation and drinking water and not for ecological sustainability purposes. The Ecostatus results are summarised in Figure 30.

EWR 16			
Components	PES	EIS	REC
Hydrology	D	MODERATE	D
Physico-chemical	C		C
Geomorphology	D/E		D/E
Fish	D		D
Invertebrates	D		D
INSTREAM	D		D
Riparian vegetation	E/F		D
ECOSTATUS	E		D

EWR 17			
Components	PES	EIS	REC
Hydrology	D	MODERATE	D
Physico-chemical	D/E		D/E
Geomorphology	D		D
Fish	D		D
Invertebrates	C/D		C/D
INSTREAM	D		D
Riparian vegetation	D		D
ECOSTATUS	D		D

EWR 18			
Components	PES	EIS	REC
Hydrology	C	MODERATE	C
Physico-chemical	C		C
Geomorphology	C/D		C/D
Fish	C		C
Invertebrates	C/D		C/D
INSTREAM	C		C
Riparian vegetation	C		C
ECOSTATUS	C		C

EWR 19			
Components	PES	EIS	REC
Hydrology	D	HIGH	C
Physico-chemical	D		C
Geomorphology	C		C
Fish	C		B
Invertebrates	C		B
INSTREAM	C		B
Riparian vegetation	B		B
ECOSTATUS	C		B

Figure 29: Summary of PES, EIS and REC for the EWR sites in the Middle Vaal

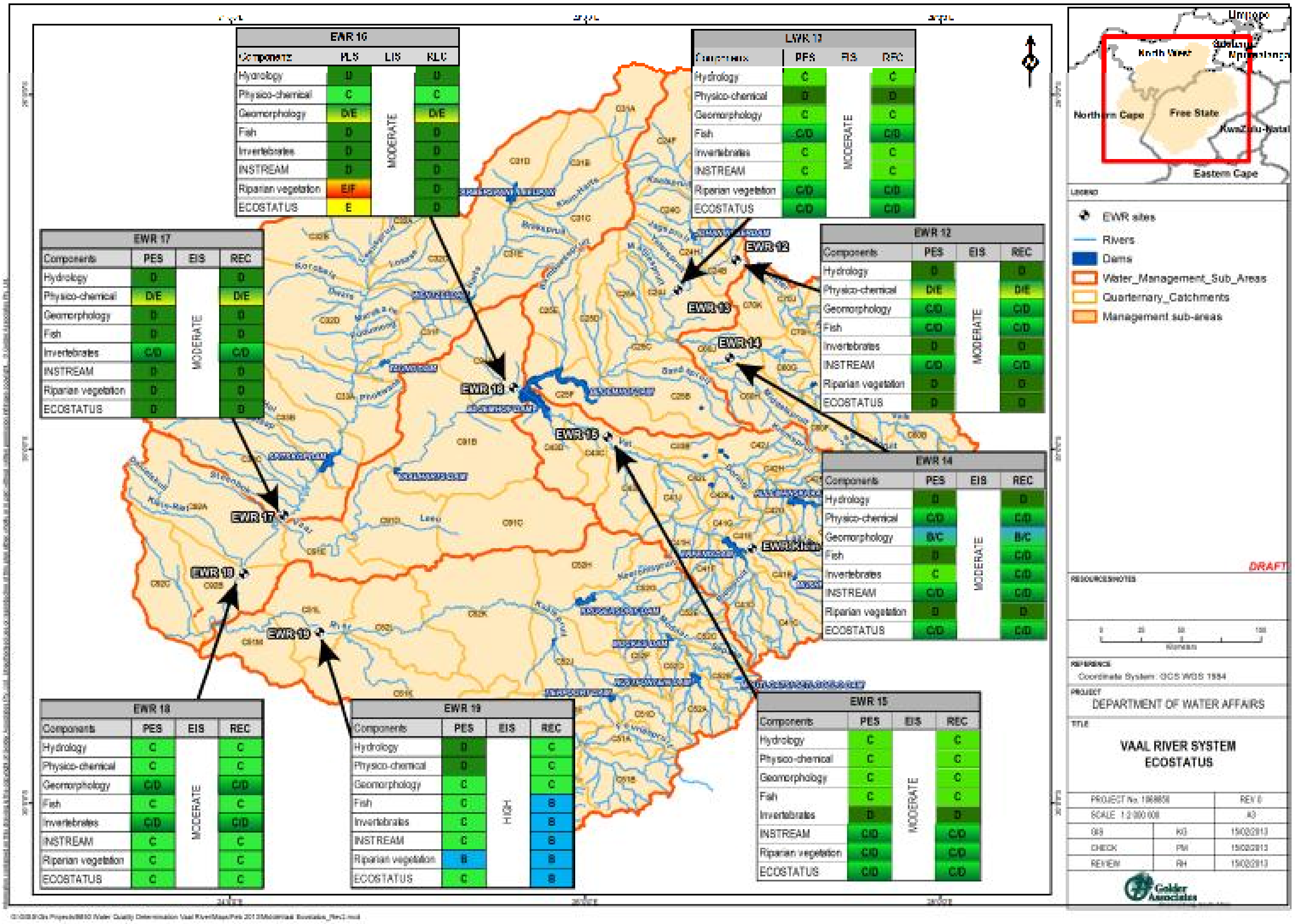


Figure 30: Summary of the Ecostatus of the EWR sites within the Middle and Lower Vaal Catchments

The hydrology of the Lower Vaal WMA is impacted in the main stem of the Vaal by the Vaal Dam, Vaal Barrage (completed in 1919) and Bloemhof Dam. The flow regime in the main stem of the Vaal is impacted by the following:

- Vaal Dam storage
- Releases from Vaal Dam to dilute salts to 600 mg/L TDS (mainly in winter)
- Releases from Vaal Dam and Vaal River Barrage to supply the Vaal Hartz irrigation scheme (completed 1938)
- Interbasin transfers into the Vaal from Lesotho and Grootdraai Dam
- Vaal Hartz irrigation scheme transfer

This altered flow regime has resulted in increased winter base flows in the Lowere Vaal River and smaller floods being reduced in summer.

Due to this regulation having being implemented in varying degrees for 90 years the aquatic organisms have adapted and the river banks are stable.

In the Riet and Harts Rivers the hydrology has changed due to increase irrigation usage, upstream dams and urban requirements. These rivers have less flow in winter as well as summer due to these anthropogenic changes.

11 ECOLOGICAL WATER REQUIREMENTS

11.1 Approach

This section of the report was revised in 2012 after review and is taken from DWA 2012 (report produced by Koekemoer Aquatic Services and Rivers for Africa (Pty) Ltd).

During the reassessment of the Ecological Water Requirement (EWR) scenario results the following constraints in the determination of EWRs were identified:

- Most of the specialists involved in the reassessment of the results were not involved in the Reserve study and therefore did not undertake the biological surveys and have not seen the EWR sites.
- Cross-sections at four key EWR sites (EWR 13, 16, 17 and 18) were placed through pools which resulted in hydraulic modelling results which could not be used.
- The hydraulic look-up tables did not include data with zero discharge in most cases which did not allow for the investigation of discharges which lie in this range. Therefore the lookup tables will not provide information for low flows below the depth of the pools. These depths are required to set low and drought flows in the fast flowing areas such as riffles.

- A range of photos at different discharges of the EWR sites were unavailable. This would have been especially useful at the sites with cross-sections through pools where biomonitoring was undertaken at downstream rapids and riffles.

- EWR sites with flows more than natural are difficult to assess without future scenarios being provided.

- Riparian vegetation indicators and zones were not surveyed at the cross-sections.

11.1.1 EWR Determination: Low Flows

The Habitat Flow Stressor Response method (HFSR) (IWR S2S, 2004; O'Keeffe *et al*., 2002), a modification of the Building Block Methodology (BBM; King and Louw, 1998) was used to determine the low (base) flow EWRs. This method is an accepted DWA method for determining EWRs.

11.1.2 Stress Indices

The basic approach was to set stress indices for fish and macroinvertebrates (referred to as inverts in this report) to aid in the determination of low flow requirements. The stress index describes the consequences of flow reduction on flow dependent biota and was determined by first assessing the response of habitat to flow reduction.

11.1.3 Habitat response

The stress index was described as an instantaneous response of habitat to flow in terms of a 0 to 10 index relevant for the specific site where:

- 0 **-** Optimum habitat with least amount of stress possible for the indicator groups (fixed at the natural maximum base flow which is based on the 10% annual value using separated natural base flows).

- 10 **-** Zero discharge (Note: Surface water may still be present). Maximum stress on indicator group.

- 2 to 9: Gradual decrease in habitat suitability and increase in stress as a result of decreased discharge.

The instantaneous response of fish habitat for spawning and nursery habitat, abundance, cover, connectivity, and water quality were derived by considering (amongst others) rated velocity depth classes (in terms of abundance) to flow changes based on a 0 **-** 5 scale where:

0 = Velocity **-** depth class is absent under the specific flow condition.

1 = Velocity **-** depth class is rare under the specific flow condition.

2 = Velocity **-** depth class is sparse under the specific flow condition.

3 = Velocity **-** depth class occurs moderately under the specific flow condition.

4 = Velocity - depth class occurs abundantly under the specific flow condition.

5 = Velocity - depth class is very abundant under the specific flow condition.

Fish habitat was then rated according to a 0 – 5 scale where:

0 = No habitat available.

1 = Very low occurrence

2 = Low occurrence

3 = Moderate occurrence

4 = Large/Good occurrence

5 = Optimum occurrence

11.1.4 Biotic response

The second step was to determine the biotic stress index which 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 changes of habitat at each stress level (as described in the habitat stress index) was then related to the response of the fish and macroinvertebrate indicators. The biota stress index was described separately for fish and macroinvertebrates. The zero stress, representing optimum habitat, would therefore represent 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 biota response for fish and macroinvertebrates at a range of low flows. The fish and macroinvertebrate stress-flow relationship will not be the same as the responses to the same flow and will/can result in different stress for fish and macroinvertebrates.

11.1.5 Integrated Stress

Due to the constraints mentioned at the beginning of the chapter, a simplified approach was followed whereby the fish stress profile was accepted as the integrated stress profile. The invertebrate stress profile was only used to assess and interpret flow requirements.

11.1.6 Determination of stress requirements

A simplified approach was followed to allow for problems associated with the constraints. The Fish Flow Habitat Assessment (FFHA) model was applied to determine the fish EWR. These flows were then assessed by the invertebrate specialists who either accepted or modified the flows if it was required. Finally the riparian vegetation specialist checked the requirements and verified whether these requirements pose any problems for the vegetation state.

11.1.7 High flows

High flows were not reassessed and the original high flows determined during the Ecological Reserve process were accepted. The high flows are provided in Appendix A with a summary of the approach.

11.1.8 Final flow requirements

The low and high flows were combined to produce the final flow requirements for the Recommended Ecological Category (REC) as:

- An EWR table, which shows the results of high flows and low flows for each month separately. Floods with a frequency higher than 1:1 are included.

- 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). EWR rules are supplied for total flows as well as for low flows only.

The low flow EWR rule table is useful for operating the system, whereas the EWR table must be used for operation of high flows.

11.2 EWR 16 (DS OF BLOEMHOF DAM, VAAL RIVER): DETERMINATION OF STRESS INDICES

The cross-section at EWR 16 was placed through a pool and therefore the hydraulic information of this site is of low confidence. This is extremely problematic in that zero flow does not equate to zero depth. This site was situated below a dam and therefore no upstream sites existed from which results could be extrapolated. More recent data collected in 2010 as part of the ORASECOM biomonitoring study (ORASECOM, 2011a and b) was however available and aided in furthering the understanding of the habitat responses to flow changes.

11.2.1 Fish indicator group

Refer to Section 3.1.1 (EWR 12).

11.2.2 Macroinvertebrate indicator group

Hydropsychidae 2 spp. was used as indicator taxa. This taxa show a strong preference for flows >0.6 m/s, as well as for cobbles and occurred at the site in previous site assessments (2005/11/02, 2007/09/27, 2008/04/03, October 2010).

11.2.3 Stress flow index

The species stress discharges in Table 18 and Table 19 indicate the discharge evaluated by specialists to determine the biota stress.

Table 18: EWR 16: Fish stress index and summarised habitat/biotic responses

Fish stress	**Flow (m^3/s)**	**Habitat and/or biotic responses**
0	88.9	Flow was based on separated base flow of natural hydrology (20% flow duration for wet season month). Habitat suitability will be optimal and comparable to wet season conditions that may have occurred at site under reference (pre-disturbance) conditions.
1	59.3	Habitat suitability close to optimal but slightly reduced due to lower than natural abundance of fast habitats.
2	40.0	Habitat suitability will be very good and meet the requirements of all life stages and processes of the indicator species.
3	30.6	It is estimated that at this flow habitats will become favourable for all life stages and requirements of the indicator species. Optimal conditions have not been reached due to the lower abundance of habitats, as compared to natural expected conditions.
4	22.8	Increased availability (abundance) of fast habitats (especially FD on cross section) will provide more adequate habitats (still of overall moderate suitability) to meet the requirements of the indicator species.
5	16.2	An improvement in overall abundance of fast habitats (especially FD) will result in a notable improvement in the suitability of the habitat for the indicator species. Habitat suitability should be moderate for all aspects considered (spawning, nursery, abundance and cover, connectivity and water quality).
6	9.2	More FD habitats will become available on the cross-section and it can therefore be expected that all fast habitats will be available for fish (FVS to FD) in other areas of the reach. The habitats are however overall still of low suitability for all aspects considered (spawning, nursery habitats, abundance and cover, connectivity and water quality).
7	5.4	According to the hydraulic information, this is the first flow where some fast habitats (FD) will become available on the cross-section. It is therefore estimated that at this flow the habitat suitability will become more favourable for the indicator species. Habitat suitability for spawning will however still be very low while the rest of the habitat requirements are of low suitability.
8	3.2	Habitat suitability will still be very low for all life-stages and requirements of indicator species. According to hydraulics, no fast habitats will be available on cross section, but

Fish stress	Flow (m^3/s)	Habitat and/or biotic responses
		it is again estimated that some fast shallow areas may occur in the reach.
9	2.02	Habitat of very low suitability for spawning, nursery areas, cover, connectivity and water quality and to maintain abundance of indicator species (BKIM). The hydraulic information of this site is of low confidence as the cross-section was done through a pool area (not rapid). Based on hydraulic information, there will be no fast habitat available in the cross-section. It is however estimated that very limited fast habitats may be available in riffle/rapid areas elsewhere in reach.
10	0	Habitat unsuitable to provide for spawning, nursery areas, cover, maintenance of connectivity and water quality of indicator fish species.

Table 19: EWR 16: Invertebrate stress index and summarised habitat/biotic responses

Invertebrate stress	Flow (m^3/s)	Habitat and/or biotic responses
0	88.6	
1	69.9	Ave. velocity 0.26 m/s; max. velocity 0.88 m/s; 5% FCS, 2%VFCS, 1% VEG.
2	40.0	Ave. velocity 0.17 m/s; max. velocity 0.6 m/s; 3% FCS, 1%VFCS, 1% VEG.
3	32.3	Ave. velocity 0.16 m/s; max. velocity 0.54 m/s; 3% FCS, 1% VEG.
4	21.3	Ave. velocity 0.13 m/s; max. velocity 0.45 m/s; 2% FCS, 1% VEG.
5	11.0	Ave. velocity 0.1 m/s; max. velocity 0.34 m/s; 1% FCS.
6	8.3	Ave. velocity 0.09 m/s; max. velocity 0.31 m/s; 1% FCS.
7	4.2	Ave. velocity 0.07 m/s; max. velocity 0.23 m/s; 5% SCS.
8	1.8	Ave. velocity 0.05 m/s; max. velocity 0.18 m/s; 3% SCS.

Invertebrate stress	Flow (m^3/s)	Habitat and/or biotic responses
9	0.6	Ave. velocity 0.04 m/s; max. velocity 0.15 m/s; 3% SCS.
10	0	

11.3 EWR 16 (DS OF BLOEMHOF DAM, VAAL RIVER): DETERMINATION OF EWR SCENARIOS

11.3.1 Ecoclassification summary of EWR 16

Based on the review, the PES determination (DWA, 2010b) for the response components was incorrect. The review resulted in a D in-stream PES however fish was now in a D and not an unacceptable E EC. The final recommendation for the REC was therefore that the in-stream components were maintained at a D EC and that non-flow related measures were implemented to address the problems relating to the deteriorated state of the vegetation component.

The most significant flow related problems were:

- There was a decrease in all the flow components, especially in the moderate to high flows which was mainly due to Bloemhof Dam especially in the wet season.
- Higher flows than natural occurred during drought periods in the dry season months.

The revised EcoClassification results are summarised in the Table 20 below. The ECs in red refer to those that have changed in Category from the Reserve study undertaken during 2007 - 2010.

Table 20: Summary of EcoClassification results

EWR 16			
Components	**PES**	**EIS**	**REC**
Hydrology	D	MODERATE	D
Physico-chemical	C		C
Geomorphology	D/E		D/E
Fish	D		D
Invertebrates	D		D
INSTREAM	D		D
Riparian vegetation	E/F		D*
ECOSTATUS	E		D

*Non-flow related measures to achieve improvements

EWR sites	ECOCLASSIFICATION			
	Original PES	Refined PES	Original REC	Refined REC
EWR 16	Instream D	Modified Instream D	Instream D	Modified Instream D

11.3.2 Hydrological considerations

The driest and wettest months were identified as August and February respectively. Droughts were set at 95% exceedance (flow) and 5% exceedance (stress). Maintenance flows were set at 40% exceedance (flow) and at 60% exceedance (stress). For the application of the DRM the Present Day (PD) hydrology was used as reference hydrology because PD hydrology was higher than natural during the dry season. Refer to Section 4.2 for detailed discussion.

11.3.3 Low flow requirements (In terms of stress)

The stress index was used to identify required stress levels at specific durations for the wet and dry month/season.

11.3.4 Low flow (in terms of stress) requirements

The flow requirements for the PES/REC are provided in Table 20 and graphically illustrated in Figure 31. The results were plotted for the wet and dry season on stress duration graphs and compared to the DRM low flow estimates for the same EC. The stress requirements (as a 'hand drawn line') are illustrated in Figure 31 .Table 21. EWR 16: Species and integrated stress requirements as well as the final integrated stress and flow requirement

Stress Duration	Fish Stress requirement	Fish Flow requirement	Invert Flow requirement	Final* stress requirement	Flow requirement (m^3/s)
Instream PES and REC: D		**FISH: D**		**INVERTEBRATES: D**	
DRY SEASON - AUG					
5%	6.68	6.60	Sufficient flow to maintain invert condition	**6.68**	**6.60**
20%	6.14	8.62		**6.14**	**8.62**
40%	5.62	11.86		**5.62**	**11.86**

WET SEASON - FEB					
5%	6.57	7.00	Sufficient flow to maintain invert condition	**6.57**	**7.00**
20%	4.88	17.00		**4.88**	**17.00**
40%	3.33	28.00		**3.33**	**28.00**

* Final refers to the final stress selected as the EWR requirement, i.e., the lowest stress.

Dry season (August) **Wet season (February)**

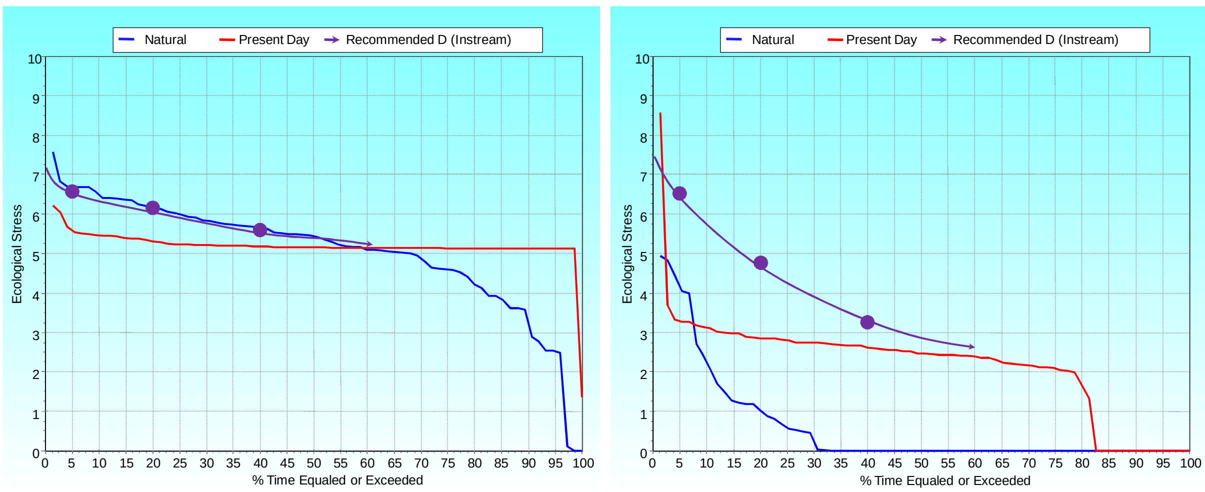


Figure 31: EWR 16: Stress duration curve for a PES and REC

As there was sufficient flow to maintain the invertebrates, **Error! Reference source not found.** provides the summarised motivations for the final requirements of the fish only.

Table 21: EWR 16: Summary of motivations

Month	**% Stress duration**	**Stress**	**Flow (m^3/s)**	**Comment**
Instream PES and REC: D		**FISH: D**		**INVERTEBRATES: D**
Aug	5% drought	6.68	6.6	**Fish:** The flow under present condition is more than under natural conditions (based on hydrology), and hence lower stress levels prevail than under natural conditions. The approach followed was therefore to use the reference stress (flow) as a benchmark to set the dry season drought flows. It is therefore estimated that drought flows could be reduced to the level of natural flows (6.68 m^3/s) but should not be allowed lower than this. This is due to the fact that the other flow durations (lower flow durations) have lower flows under present conditions compared to natural and hence higher stress. The risk

Month	% Stress duration	Stress	Flow (m^3/s)	Comment
				therefore exists that should the stress be increased to more than natural during drought conditions, the overall EC may be reduced. Habitat suitability at this flow is therefore estimated to be adequate to maintain the PES (should the maintenance flows be met).
	40% maintenance	5.62	11.86	**Fish:** As discussed above, the PD flows are higher than under natural condition (in the higher flow duration scale, including 60% and 95% durations). The approach was therefore to use the natural flows as a gauge to determine the maintenance flow to maintain the PES. The flows, and stress level, recommended are therefore close to natural conditions during dry season and should be adequate to maintain the PES. It must however be emphasized that the lower flow durations will follow the present day curve as a guide. Because the recommended flow will be similar to those expected under natural conditions, the habitat suitability for the indicator species at this flow is expected to be more than adequate to maintain the indicator species during the dry season.
Feb	5% drought	6.57	7	**Fish:** A similar scenario as described above for the dry season exists for the wet season drought; there is currently more flow than natural during this flow duration. It was however decided that a lower than natural flow during wet season droughts will be adequate to maintain the low PES of D for fish and invertebrates. A flow of 7 m^3/s during the wet season drought will ensure at least some fast habitats to allow spawning of the indicator fish species guild. Although habitat suitability will be overall low at this flow/stress level, it will be suitable to adequate to maintain the fish in its present state.
	40% maintenance	3.33	28	**Fish:** Although this flow is notably lower than the natural and present day flows (based on hydrology) in the reach, it will still result in very low stress on the habitat of indicator fish species. This stress level will therefore allow for good habitat suitability for all aspects considered for the indicator fish guild. These flows will provide a diversity of habitats and although the fast habitat diversity is not reflected on the cross section (hydraulic) information, it is estimated that other areas in the reach will reflect this composition.

11.3.5 Riparian vegetation flow requirements

The low flow requirements, set by the instream biotic components were checked (and modified if necessary) to ensure that it catered for any riparian vegetation (specifically marginal) requirements.

In the absence of surveyed vegetation data, assumptions were that sedges (*C. longus* and *C. denudatus*) grow in a band along the active channel and will be stable since the profile appeared to be in a pool area, at an elevation above the channel bed of about 2.7 m (as seen from photos – see Figure 32 below). It is possible that important profile detail has been lost due to survey points being far apart and that sedge habitat is not shown on profile, which is evident on the photos. The discharge required to inundate the base of the marginal zone community is 32.4 m^3/s. Flood requirements were not specified originally for vegetation. This was reviewed and details are provided in Appendix A.

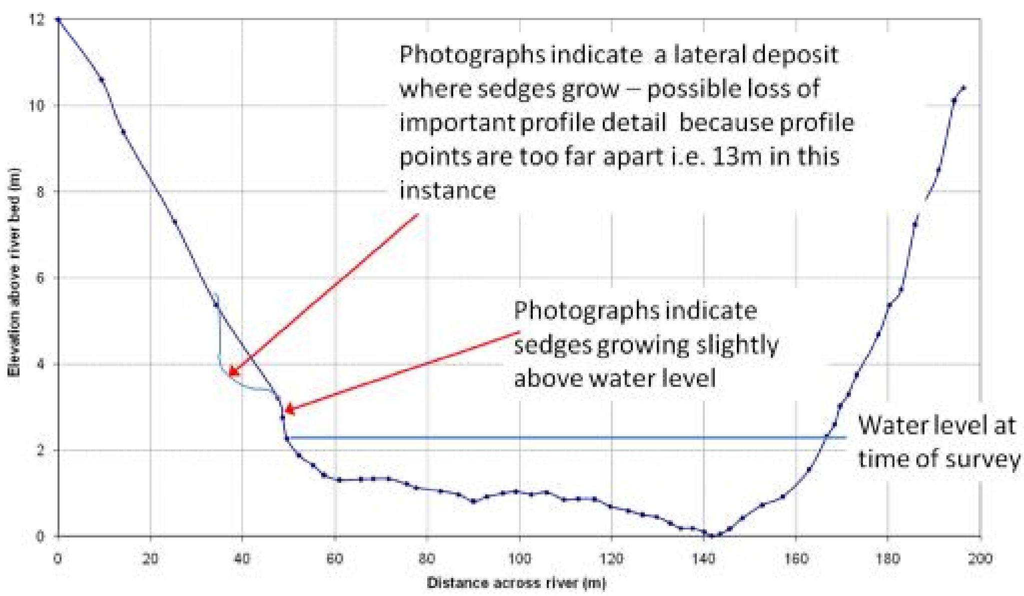


Figure 32: Assumed vegetation distribution at EWR 16

The low flows set by in-stream faunal requirements are provided in Table 22.

Table 22: Verification of low flow requirements for riparian vegetation

Season	Stress	Flow (m^3/s)	Elevation (m)	Comment
Dry (Aug)	6.68	6.60	1.64	Marginal zone vegetation rooting level is approximately 100 cm above water level. Drought stress mortality is expected, especially of higher elevation sedges in the lower zone.
	5.62	11.86	1.94	Marginal zone vegetation rooting level is approximately 70 cm above water level. Flows seem slightly low and will not likely be sufficient to maintain a high proportion of sedge survival, but confidence is low as the position of vegetation has been estimated from a combination of photos and the profile.
Wet (Feb)	6.57	7	1.68	Marginal zone vegetation rooting level is approximately 100 cm above water level. Drought stress mortality is expected, as well as reproductive abortion, especially of higher elevation sedges in the lower

Season	Stress	Flow (m^3/s)	Elevation (m)	Comment
				zone.
	3.33	28	2.6	Marginal and lower zone vegetation is not yet inundated with rooting level at 10 cm above water level. If floods mentioned above occur, then an expansion of vegetation towards the channel will be prevented. Growing season transpiration demands are likely to be met but slightly higher flows of up to 36 m^3/s would better maintain the PES.

11.3.6 Final low flow requirements

To produce the final results, the DRM results for the specific category were modified according to specialists' requirements provided in Figure 33. There are a range of options one can use to make these modifications, such as changing the total volume required for the year, specific monthly volumes, either drought or maintenance flow durations, seasonal distribution and changing the category rules and shape factors. The following changes were required:

Parameter	FEB		AUG	
	DRM	EWR	DRM	EWR
High flow factors	-9	-9	0	0
Low Flow DC Shape	9	5	8	5
DC Upper % Shift	91	98	97	100
DC Lower % Shift	0	20	0	20
DC Low Flow Max.	130	160	130	164
High Flow DC Shape	8	4	8	4

Dry Season (August) **Wet Season (February)**

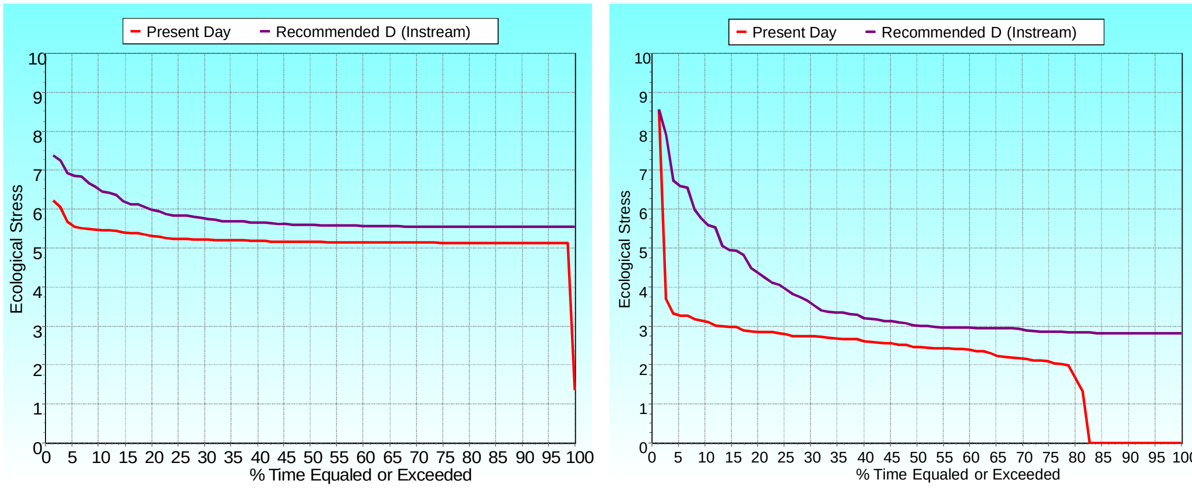


Figure 33: EWR 16: Final stress requirements for low flows

11.3.7 Final flow requirements

As present day (PD) hydrology was used as reference flows in the DRM the comparative percentages of the EWR are provided for both natural (virgin) and PD hydrology. The low and high flows were combined to produce the final flow requirements for the PES/REC EC as:

- An EWR table, which shows the results for each month for high flows and low flows separately (Table 22). Floods with a high frequency are not included in the modelled results as they cannot be managed.

- 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). EWR rules are supplied for total flows as well as for low flows only (Table 23).

The low flow EWR rule table is useful for operating the system, whereas the EWR table must be used for operation of high flows.

Table 23: EWR 16: EWR table (m^3/s) for In-stream PES and REC: D

Desktop version:		**2**	**Virgin MAR (MCM)**	**1699.32**
			Present Day MAR (MCM)	**3242.51**
BFI index	**0.416**	**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	7.753	6.325		
NOVEMBER	8.317	6.785	50	5
DECEMBER	8.534	6.963		
JANUARY	10.119	8.257	50	5
FEBRUARY	13.53	3.412	50	5
MARCH	10.986	8.965	50	5
APRIL	8.675	7.078		
MAY	6.99	5.704		
JUNE	5.775	4.712		
JULY	5.716	4.664		
AUGUST	5.46	4.454		
SEPTEMBER	6.895	5.626		
TOTAL MCM	258.422	192.401	163.814	
% OF VIRGIN	7.97	5.93	5.05	
% OF PD	15.21	11.32	9.64	

Total IFR	422.237
% of VIRGIN MAR	13.02
% of PD MAR	24.85

Table 24: EWR 16: Assurance rules (m^3/s) for In-stream PES and REC: D

Desktop Version 2, Printed on 7/27/2012

Summary of IFR rule curves for: EWR5 (EWR 16)

Determination based on defined BBM Table with site specific assurance rules.

Regional Type: Vaal REC = D

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

	% Points									
Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	20.071	20.071	19.986	19.815	19.481	18.838	17.630	15.462	11.875	7.522
Nov	47.993	27.261	25.814	25.289	24.525	23.939	22.936	21.933	18.587	9.767
Dec	20.397	20.397	20.309	20.129	19.767	19.054	17.691	15.219	11.186	7.047
Jan	51.393	48.547	39.792	38.269	37.765	36.316	33.160	27.419	18.116	9.971
Feb	62.413	52.687	39.063	37.211	35.793	34.553	33.205	32.077	18.941	5.380
Mar	52.098	52.098	28.655	27.856	26.800	25.721	24.783	23.215	20.038	10.754
Apr	22.458	22.458	20.471	19.518	18.507	17.897	16.308	15.139	13.287	8.417
May	18.096	16.327	16.103	15.946	15.479	15.128	14.438	13.878	11.039	7.216
Jun	14.032	14.032	13.973	13.855	13.620	13.166	12.308	10.761	8.211	5.192
Jul	13.094	13.094	13.040	12.933	12.721	12.310	11.534	10.135	7.829	5.098
Aug	12.507	12.507	12.456	12.354	12.151	11.759	11.017	9.681	7.478	4.869

Sep	15.795	15.795	15.728	15.591	15.317	14.778	13.746	11.875	8.822	5.690

Reserve flows without High Flows

Oct	20.071	20.071	19.986	19.815	19.481	18.838	17.630	15.462	11.875	7.522
Nov	19.878	19.878	19.767	19.518	18.997	17.982	16.178	13.373	9.842	7.129
Dec	20.397	20.397	20.278	20.008	19.434	18.304	16.290	13.194	9.456	7.047
Jan	24.185	24.185	24.041	23.712	23.006	21.608	19.117	15.312	10.829	8.357
Feb	32.290	32.290	32.034	31.454	30.221	27.790	23.462	16.807	8.771	3.593
Mar	26.257	26.257	26.104	25.757	25.018	23.563	20.971	16.986	12.174	9.073
Apr	22.458	22.458	20.471	19.518	18.507	17.897	16.308	15.139	13.287	8.417
May	18.096	16.327	16.103	15.946	15.479	15.128	14.438	13.878	11.039	7.216
Jun	14.032	14.032	13.953	13.776	13.405	12.682	11.398	9.401	6.888	4.957
Jul	13.094	13.094	13.001	12.775	12.283	11.347	9.827	7.829	5.882	4.801
Aug	12.507	12.507	12.418	12.202	11.733	10.838	9.387	7.478	5.618	4.585
Sep	15.794	15.794	15.678	15.389	14.752	13.533	11.569	9.056	6.755	5.690

Natural Duration curves

Oct	35.282	34.547	33.961	33.397	32.908	32.560	31.717	30.847	29.159	25.284
Nov	114.715	27.261	25.814	25.289	24.525	23.939	22.936	21.933	20.926	16.667
Dec	128.752	32.463	30.776	29.208	28.383	26.867	25.512	24.895	22.790	16.211
Jan	272.771	108.479	39.792	38.269	37.765	36.932	35.428	34.274	30.746	24.884
Feb	542.493	52.687	39.063	37.211	35.793	34.553	33.205	32.077	30.849	26.025
Mar	204.786	75.000	28.655	27.856	26.800	25.721	24.783	23.215	20.038	12.605
Apr	97.793	23.526	20.471	19.518	18.507	17.897	16.308	15.139	13.291	10.965
May	23.197	16.327	16.103	15.946	15.479	15.128	14.438	13.878	12.306	9.935

Jun	20.212	14.556	14.537	14.460	14.174	13.985	13.750	13.434	12.708	8.816
Jul	17.163	17.152	17.115	17.025	16.935	16.760	16.413	15.905	14.852	12.776
Aug	15.311	15.304	15.252	15.188	15.121	14.957	14.688	14.158	12.944	8.957
Sep	34.155	34.082	33.981	33.804	33.611	33.306	32.762	32.049	30.166	27.041

11.4 EWR 17 (Lloyds Weir, Harts River): Determination of Stress Indices

11.4.1 Indicator species or group

Fish indicator group

Refer to Section 11.2.1.

Macroinvertebrate indicator group

Hydropsychidae 2 spp. was used as indicator taxa and occurred at the site in previous site assessments October 2007, April 2008 (this Reserve study) and March 2010 (river health assessment).

11.4.2 Stress flow index

The species stress discharges in Table 25 and Table 26 indicates the discharge evaluated by specialists to determine the biota stress.

Table 25: EWR 17: Fish stress index and summarised habitat/biotic responses

Fish stress	Flow (m^3/s)	Habitat and/or biotic responses
0	3.6	Value based on separated base flow of natural hydrology (20% flow duration for wet season month). Habitat suitability will be optimal and comparable to wet season conditions that may have occurred at site under reference (pre-disturbance) conditions.
1	3.0	Habitat suitability close to optimal but slightly reduced due to lower than natural abundance of fast habitats.
2	2.4	Habitat suitability will be good to meet the requirements of all life stages and processes of the indicator species.
3	1.9	It is estimated that at this flow habitats will become more favourable for all life stages and requirements of the indicator species.

Fish stress	**Flow (m^3/s)**	**Habitat and/or biotic responses**
4	1.6	Increased availability (abundance) of fast habitats will provide more adequate habitats (still of overall moderate suitability) to meet the requirements of the indicator species. Spawning habitats still expected to be of low suitability.
5	1.3	At this flow, some fast habitats will become available at the cross section and therefore more fast habitats can be expected to become available in the reach. The habitats are however overall still of low suitability for spawning but moderate for all other aspects considered (nursery habitats, abundance and cover, connectivity and water quality).
6	0.9	At this flow, very limited fast habitats will become available in the reach (not on cross section) and therefore create slightly more favourable conditions for the indicator species. The habitats are however overall still of very low to low suitability for all aspects considered (spawning, nursery habitats, abundance and cover, connectivity and water quality).
7	0.4	It is estimated that at this flow some fast habitats will become available that may be of very low suitability for spawning of indicator species. Habitat suitability will still also be very low for creating nursery areas and low for other (abundance, cover, connectivity and water quality) requirements of indicator species.
8	0.3	Habitat still unsuitable for spawning and of very low suitability to provide nursery areas, abundance, cover, connectivity and water quality for indicator species (BAEN). Based on hydraulic information, there will be no fast habitat available in cross-section and it is estimated that there will also not be much suitable fast habitats in other areas of the reach.
9	0.05	Habitat unsuitable for spawning and nursery areas of very low suitability to provide abundance, cover, connectivity and water quality for indicator species. The hydraulic information of this site is of low confidence as the cross-section seems to be through a pool area (not rapid). Based on hydraulic information, there will be no fast habitat available in cross-section and it is estimated that there will also not be suitable fast habitats in other areas of the reach.
10	0	Habitat unsuitable to provide for spawning, nursery areas, cover, maintenance of connectivity and water quality of indicator fish species (BAEN).

Table 26: EWR 17: Invertebrate stress index and summarised habitat/biotic responses

Invertebrate stress	Flow (m^3/s)	Habitat and/or biotic responses
0	3.6	
1	3.1	Ave. velocity 0.14 m/s; max. velocity 0.46 m/s; 2% SCS, 3% VEG.
2	2.8	Ave. velocity 0.13 m/s; max. velocity 0.44 m/s; 2% SCS, 4% VEG.
3	2.3	Ave. velocity 0.11 m/s; max. velocity 0.4 m/s; 2% SCS, 4% VEG.
4	1.9	Ave. velocity 0.1 m/s; max. velocity 0.36 m/s; 2% SCS, 4% VEG.
5	1.4	Ave. velocity 0.09 m/s; max. velocity 0.3 m/s; 2% SCS, 3% VEG.
6	1.2	Ave. velocity 0.08 m/s; max. velocity 0.27 m/s; 1% SCS, 3% VEG.
7	0.7	Ave. velocity 0.06 m/s; max. velocity 0.2 m/s; 1% SCS, 3% VEG.
8	0.3	Ave. velocity 0.03 m/s; max. velocity 0.11 m/s; 2% VEG.
9	0.1	Ave. velocity 0.02 m/s; max. velocity 0.06 m/s; 1% VEG.
10	0	

11.5 EWR 17 (Lloyds Weir, Harts River): Determination of EWR Scenarios

11.5.1 Ecoclassification summary of EWR 17

The review agreed with the report recommendation (DWA, 2010b) that the PES of a D had to be maintained. It must however be noted that the vegetation percentage had changed significantly although in the same category, it was now verging on a D/E PES. Non-flow related measures to address the problems relating to a deteriorating state of the vegetation component have to be addressed. Water quality management is also crucial for the Harts River system as it is an unacceptable D/E PES.

The most significant non-flow related problems were:

- Deteriorated water quality due to mining and WWTW discharge as well as increased nutrients due to agriculture.

The flow regime has been severely impacted on by Spitskop Dam as well as other dams, the interbasin transfer from the Vaal River and irrigation return flows. The present flow in the Harts River is mainly due to irrigation return flows and no other natural flow. The Harts River does not function as an ephemeral river any more. It was therefore recommended that the PD flows were used as reference flows.

The revised EcoClassification results are summarised in the Table 27 below. The ECs in red refer to those that have changed in Category from the Reserve study undertaken during 2007 - 2010.

Table 27: Summary of EcoClassification results

EWR 17			
Components	**PES**	**EIS**	**REC**
Hydrology	D	MODERATE	D
Physico-chemical	D/E		D/E
Geomoprhology	D		D
Fish	D		D
Invertebrates	C/D		C/D
INSTREAM	D		D
Riparian vegetation	D		D
ECOSTATUS	D		D

EWR site	**ECOCLASSIFICATION**			
	Original PES	**Refined PES**	**Original REC**	**Refined REC**
EWR 17	D	Modified D	D	Modified D

11.5.2 Hydrological considerations

The driest and wettest months were identified as August and February respectively. Droughts were set at 95% exceedance (flow) and 5% exceedance (stress). Maintenance flows were set at 40% exceedance (flow) and at 60% exceedance (stress).

11.5.3 Low flow requirements (in terms of stress)

The stress index was used to identify required stress level at specific durations for the wet and dry month/season.

11.5.4 Low flow (in terms of stress) requirements

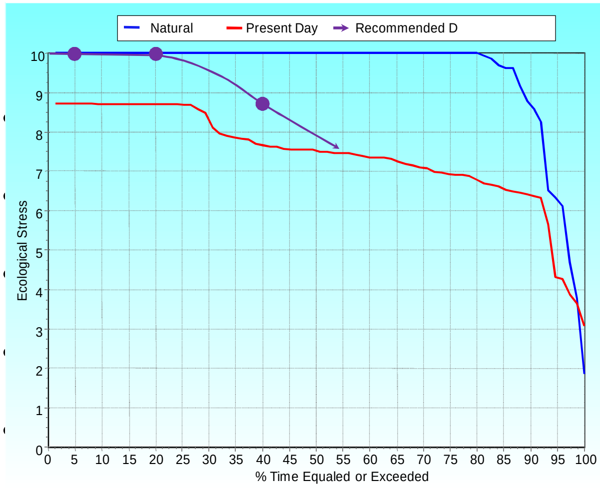
The flow requirements for the D PES/REC are provided in Table 28 and graphically illustrated in Figure 34. The results were plotted for the wet and dry season on stress duration graphs and compared to the DRM low flow estimates for the same EC. The stress requirements (as a 'hand drawn line') are illustrated in Figure 34.

Table 28: EWR 17: Species and integrated stress requirements as well as the final integrated stress and flow requirement

Stress Duration	Fish Stress requirement	Fish Flow requirement	Invert Flow requirement	Final* stress requirement	Flow requirement (m^3/s)
PES and REC: D **FISH: D** **INVERTEBRATES: C/D**					
DRY SEASON - AUG					
5%	10	0	Sufficient flow to maintain invert condition	**10**	**0**
20%	10	0		**10**	**0**
40%	8.78	0.1		**8.78**	**0.1**
WET SEASON - FEB					
5%	8.36	0.2	Sufficient flow to maintain invert condition	**8.36**	**0.2**
20%	6.87	0.5		**6.87**	**0.5**
40%	6.65	0.6		**6.65**	**0.6**

* Final refers to the final stress selected as the EWR requirement, i.e., the lowest stress.

Dry season (August)



Wet season (February)

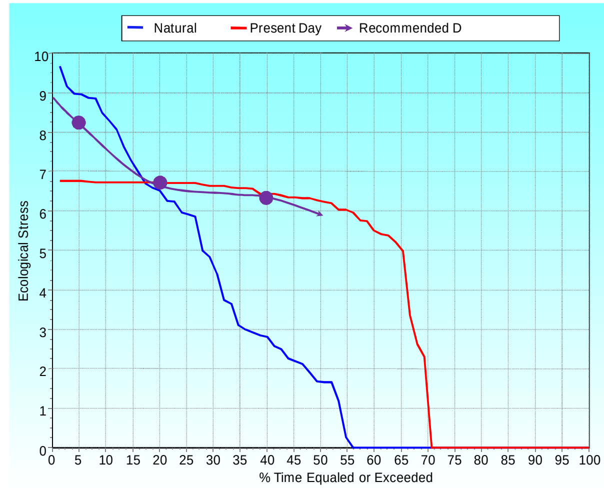


Figure 34: EWR 17: Stress duration curve for a PES and REC

As there was sufficient flow to maintain the invertebrates, Table 29 provides the summarised motivations for the final requirements of the fish only.

Table 29: EWR 17: Summary of motivations

Month	% Stress duration	Stress	Flow (m^3/s)	Comment
PES and REC: D **INVERTEBRATES: C/D**				**FISH: D**
Aug	5% drought	10	0	**Fish:** The present dry season flows at this site is significantly higher than the natural dry season flows for most flow durations. Zero flows occurred naturally during drought conditions (95% flow duration), and therefore it is estimated that current zero flows during droughts should not impact the status of the fish assemblage.
	40% maintenance	8.78	0.1	**Fish:** As discussed above, the present day flows are higher than the natural flows in the dry season. Under natural conditions, zero flows occurred even under maintenance flows (60% flow duration). It was however decided to not recommend zero flows for present day dry season maintenance flows. This was because should the Harts River have dried out completely (no pools for refuge), there would have been connectivity between the Vaal River and the Harts River (no migration barriers). Fish would therefore have been able to recolonise the Harts River from the Vaal River should this scenario have occurred (which is probably based on the natural hydrology). Under present conditions migration barriers (weirs, dam walls) may prevent recolonisation, and therefore it is recommended that some maintenance flows should be

Month	% Stress duration	Stress	Flow (m^3/s)	Comment
				catered for to ensure the maintenance of some refuge areas (pools).
Feb	5% drought	8.36	0.2	**Fish:** The above mentioned scenario is also valid for the wet season drought flows, where there are currently more flows than under natural conditions. The recommended flows is therefore lower than under present conditions but still higher than natural, to reduce the potential impact of increased stress (less flow than natural) during the maintenance periods. The recommended flows will still result in very high stress levels on the indicator species during the wet season droughts, but should be adequate to maintain the fish in the PES under drought conditions.
	40% maintenance	6.65	0.6	**Fish:** The present day maintenance flows are notably lower than under natural conditions. Flows could therefore not be reduced much from the present day flows to ensure that the fish remains in its PES. At the recommended flow, the fish guild will be under relatively high stress, but adequate habitats should be available to allow for all requirements of the indicator species in terms of spawning, nursery, cover, abundance, connectivity and water quality and maintenance in the PES.

11.5.5 Riparian vegetation flow requirements

The low flow requirements, set by the instream biotic components were checked (and modified if necessary) to ensure that it catered for any riparian vegetation (specifically marginal) requirements.

Both reeds and grasses appeared to be growing at or just below the water's edge when the survey was done (as appeared on site photos). This puts the marginal zone vegetation lower limit at about 0.95 m above the channel bed, but it may also be lower (Figure 35). The discharge required to inundate this level is 0.79 m^3/s. The prevalence of high density aquatic vegetation (*Ceratophyllum* spp.) at the site also indicated the perennial availability of water in the channel (flowing or non-flowing).

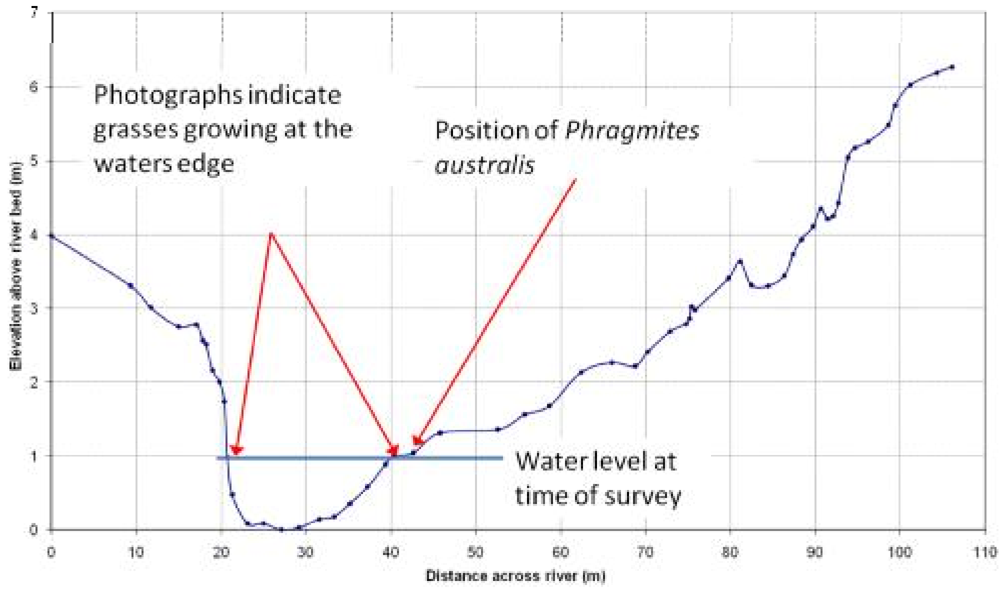


Figure 35: Assumed vegetation distribution at EWR 17

The low flows set by in-stream faunal requirements are provided in Table 30.

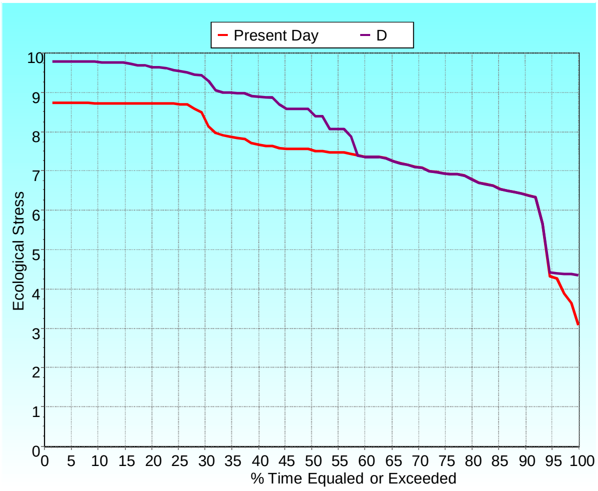
Table 30: Verification of low flow requirements for riparian vegetation

Season	Stress	Flow (m^3/s)	Elevation (m)	Comment
Dry (Aug)	10	0	0.14	Marginal zone vegetation rooting level is approximately 80 cm above water level. Drought stress mortality is expected, especially of higher elevation grasses in the lower zone, and some peripheral aquatic vegetation.
	8.78	0.1	0.57	Marginal zone vegetation rooting level is approximately 35 cm above water level. Flows seem slightly low but will likely be sufficient to maintain a high proportion of marginal zone vegetation survival.
Wet (Feb)	8.36	0.2	0.68	Marginal zone vegetation rooting level is approximately 25 cm above water level. Drought stress mortality is not expected, and reproductive abortion will be low.
	6.65	0.6	0.9	Marginal and lower zone vegetation is slightly inundated with rooting level at or just below water level. Growing season transpiration demands will be met and the PES will be maintained.

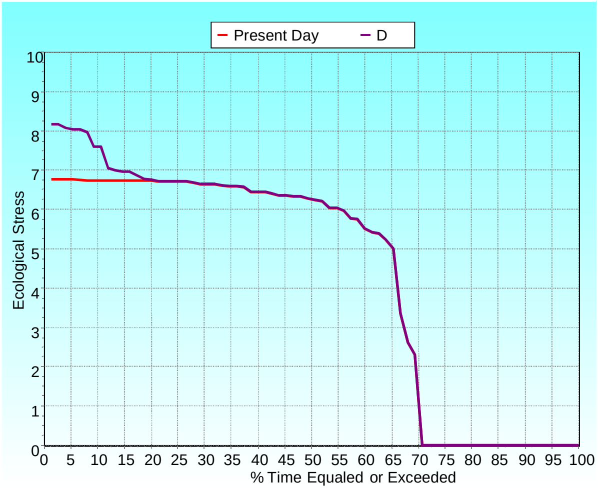
11.5.6 Final low flow requirements

To produce the final results, the DRM results for the specific category were modified according to specialists' requirements Figure 36. There are a range of options one can use to make these modifications, such as changing the total volume required for the year, specific monthly volumes, either drought or maintenance flow durations, seasonal distribution and changing the category rules and shape factors. The following changes were required:

Parameter	FEB		AUG	
	DRM	EWR	DRM	EWR
High flow factors	-9	-9	0	0
Low Flow DC Shape	9	10	11	10
DC Upper % Shift	83	99	97	97
DC Lower % Shift	0	0	0	0
DC Low Flow Max.	143	95	157	78
High Flow DC Shape	11	11	11	18



Dry Season (August)



Wet Season (February)

Figure 36: EWR 17: Final stress requirements for low flows

11.5.7 Final flow requirements

The low and high flows were combined to produce the final flow requirements for each EC as:

- An EWR table, which shows the results for each month for high flows and low flows separately (Table 31). Floods with a high frequency are not included in the modelled results as they cannot be managed.

- 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). EWR rules are supplied for total flows as well as for low flows only (Table 31).

The low flow EWR rule table is useful for operating the system, whereas the EWR table must be used for operation of high flows.

Table 31: EWR 17: EWR table (m^3/s) for PES and REC: D

Desktop version:		**2**	**Virgin MAR (MCM)**	**147.85**
			Present Day MAR (MCM)	**124.72**
BFI index	**0.236**	**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	1.5	0.001		
NOVEMBER	2	0.001	3 8 3	5 7 5
DECEMBER	2.5	0.001		
JANUARY	3	0.001		
FEBRUARY	5.5	0.201		
MARCH	5	0.001	3 8 3	5 7 5

APRIL	4	0.001		
MAY	3	0.001		
JUNE	2.5	0.001		
JULY	2	0.001		
AUGUST	1.5	0.001		
SEPTEMBER	1	0.001		
TOTAL MCM	87.48	0.515	19.723	
% OF VIRGIN	59.17	0.35	13.34	
% OF PD	70.14	0.41	15.81	
Total IFR	107.203			
% of VIRGIN MAR	72.51			
% of PD MAR	85.95			

Table 32: EWR 17: Assurance rules (m^3/s) for PES and REC: D

Desktop Version 2, Printed on 2012/10/29

Summary of IFR rule curves for: EWR6 Generic Name (EWR 17)

Determination based on defined BBM Table with site specific assurance rules.

Regional Type: Vaal REC = D

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

% Points

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.646	0.407	0.399	0.396	0.396	0.285	0.133	0.061	0.029	0.017
Nov	1.752	0.516	0.401	0.386	0.382	0.378	0.378	0.378	0.376	0.374

Dec	3.118	1.296	0.694	0.597	0.564	0.545	0.366	0.148	0.052	0.021
Jan	3.776	3.584	2.307	1.090	0.851	0.780	0.458	0.170	0.050	0.025
Feb	7.239	6.843	5.560	1.128	0.790	0.695	0.608	0.532	0.317	0.246
Mar	10.503	9.817	4.406	2.285	0.728	0.590	0.362	0.276	0.246	0.240
Apr	5.182	4.891	3.434	1.377	0.775	0.255	0.120	0.104	0.101	0.062
May	1.527	1.191	0.810	0.743	0.646	0.523	0.067	0.066	0.064	0.053
Jun	0.961	0.849	0.752	0.698	0.648	0.292	0.122	0.052	0.026	0.020
Jul	0.904	0.758	0.680	0.627	0.405	0.178	0.077	0.036	0.021	0.016
Aug	0.732	0.579	0.429	0.385	0.191	0.080	0.035	0.018	0.012	0.010
Sep	0.428	0.266	0.158	0.154	0.154	0.068	0.029	0.014	0.009	0.008

Reserve flows without High Flows

Oct	0.646	0.407	0.399	0.396	0.396	0.344	0.165	0.074	0.034	0.018
Nov	1.752	0.516	0.401	0.386	0.382	0.378	0.306	0.133	0.054	0.024
Dec	3.108	1.296	0.694	0.597	0.564	0.545	0.282	0.113	0.043	0.021
Jan	3.765	3.531	2.307	1.090	0.851	0.780	0.344	0.127	0.042	0.025
Feb	7.259	6.933	5.560	1.128	0.790	0.695	0.608	0.570	0.348	0.246
Mar	6.381	6.022	4.406	2.285	0.728	0.590	0.362	0.276	0.106	0.042
Apr	5.182	4.891	3.434	1.377	0.775	0.255	0.120	0.104	0.101	0.062
May	1.527	1.191	0.810	0.743	0.646	0.523	0.067	0.066	0.064	0.053
Jun	0.961	0.849	0.752	0.698	0.648	0.359	0.151	0.062	0.029	0.020
Jul	0.904	0.758	0.680	0.627	0.475	0.215	0.093	0.042	0.022	0.016
Aug	0.732	0.579	0.429	0.385	0.191	0.080	0.035	0.018	0.012	0.010
Sep	0.428	0.266	0.158	0.154	0.154	0.082	0.034	0.016	0.009	0.008

Natural Duration curves

Oct	0.646	0.407	0.399	0.396	0.396	0.395	0.392	0.392	0.392	0.388
Nov	1.752	0.516	0.401	0.386	0.382	0.378	0.378	0.378	0.376	0.374
Dec	3.805	1.296	0.694	0.597	0.564	0.545	0.541	0.541	0.538	0.537
Jan	19.609	6.870	2.307	1.090	0.851	0.780	0.765	0.754	0.752	0.750
Feb	28.807	19.742	5.560	1.128	0.790	0.695	0.608	0.570	0.563	0.561
Mar	29.514	13.534	4.406	2.285	0.728	0.590	0.362	0.276	0.246	0.240
Apr	23.646	9.383	3.434	1.377	0.775	0.255	0.120	0.104	0.101	0.099
May	1.527	1.191	0.810	0.743	0.646	0.523	0.067	0.066	0.064	0.063
Jun	0.961	0.849	0.752	0.698	0.648	0.579	0.421	0.062	0.061	0.059
Jul	0.904	0.758	0.680	0.627	0.586	0.564	0.444	0.093	0.091	0.090
Aug	0.732	0.579	0.429	0.385	0.362	0.343	0.258	0.119	0.117	0.115
Sep	0.428	0.266	0.158	0.154	0.154	0.154	0.152	0.150	0.150	0.147

11.6 EWR 18 (Schmidtsdrift, Vaal River): Determination of Stress Indices

The cross-section at EWR 18 was placed through a pool and therefore the hydraulic information of this site is of low confidence. This is extremely problematic in that zero flow does not equate to zero depth. No upstream sites existed from which results could be extrapolated. More recent data collected in 2010 as part of the ORASECOM biomonitoring study (ORASECOM, 2011a and b) was however available and aided in furthering the understanding of the habitat responses to flow changes.

11.6.1 Indicator species or group

Fish indicator group:

Refer to 11.2.1.

Macroinvertebrate indicator group:

Hydropsychidae 2 spp. was used as indicator taxa (refer to Section 3.1.3). This taxa has occurred at the site during 2012 river health surveys, as well as within the reach between Schmitsdrift and Douglas, between 2004 and 2012 (Rivers Database data). However, this taxa was not found during the two Reserve assessments for this study.

11.6.2 Stress flow index

The species stress discharges in Table 33 and Table 34 indicate the discharge evaluated by specialists to determine the biota stress.

Table 33: EWR 18: Fish stress index and summarised habitat/biotic responses

Fish stress	Flow (m^3/s)	Habitat and/or biotic responses
0	91.7	Value based on separated base flow of natural hydrology (20% flow duration for wet season month). Habitat suitability will be optimal and comparable to wet season conditions that may have occurred at site under reference (pre-disturbance) conditions.
1	52.7	Habitat suitability close to optimal but slightly reduced due to lower than natural abundance of fast habitats.
2	32.3	Habitat suitability will be very good to meet the requirements of all life stages and processes of the indicator species.
3	23.7	Maximum velocities on the cross section will reach approximately 0.25 m/s. It is estimated that at this flow habitats will become favourable for all life stages and requirements of the indicator species. Optimal conditions have not been reached due to the lower abundance of habitats, as compared to natural expected conditions.
4	17.8	Maximum velocities on the cross section will reach approximately 0.2 m/s. Increased availability (abundance) of fast habitats elsewhere in reach will provide more adequate habitats (still of overall moderate suitability) to meet the requirements of the indicator species.
5	14.3	According to the hydraulic information, at this flow maximum velocity will reach at least 0.1 m/s (on the cross section). An improvement in overall abundance of fast habitats in the reach will result in a notable improvement in the suitability of the habitat for the indicator species. Habitat suitability will however still be low for spawning but moderate for all other aspects considered (nursery, abundance and cover, connectivity and water quality).
6	9.5	According to the hydraulic information, at this flow maximum velocity will reach at least 0.1 m/s (on the cross section). It is therefore estimated that at this flow the habitat suitability will become more favourable for the indicator species as more fast habitats will become available elsewhere in the reach. Habitat suitability for spawning will however still be very low while the rest of the habitat requirements are of low suitability.

Fish stress	Flow (m^3/s)	Habitat and/or biotic responses
7	5.8	It is therefore estimated that at this flow the habitat suitability will become slightly more favourable for the indicator species as more fast habitats will become available elsewhere in the reach (not on cross section based on hydraulic information). Habitat suitability for spawning will however still be very low while the rest of the habitat requirements are of low suitability.
8	3.6	Habitat suitability will still be very low for all life-stages and requirements of indicator species. According to hydraulics, no fast habitats will be available on cross section, but it is again estimated that some fast shallow areas may occur elsewhere in the reach under this flow.
9	1.5	Habitat unsuitable to meet spawning requirements and of very low suitability for nursery areas, cover, connectivity and water quality and to maintain abundance of indicator species (BKIM). The hydraulic information of this site is of low confidence as the cross-section was done through a pool area (not flow sensitive section such as rapid or riffle). Based on hydraulic information, there will be no fast habitat available in cross-section. It is however estimated that very limited fast habitats may become available in riffle/rapid areas elsewhere in reach under these flows.
10	0	Habitat unsuitable to provide for spawning, nursery areas, cover, maintenance of connectivity and water quality of indicator fish species (BKIM).

Table 34: EWR 18: Invertebrate stress index and summarised habitat/biotic responses

Invertebrate stress	Flow (m^3/s)	Habitat and/or biotic responses
0	91	
1	84.7	Ave. velocity 0.1 7m/s; max. velocity 0.61 m/s; 6% SCS, 1%FCS, 1% VEG.
2	56.4	Ave. velocity 0.13 m/s; max. velocity 0.44 m/s; 6% SCS, 1%FCS, 1% VEG.
3	39.3	Ave. velocity 0.1 m/s; max. velocity 0.34 m/s; 2% SCS, 1% VEG.
4	33.9	Ave. velocity 0.08 m/s; max. velocity 0.31 m/s; 1% SCS, 1% VEG.

Invertebrate stress	Flow (m^3/s)	Habitat and/or biotic responses
5	26.8	Ave. velocity 0.07 m/s; max. velocity 0.25 m/s; 1% SCS, 1% VEG.
6	19.3	Ave. velocity 0.05 m/s; max. velocity 0.2 m/s; 1% SCS, 1% VEG.
7	11.4	Ave. velocity 0.04 m/s; max. velocity 0.13 m/s; 1% SCS, 1% VEG.
8	7.8	Ave. velocity 0.03 m/s; max. velocity 0.1 m/s; 1% VEG.
9	1.7	Ave. velocity 0.01 m/s; max. velocity 0.03 m/s; 1% VEG.
10	0	

11.7 EWR 18 (Schmidtsdrift, Vaal River): Determination of EWR Scenarios

11.7.1 Ecoclassification summary of EWR 18

Based on the review, the vegetation component was in a better condition than determined during the Reserve study (DWA, 2010b). This resulted in a C PES EcoStatus. Due to the moderate EIS the REC was set to maintain the PES.

The most significant flow related problems were:

- Reduced base flows and moderate and other flood events occurred at the site. This was mainly due to the operation of the lower part of the Vaal River system to only release adequate water from Bloemhof Dam to satisfy the user needs with little or no spills at Douglas Weir to the Orange River. This resulted in dry season flows being significantly less than natural.

The most significant non-flow related problems were:

- Deteriorated water quality due to mining discharge as well as increased nutrients due to agriculture.

The revised EcoClassification results are summarised in the Table 35 below. The ECs in red refer to those that have changed in Category from the Reserve study undertaken during 2007 - 2010.

EWR 18			
Components	**PES**	**EIS**	**REC**
Hydrology	C	MODERATE	C
Physico-chemical	C		C
Geomorphology	C/D		C/D
Fish	C		C
Invertebrates	C/D		C/D
INSTREAM	C		C
Riparian vegetation	C		C
ECOSTATUS	C		C

Table 35: Summary of EcoClassification results

EWR site	ECOCLASSIFICATION			
	Original PES	Refined PES	Original REC	Refined REC
EWR 18	C/D	C	C/D	C

11.7.2 Hydrological considerations

The driest and wettest months were identified as August and February respectively. Droughts were set at 95% exceedance (flow) and 5% exceedance (stress). Maintenance flows were set at 40% exceedance (flow) and at 60% exceedance (stress).

The modelled present day hydrology appeared to be very low especially during the wet season where the 60^{th} percentile (maintenance flows) were between 1 and 2 m^3/s. A discussion with the hydrologist (Susan Swart, *pers. comm.*) led to the conclusion that there was likely to be low confidence in the modelled present day hydrology and that there was possibly more water in the system than modelled. This was due to various factors, amongst others the abstraction to the Vaal Gamagara transfer which was included in the modelling as the full allocation without verification of what was actually being used. The observed data from Schmidtsdrift gauge (C9H024) was then investigated. Even with the limited data (1995 – 2007) available for this gauge, flow hardly ever dropped to the levels indicated by the modelled data during the wet season. Based on this information, flows were set higher than present day modelled data during the wet season. This was done not because the objective was to improve the EC, but to maintain it, taking a more realistic present day hydrology into account. Any percentages comparing EWR to present day would therefore not be relevant as the specialists believed the present hydrology was underestimated during the wet season.

11.7.3 Low flow requirements (in terms of stress)

The stress index was used to identify required stress level at specific durations for the wet and dry month/season.

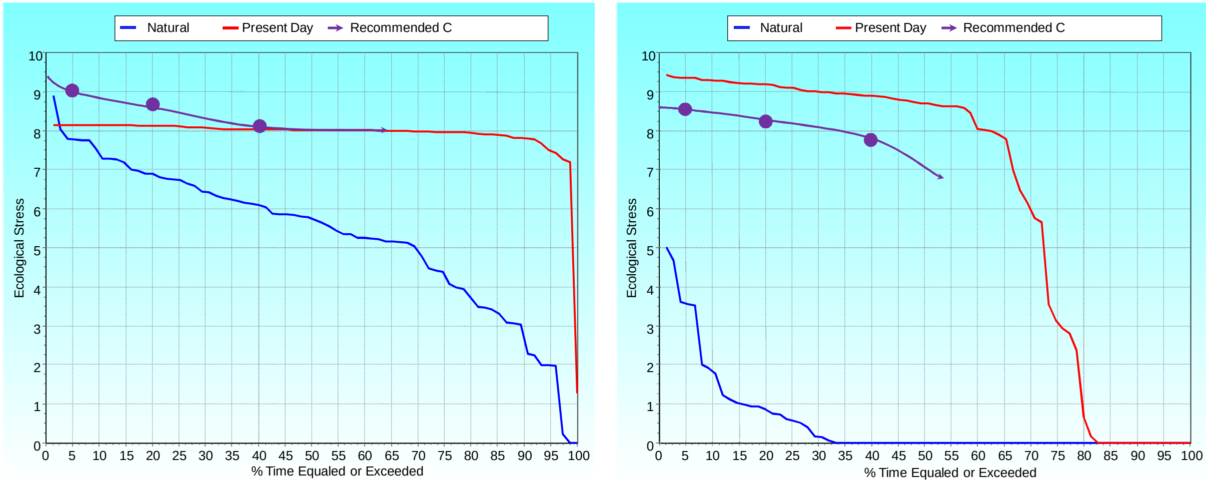
11.7.4 Low flow (in terms of stress) requirements

The flow requirements for the C PES/REC are provided in Table 36 and graphically illustrated in Figure 37. The results were plotted for the wet and dry season on stress duration graphs and compared to the DRM low flow estimates for the same EC. The stress requirements (as a 'hand drawn line') are illustrated in Figure 37. Summarised motivations for the final requirements are provided in Table 36.

Table 36: EWR 18: Species and integrated stress requirements as well as the final integrated stress and flow requirement

Stress Duration	Fish Stress requirement	Fish Flow requirement	Invert Flow requirement	Final* stress requirement	Flow requirement (m^3/s)
PES and REC: C			**FISH: C**	**INVERTEBRATES: C/D**	
DRY SEASON - AUG					
5%	9	1.5	Sufficient flow to maintain invert condition	**9**	**1.5**
20%	8.76	2		**8.76**	**2**
40%	8.29	3		**8.29**	**3**
WET SEASON - FEB					
5%	8.76	2	Sufficient flow to maintain invert condition	**8.76**	**2**
20%	8.29	3		**8.29**	**3**
40%	7.81	4		**7.81**	**4**

* Final refers to the final stress selected as the EWR requirement, i.e., the lowest stress.



Dry season (August) **Wet season (February)**

Figure 37: EWR 18: Stress duration curve for a PES and REC

As there was sufficient flow to maintain the invertebrates, Table 37 provides the summarised motivations for the final requirements of the fish only.

Table 37: EWR 18: Summary of motivations

Month	% Stress duration	Stress	Flow m^3/s	Comment
PES and REC: C **INVERTEBRATES: C/D**				**FISH: C**
Aug	5% drought	9	1.5	**Fish:** The flow regime at the site has been drastically altered from natural conditions, both in terms of volume and frequency. The seasonality has also been reversed at the site under present condition, resulting in higher dry season flows than wet season flows. This flow/stress value requested is therefore notably less than natural and present conditions, but realistic when compared to the requested wet season drought flows, to ensure some seasonal variation to be catered for (i.e. higher drought flows during wet season than during dry season). The flow/stress level will therefore result in very unsuitable habitats for the indicator guild but should create some refuge areas and allow for survival during this stressed period.
	40% maintenance	8.29	3	**Fish:**. Due to the highly stressed current situation (especially in the wet season due to very low flows), the dry season maintenance flows cannot be allowed to be reduced much from those occurring under present condition. At this recommended flow/stress, habitat suitability for the indicator guild will be very low, but should be adequate to

Month	% Stress duration	Stress	Flow m^3/s	Comment
				maintain the fish in the PES.
Feb	5% drought	8.76	2	**Fish:** The flows reflected by the present hydrology seemed unrealistic and not adequate to maintain the PES. An evaluation of daily flows recorded at a measuring weir in close proximity to the site confirmed that higher flows actually occur under present conditions. The recommended flows are therefore higher than those reflected for the site by the present hydrology. These recommended flows will still result in very high stress levels on the indicator species during the wet season, but should be adequate to maintain the fish in the PES under drought conditions.
	40% maintenance	7.81	4	**Fish:** As described above, the requested flows are higher than indicated for the site under present hydrology, but reflective of actual conditions (based on measured flows). This recommended flow is therefore significantly lower than the reference flows, and will result in high stress on the fish. Habitat conditions should however be suitable to allow for all requirements of the indicator species in terms of spawning, nursery, cover, abundance, connectivity and water quality.

11.7.5 Riparian vegetation flow requirements

The low flow requirements, set by the instream biotic components were checked (and modified if necessary) to ensure that it catered for any riparian vegetation (specifically marginal) requirements.

In the absence of surveyed vegetation data, assumptions are that sedges (*Cyperus congestus* and *C. laevigatus*) grow in a band along the active channel at an elevation above the channel bed of about 3.48 m and *Salix mucronata* at an elevation of about 3.98 m (as seen from photos – see Figure 15.2 below). The discharge required to inundate the base of the marginal zone (sedge) community is 7.8 m^3/s, and 18 m^3/s for *S. mucronata*.

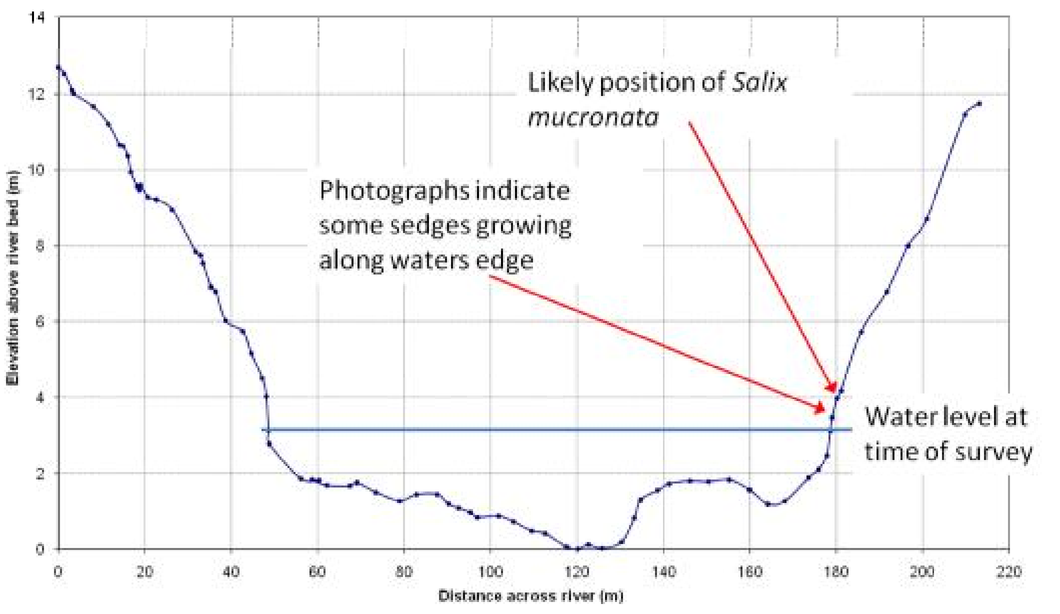


Figure 38: Assumed vegetation distribution at EWR 18

The low flows set by in-stream faunal requirements are provided in Table 38.

Table 38: Verification of low flow requirements for riparian vegetation

Season	Stress	Flow (m^3/s)	Elevation (m)	Comment
Dry (Aug)	9	1.5	2.77	Marginal zone vegetation rooting level is approximately 75 cm above water level. Drought stress mortality is expected, especially of higher elevation sedges in the lower zone.
	8.29	3	3.05	Marginal zone vegetation rooting level is approximately 40 cm above water level. Flows sufficient to maintain PES.
Wet (Feb)	8.76	2	2.98	Marginal zone vegetation rooting level is approximately 50 cm above water level. Drought stress mortality is expected, as well as reproductive abortion, especially of higher elevation sedges in the lower zone, but is in keeping with what is expected for drought.
	7.81	4	3.18	Marginal and lower zone vegetation is not yet inundated with rooting level at 30 cm above water level. Flow seems low for maintenance during the growing season and only marginally higher than dry season maintenance. In order for sedges not to expand towards the channel, these flows should be closer to 6.4 m^3/s or floods smaller than the 120 m^3/s should be set. The recommended flooding regime will cater for

Season	Stress	Flow (m^3/s)	Elevation (m)	Comment
				expansion of sedges.

11.7.6 Final low flow requirements

To produce the final results, the DRM results for the specific category were modified according to specialists' requirements Figure 39. There are a range of options one can use to make these modifications, such as changing the total volume required for the year, specific monthly volumes, either drought or maintenance flow durations, seasonal distribution and changing the category rules and shape factors. The following changes were required:

Parameter	FEB		AUG	
	DRM	EWR	DRM	EWR
High flow factors	-9	-9	0	0
Low Flow DC Shape	9	13	8	13
DC Upper % Shift	91	90	97	100
DC Lower % Shift	0	0	0	0
DC Low Flow Max.	130	70	130	157
High Flow DC Shape	8	9	8	11

Dry Season (August) **Wet Season (February)**

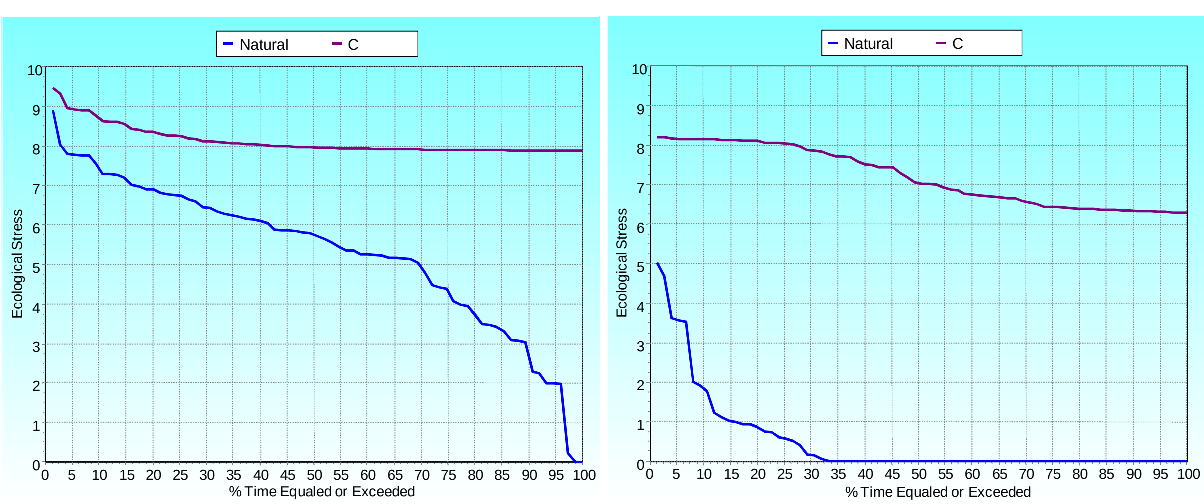


Figure 39: EWR 18: Final stress requirements for low flows

11.7.7 Final flow requirements

The low and high flows were combined to produce the final flow requirements for each EC as:

- An EWR table, which shows the results for each month for high flows and low flows separately (Table 39). Floods with a high frequency are not included in the modelled results as they cannot be managed.

- 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). EWR rules are supplied for total flows as well as for low flows only (Table 39).

The low flow EWR rule table is useful for operating the system, whereas the EWR table must be used for operation of high flows.

Table 39: EWR 18: EWR table (m^3/s) for PES and REC: C

Desktop version:		**2**	**Virgin MAR (MCM)**	**3347.193**
			Present Day MAR (MCM)	**1177.28**
BFI index	**0.306**	**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	2.039	0.739		
NOVEMBER	3.167	1.725	35 120	7
DECEMBER	3.589	1.95	120	
JANUARY	4.454	2.414	35 120	7
FEBRUARY	5.989	3.239	35 120	7

MARCH	5.131	2.776	35	7
APRIL	3.91	2.123		
MAY	2.412	1.319		
JUNE	1.65	0.912		
JULY	1.361	0.756		
AUGUST	1.335	0.688		
SEPTEMBER	1.412	0.784		
TOTAL MCM	95.197	50.709	162.19	
% OF VIRGIN	2.84	1.51	4.85	
% OF PD	8.09	4.31	13.78	
Total IFR	257.387			
% of VIRGIN MAR	7.69			
% of PD MAR	21.86			

Table 40: EWR 18: Assurance rules (m^3/s) for PES and REC: C

Desktop Version 2, Printed on 2012/10/21

Summary of IFR rule curves for: EWR7 Generic Name (EWR 18)

Determination based on defined BBM Table with site specific assurance rules.

Regional Type: Vaal REC = C

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

% Points

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	4.756	4.633	4.376	3.927	3.269	2.482	1.726	1.165	0.859	0.764

Nov	50.758	40.377	31.828	24.258	14.383	10.208	6.828	4.757	3.824	3.621
Dec	6.747	6.540	6.102	5.366	4.397	3.408	2.639	2.193	2.007	1.980
Jan	40.349	32.489	25.866	19.825	12.012	8.578	5.962	4.489	3.896	3.838
Feb	55.580	44.369	35.002	26.573	15.714	11.207	7.849	6.015	5.307	5.269
Mar	25.916	24.977	22.983	19.635	15.227	10.729	7.230	5.201	4.352	4.233
Apr	7.366	7.197	6.843	6.223	5.324	4.266	3.284	2.589	2.237	2.156
May	5.066	4.951	4.712	4.292	3.679	2.945	2.240	1.716	1.431	1.343
Jun	3.848	3.736	3.503	3.107	2.567	1.980	1.479	1.149	0.984	0.931
Jul	3.501	3.374	3.110	2.679	2.133	1.593	1.178	0.929	0.813	0.773
Aug	3.791	3.620	3.266	2.716	2.068	1.483	1.073	0.846	0.744	0.710
Sep	3.639	3.530	3.303	2.918	2.393	1.823	1.336	1.014	0.854	0.802

Reserve flows without High Flows

Oct	4.780	4.729	4.632	4.459	4.163	3.693	3.010	2.139	1.245	0.764
Nov	6.672	6.580	6.398	6.067	5.521	4.724	3.729	2.720	1.976	1.756
Dec	6.771	6.646	6.386	5.917	5.190	4.248	3.263	2.478	2.049	1.980
Jan	7.427	7.252	6.884	6.238	5.316	4.267	3.344	2.743	2.474	2.446
Feb	8.327	8.096	7.604	6.782	5.717	4.661	3.875	3.446	3.280	3.271
Mar	8.557	8.361	7.948	7.224	6.185	4.990	3.917	3.198	2.862	2.813
Apr	7.378	7.248	6.981	6.499	5.750	4.765	3.705	2.818	2.290	2.156
May	5.082	5.016	4.885	4.648	4.257	3.685	2.957	2.194	1.591	1.343
Jun	3.873	3.836	3.767	3.643	3.434	3.102	2.617	1.993	1.338	0.931
Jul	3.535	3.512	3.471	3.401	3.281	3.081	2.757	2.254	1.542	0.773
Aug	3.841	3.824	3.798	3.754	3.683	3.562	3.354	2.983	2.287	1.028

Sep	3.667	3.643	3.599	3.524	3.396	3.180	2.830	2.287	1.522	0.802

Natural Duration curves

Oct	237.254	112.358	49.899	35.786	24.888	20.109	14.027	10.167	4.197	2.031
Nov	403.376	219.950	169.815	129.298	79.541	69.626	43.434	32.099	11.856	6.474
Dec	429.686	254.058	196.640	155.249	122.879	95.262	65.632	42.298	22.424	9.095
Jan	477.894	278.950	215.565	187.108	148.454	129.085	80.111	66.577	43.287	17.066
Feb	720.503	382.263	194.213	141.158	120.672	107.089	86.314	62.550	36.905	15.422
Mar	402.416	255.037	212.862	120.445	87.814	72.670	58.598	44.202	24.698	12.653
Apr	222.473	152.917	97.272	64.387	46.856	39.309	32.824	26.717	13.789	4.275
May	75.414	49.970	32.460	23.271	17.208	14.490	12.414	9.928	5.783	1.770
Jun	42.604	28.630	16.937	14.552	11.181	9.973	8.329	6.759	5.648	2.307
Jul	34.345	20.759	14.845	13.314	11.596	9.943	8.001	6.642	5.462	2.121
Aug	29.898	20.845	15.076	13.135	10.853	9.390	7.893	6.463	5.134	3.554
Sep	37.369	24.738	17.103	13.175	11.397	8.823	6.910	5.822	4.255	2.936

11.8 EWR 19 (Lilydale Lodge, Riet River): Determination of Stress Indices

11.8.1 Indicator species or group

Fish indicator group:

Refer to Section 11.2.1.

Macroinvertebrate indicator group:

Hydropsychidae 2 spp. was used as indicator taxa. This taxa has occurred previously at the site during October 2007 (this Reserve study) and May 2012 (river health assessment).

Stress flow index

The species stress discharges in Table 41 and Table 42 indicates the discharge evaluated by specialists to determine the biota stress.

Table 41: EWR 19: Fish stress index and summarised habitat/biotic responses

Fish stress	Flow (m^3/s)	Habitat and/or biotic responses
0	5.5	Value based on separated base flow of natural hydrology (20% flow duration for wet season month). Habitat suitability will be optimal and comparable to wet season conditions that may have occurred at site under reference (pre-disturbance) conditions.
1	3.9	Habitat suitability close to optimal but slightly reduced due to lower than natural abundance of fast habitats.
2	2.6	Habitat suitability will be good to meet the requirements of all life stages and processes of the indicator species.
3	1.9	It is estimated that at this flow habitats will become favourable for all life stages and requirements of the indicator species. Spawning habitats are still of low requirement, while the rest of the habitats are moderate. Optimal conditions have not been reached due to the lower abundance of habitats, as compared to natural expected conditions.
4	1.4	Increased availability (abundance) of fast habitats in reach will provide more adequate habitats (still of overall moderate suitability) to meet the requirements of the indicator species.
5	1.01	According to the hydraulic information, at this flow the diversity of fast habitats will increase. An improvement in overall abundance of fast habitats in the reach will result in a notable improvement in the suitability of the habitat for the indicator species. Habitat suitability will however still be very low for spawning but moderate for all other aspects considered nursery, abundance and cover, connectivity and water quality).
6	0.7	According to the hydraulic information, at this flow the diversity of fast habitats (velocity-depth categories) will increase. It is therefore estimated that at this flow the habitat suitability will become more favourable for the indicator species in the reach. Habitat suitability for spawning will however still be very low while the rest of the habitat requirements are of low suitability.
7	0.4	It is estimated that at this flow the habitat suitability will become slightly more favourable for the indicator species as some fast habitats will become available in the

Fish stress	Flow (m^3/s)	Habitat and/or biotic responses
		reach. Habitat suitability for spawning and nursery areas will however still be very low while the rest of the habitat requirements are of low suitability.
8	0.1	Habitat suitability will still be unsuitable to meet the spawning requirements of the indicator species, and of very low suitability for all other aspects considered. According to hydraulics, no fast habitats will be available in the reach under this flow.
9	0.03	Habitat unsuitable to meet spawning and nursery area requirements and of very low suitability for cover, connectivity and water quality and to maintain abundance of indicator species (BAEN). Based on hydraulic information, there will be no fast habitat available in the reach under these flows.
10	0	Habitat unsuitable to provide for spawning, nursery areas, cover, maintenance of connectivity and water quality of indicator fish species (BAEN).

Table 42: EWR 19: Invertebrate stress index and summarised habitat/biotic responses

Invertebrate stress	Flow (m^3/s)	Habitat and/or biotic responses
0	5.5	
1	4.5	Ave. velocity 0.16 m/s; max. velocity 0.52 m/s; 3% FCS, 1% VEG.
2	2.8	Ave. velocity 0.14 m/s; max. velocity 0.46 m/s; 3% FCS, 1% VEG.
3	2.2	Ave. velocity 0.12 m/s; max. velocity 0.42 m/s; 2% FCS, 1% VEG.
4	1.2	Ave. velocity 0.1 m/s; max. velocity 0.34 m/s; 1% FCS, 1% VEG.
5	0.8	Ave. velocity 0.09 m/s; max. velocity 0.31 m/s; 1% FCS, 1% VEG.
6	0.5	Ave. velocity 0.08 m/s; max. velocity 0.26 m/s; 8% SCS, 1% VEG.
7	0.2	Ave. velocity 0.05 m/s; max. velocity 0.18 m/s; 5% SCS, 1% VEG.

Invertebrate stress	Flow (m^3/s)	Habitat and/or biotic responses
8	0.1	Ave. velocity 0.06 m/s; max. velocity 0.21 m/s; 6% SCS, 1% VEG.
9	0.01	Ave. velocity 0.03 m/s; max. velocity 0.11 m/s; 1% SCS, 1% VEG.
0	0	

11.9 EWR 19 (Lilydale Lodge, Riet River): Determination of EWR Scenarios

11.9.1 Ecoclassification summary of EWR 19

Based on the review, the vegetation and fish component was in a better condition than determined during the Reserve study (DWA, 2010b). It is acknowledged that the changes in land use and addressing non-flow related issues since the Reserve studies have contributed to the changes in EWR. The refined and current results indicated a C PES rather than the reported D PES. Due to the HIGH EIS the REC should be improved to a B EcoStatus.

The revised EcoClassification results are summarised in the Table 43 below. The ECs in red refer to those that have changed in Category from the Reserve study undertaken during 2007 - 2010.

EWR 19			
Components	PES	EIS	REC
Hydrology	D	HIGH	C
Physico-chemical	D		C
Geomorphology	C		C
Fish	C		B
Invertebrates	C		B
INSTREAM	C		B
Riparian vegetation	B		B
ECOSTATUS	C		B

Table 43: Summary of EcoClassification results

EWR site	ECOCLASSIFICATION			
	Original PES	**Refined PES**	**Original REC**	**Refined REC**
EWR 19	D	C	D	B

The EIS is HIGH and the REC is therefore an improvement of the PES to a B EC This implies an improvement in flows.

The most significant flow-related problems were:

- Increased dry season baseflows and reduction in moderate events and event hydrology. Dams upstream in the system reduce the flood events. Return flows from irrigation and possibly the transfer of water from the Orange River increases the winter baseflows.

The most significant non-flow related problems were:

- Diffuse pollution from agricultural practices leading to an increase in salinity levels and moderate nutrient levels.

11.9.2 Hydrological considerations

The driest and wettest months were identified as July and February respectively. Droughts were set at 95% exceedance (flow) and 5% exceedance (stress). Maintenance flows were set at 40% exceedance (flow) and at 60% exceedance (stress).

The Orange Riet transfer scheme enters the Riet River upstream of the EWR site. The Riet-Modder River hydrology was undertaken by Ninham Shand as part of the VRSAU study and there are indications that the simulations are inaccurate and not representative of present conditions in the river system (Susan Swart, *pers. comm.*). EWR 19 is influenced by the Orange River transfer. The transfer is based on only supplying the requirements of farmers that have access to the channel. Additional flow in the Riet-Modder River system can therefore only be ascribed to irrigation return flows. Furthermore ad hoc transfers from the Orange River are made only when there are water quality problems in the Riet River due to low flow and this makes accurate simulation difficult. The general consensus is that ad hoc releases may not be more than 5 MCM/a and this transfer was not included in the flow simulation at EWR 19 (Susan Swart, *pers. comm*.).

The modelled present day hydrology indicates that flows are mostly higher than Present Day, especially during the dry season. It must be noted that there was uncertainty regarding the hydrology, but that this situation agreed with the observations made by the specialists. To improve the EcoStatus to a B, decreased dry season flows will be required as one of the main factors. Due to the low confidence in the modelled present day hydrology, there was no resolution to distinguish between a C and a B EcoStatus. Present day flows will therefore maintain the C EC, and flows lower than Present Day were set that would also maintain the C EC. For the application of the DRM the PD hydrology was used as reference hydrology. It is likely that as one moves towards natural, these decreased flows could result in a B EcoStatus if other non-flow related activities are also addressed.

11.9.3 Low flow requirements (in terms of stress)

The stress index was used to identify required stress levels at specific durations for the wet and dry month/season.

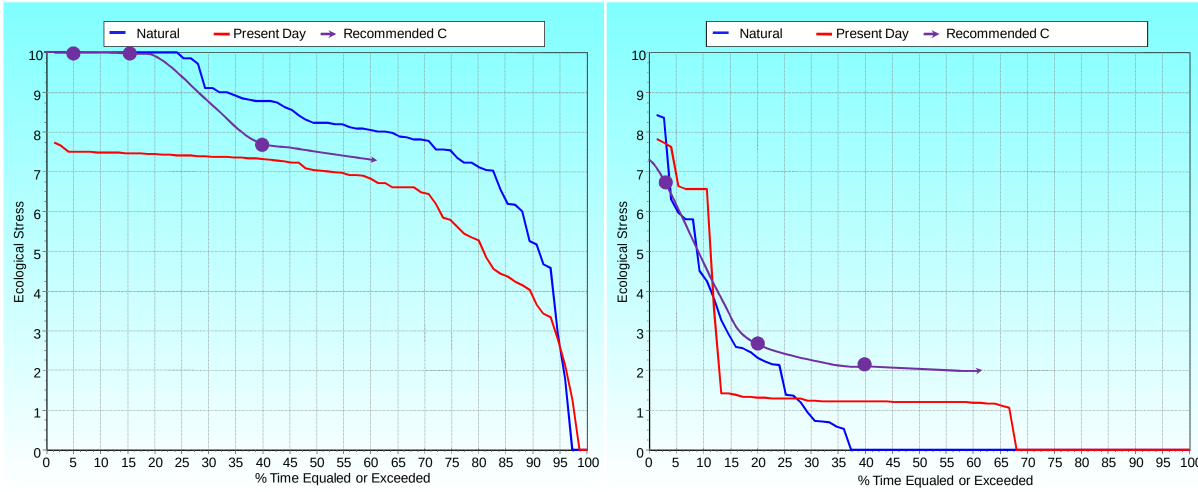
11.9.4 Low flow (in terms of stress) requirements

The flow requirements for the C PES are provided in Table 44 and graphically illustrated in Figure 40. The results were plotted for the wet and dry season on stress duration graphs and compared to the DRM low flow estimates for the same EC. The stress requirements (as a 'hand drawn line') are illustrated in Table 44.

Table 44: EWR 19: Species and integrated stress requirements as well as the final integrated stress and flow requirement

Stress Duration	Fish Stress requirement	Fish Flow requirement	Invert Flow requirement	Final* stress requirement	Flow requirement (m^3/s)
PES: C			**FISH: C**	**INVERTEBRATES: C**	
DRY SEASON - AUG					
5%	10	0	Sufficient flow to maintain invert condition	**10**	**0**
20%	10	0		**10**	**0**
40%	7.7	0.2		**7.7**	**0.2**
WET SEASON - FEB					
5%	6.78	0.5	Sufficient flow to maintain invert condition	**6.78**	**0.5**
20%	2.83	2		**2.83**	**2**
40%	2.11	2.5		**2.11**	**2.5**

* Final refers to the final stress selected as the EWR requirement, i.e., the lowest stress.



Dry season (July) **Wet season (February)**

Figure 40: EWR 19: Stress duration curve for a PES

As there was sufficient flow to maintain the invertebrates, Table 45 provides the summarised motivations for the final requirements of the fish only.

Table 45: EWR 19: Summary of motivations

Month	**% Stress duration**	**Stress**	**Flow m^3/s**	**Comment**
PES and REC: C INVERTEBRATES: C				**FISH: C**
Jul	5% drought	10	0	**Fish:** The present dry season flows at this site are significantly higher than the natural dry season flows for most flow durations. Zero flows occurred naturally during drought conditions (95% flow duration), and therefore it is estimated that current zero flows during droughts should not impact the status of the fish assemblage.
	40% maintenance	7.7	0.2	**Fish:** As discussed above, the present day flows are higher than the natural flows in the dry season, even under maintenance flows (60% flow duration). It was however decided to not recommend such low flows comparable to natural conditions for present day dry season maintenance flows. Should the Riet River have dried out completely (no pools for refuge) under natural condition, there would have been connectivity between the Vaal and the Riet Rivers (no migration barriers). Fish would therefore have been able to recolonise the Riet River from the Vaal River under these conditions which is probably based on the natural hydrology. Under present conditions migration barriers (weirs, dam walls) may prevent the recolonisation, and

Month	% Stress duration	Stress	Flow m^3/s	Comment
				therefore it is recommended that higher than natural maintenance flows should be catered for to ensure the maintenance of some refuge areas (pools). There is also more stress under present condition compared to natural during the wet season, and therefore the dry season stress should not be increased too much from present day flows as this may result in an overall decrease in the PES. The recommended flows for the dry season maintenance period will therefore be adequate to sustain the indicator fish guild during the dry season.
Feb	5% drought	6.78	0.5	**Fish:** The above mentioned scenario is not valid for the wet season, when present day flows are lower than natural. The fish guild will be subjected to relatively high stress in the dry season, and therefore wet season flows should not be decreased significantly from its present levels as this could lead to overall increase in stress and a decreased in the PES of the indicator fish guild. The recommended flows will still result in relatively high stress level on the indicator species during the wet season droughts, but should be adequate to maintain the fish in the PES under drought conditions. **Inverts:** Ave. velocity = 0.08 m/s, Max. velocity = 0.26 m/s, VEG = 1%.
	40% maintenance	2.11	2.5	**Fish:** The present day maintenance flows are notably lower than under natural conditions. It was however determined that flows could be reduced further without significantly impacting on the PES, as the stress will still remain relatively low on the indicator fish guild. At the recommended flow, adequate habitats should be available to allow for all requirements of the indicator species in terms of spawning, nursery, cover, abundance, connectivity and water quality and maintenance in the PES.

Riparian vegetation flow requirements

The low flow requirements, set by the instream biotic components were checked (and modified if necessary) to ensure that it catered for any riparian vegetation (specifically marginal) requirements.

In the absence of surveyed vegetation data, assumptions are that sedges (*Cyperus marginatus*, *Juncus rigidus* and *Schoenoplectus muricinux*) grow on mid-channel features and in clumps along the active channel at an elevation above the channel bed of between 0.8 and 1 m and *Phragmites australis* at an elevation of about

0.9 to 1.3 m (as seen from photos – see Figure 17.2 below). The discharge required to inundate the base of the marginal zone (sedge) community is 4.5 to 9.5 m^3/s, and 6.5 to 24 m^3/s for reeds.

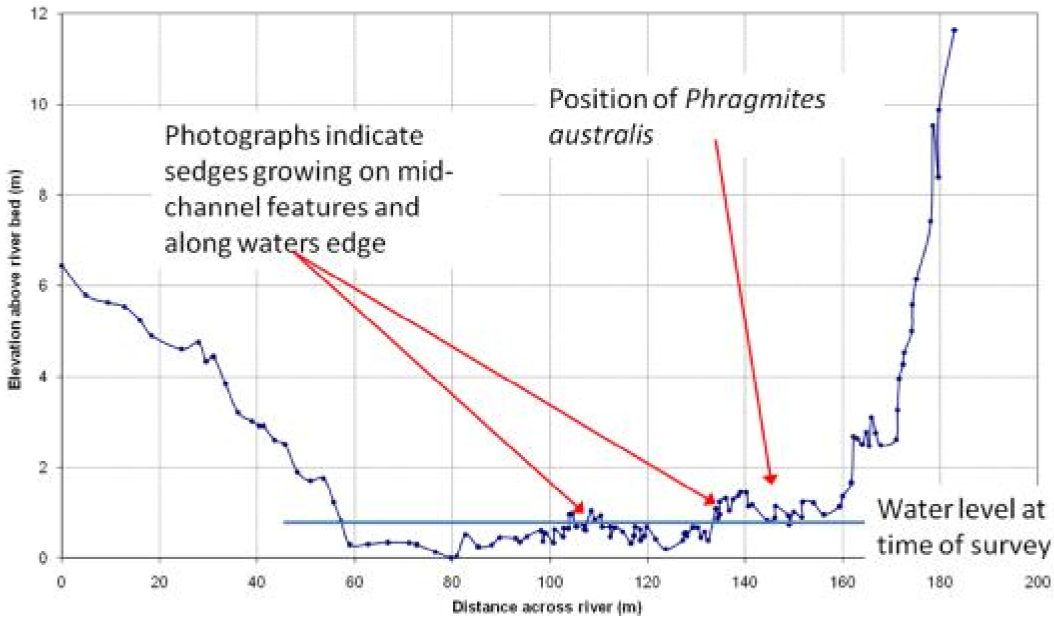


Figure 41: Assumed vegetation distribution at EWR 19

The low flows set by in-stream faunal requirements are provided in Table 46.

Table 46: Verification of low flow requirements for riparian vegetation

Season	Stress	Flow (m^3/s)	Elevation (m)	Comment
Dry (Jul)	5	0	0.1	Marginal zone vegetation rooting level is approximately 70 to 120 cm above water level. Drought stress mortality is expected, especially of higher elevation sedges and reeds in the lower zone.
	40	0.2	0.38	Marginal zone vegetation rooting level is approximately 40 to 90 cm above water level. Flows seem slightly low and may result in some mortality, especially at the upper edge of reed beds and sedges. Dry season maintenance flow is less than wet season drought.
Wet (Feb)	5	0.5	0.45	Marginal zone vegetation rooting level is approximately 35 to 75 cm above water level. Drought stress mortality is expected (but likely to be low), as well as reproductive abortion, especially of higher elevation sedges and reeds in the lower zone.
	40	2.5	0.68	Marginal and lower zone vegetation is not yet inundated with rooting level at 10 to 60 cm above water level. This flow seems low and may

Season	Stress	Flow (m^3/s)	Elevation (m)	Comment
				result in expansion of the marginal zone vegetation towards the channel if habitat is available, especially since no smaller floods were required for vegetation. During the original assessment no floods in the range of 25 m^3/s was specified for riparian vegetation. However, if floods required for in-stream fauna (25 to 35 m^3/s) occur, then an expansion of vegetation towards the channel will be prevented and the marginal and lower zone will be inundated. This should happen four times in the summer or late summer.

Final low flow requirements

To produce the final results, the DRM results for the specific category were modified according to specialists' requirements Figure 42. There are a range of options one can use to make these modifications, such as changing the total volume required for the year, specific monthly volumes, either drought or maintenance flow durations, seasonal distribution and changing the category rules and shape factors. The following changes were required:

Parameter	FEB		JUL	
	DRM	EWR	DRM	EWR
High flow factors	1	1	1	1
Low Flow DC Shape	-9	-9	-9	-9
DC Upper % Shift	17	3	19	9
DC Lower % Shift	82	95	77	79
DC Low Flow Max.	0	0	0	30
High Flow DC Shape	200	188	200	172

Dry Season (July) **Wet Season (February)**

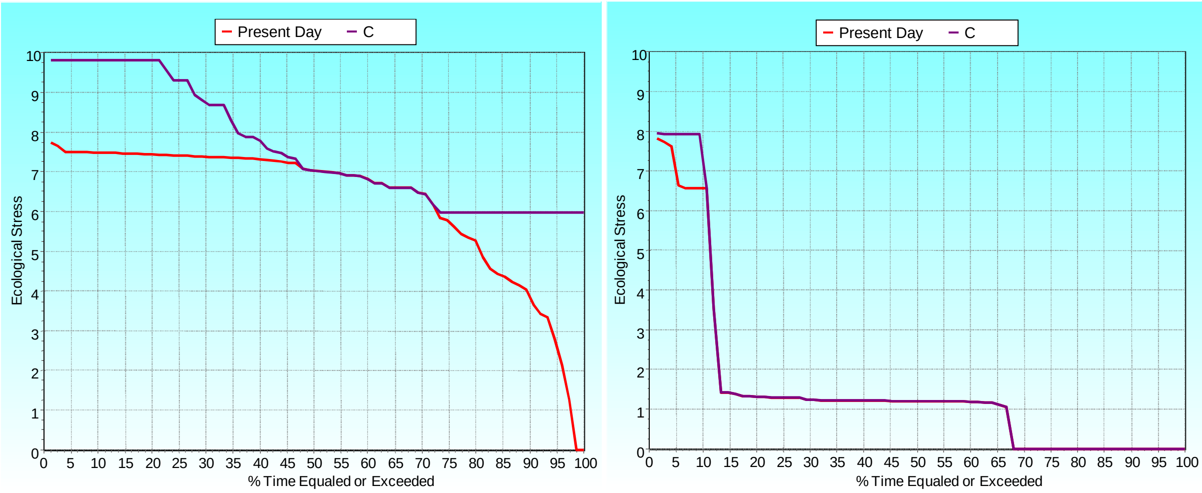


Figure 42: EWR 19: Final stress requirements for low flows

Final flow requirements

The low and high flows were combined to produce the final flow requirements for each EC as:

- An EWR table, which shows the results for each month for high flows and low flows separately (Table 47). Floods with a high frequency are not included in the modelled results as they cannot be managed.
- 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). EWR rules are supplied for total flows as well as for low flows only (Table 47).

The low flow EWR rule table is useful for operating the system, whereas the EWR table must be used for operation of high flows.

Table 47: EWR 19: EWR table (m^3/s) for PES: C

Desktop version:		**2**	**Virgin MAR (MCM)**	**403.86**
			Present Day MAR (MCM)	**247.67**
BFI index	**0.224**	**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	0.753	0		
NOVEMBER	1.179	0.012	4 25	3 7
DECEMBER	1.246	0.015	4	3
JANUARY	2.282	0.007	4 25	3 7
FEBRUARY	4.736	0.087	25	7

Desktop version:		**2**	**Virgin MAR (MCM)**	**403.86**
			Present Day MAR (MCM)	**247.67**
BFI index	**0.224**	**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)**
MARCH	4.504	0.011	4 25	3 7
APRIL	2.822	0		
MAY	1.344	0		
JUNE	0.616	0		
JULY	0.392	0		
AUGUST	0.45	0		
SEPTEMBER	0.565	0		
TOTAL MCM	54.274	0.33	116.744	
% OF VIRGIN	13.44	0.08	28.91	
% OF PD	21.91	0.13	47.14	
Total IFR	171.018			
% of VIRGIN MAR	42.35			
% of PD MAR	69.05			

Table 48: EWR 19: Assurance rules (m^3/s) for PES: C

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

Desktop Version 2, Printed on 2012/12/14

Summary of IFR rule curves for: EWR8 Generic Name (EWR 19)

Determination based on defined BBM Table with site specific assurance rules.

Regional Type: Vaal REC = C

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

% Points

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.399	1.351	1.186	0.866	0.340	0.211	0.071	0.021	0.009	0.009
Nov	2.924	2.886	2.870	2.778	2.627	2.554	2.458	1.493	0.274	0.274
Dec	3.965	3.379	3.371	3.368	2.654	1.795	1.011	0.471	0.208	0.158

Jan	20.602	4.749	4.648	4.641	4.630	4.618	4.581	4.036	0.650	0.145
Feb	33.069	16.997	9.780	3.617	3.592	3.584	3.576	3.555	0.556	0.210
Mar	25.939	12.526	4.398	2.180	2.113	2.106	2.087	2.057	1.464	0.343
Apr	5.637	5.537	5.251	1.354	0.802	0.660	0.648	0.257	0.035	0.035
May	2.831	2.804	1.777	1.157	0.429	0.373	0.218	0.046	0.018	0.018
Jun	1.224	1.224	1.193	0.864	0.426	0.119	0.027	0.008	0.008	0.008
Jul	0.713	0.713	0.590	0.515	0.208	0.040	0.008	0.004	0.004	0.004
Aug	0.854	0.854	0.772	0.492	0.191	0.052	0.014	0.006	0.005	0.005
Sep	1.123	1.105	0.969	0.378	0.308	0.106	0.031	0.010	0.007	0.007

Reserve flows without High Flows

Oct	1.399	1.383	1.343	1.256	0.340	0.295	0.269	0.155	0.009	0.009
Nov	2.313	2.287	2.233	2.129	1.939	1.619	1.146	0.565	0.070	0.026
Dec	2.587	2.563	2.520	2.445	2.312	2.087	1.716	1.145	0.376	0.031
Jan	4.994	4.749	4.648	4.641	4.630	4.469	4.048	3.259	0.650	0.038
Feb	10.365	10.306	9.780	3.617	3.592	3.584	3.576	3.555	0.556	0.152
Mar	9.511	9.435	4.398	2.180	2.113	2.106	2.087	2.057	0.477	0.071
Apr	5.637	5.587	5.474	1.354	0.802	0.660	0.648	0.637	0.035	0.035
May	2.831	2.817	1.777	1.157	0.429	0.373	0.351	0.200	0.018	0.018
Jun	1.224	1.224	1.214	0.864	0.529	0.374	0.254	0.027	0.008	0.008
Jul	0.713	0.713	0.590	0.515	0.433	0.256	0.057	0.004	0.004	0.004
Aug	0.854	0.854	0.831	0.523	0.343	0.323	0.106	0.013	0.005	0.005
Sep	1.123	1.116	1.082	0.378	0.328	0.313	0.240	0.049	0.007	0.007

Natural Duration curves

Oct	4.040	4.029	4.014	3.398	0.340	0.295	0.269	0.261	0.246	0.231
Nov	2.924	2.886	2.870	2.778	2.627	2.554	2.458	1.493	0.274	0.274
Dec	3.965	3.379	3.371	3.368	3.356	3.353	3.282	2.128	0.429	0.429
Jan	20.602	4.749	4.648	4.641	4.630	4.618	4.581	4.036	0.650	0.145
Feb	52.038	16.997	9.780	3.617	3.592	3.584	3.576	3.555	0.556	0.210
Mar	70.538	12.526	4.398	2.180	2.113	2.106	2.087	2.057	1.859	0.343
Apr	34.857	12.419	6.578	1.354	0.802	0.660	0.648	0.637	0.390	0.275
May	16.241	3.028	1.777	1.157	0.429	0.373	0.351	0.340	0.317	0.251
Jun	3.862	1.636	1.331	0.864	0.529	0.374	0.347	0.332	0.316	0.277
Jul	1.576	1.068	0.590	0.515	0.433	0.347	0.325	0.306	0.291	0.240
Aug	1.225	1.124	0.907	0.523	0.343	0.329	0.314	0.302	0.284	0.237
Sep	2.789	2.782	2.774	0.378	0.328	0.313	0.305	0.301	0.285	0.227

11.9.5 Water quality

The Vaal River at Vaalharts weir (C9H008) display high salts (479 mg/ℓ) and an unacceptable high phosphate concentrations (0.117 mg/ℓ). The high nutrients stimulate algal and water hyacinths growth (DWAF, 2009a).

The water quality in the Harts River was extremely poor; 5/7 parameters were in the unacceptable range. The TDS concentration in the Harts at Delportshoop, Lloyds weir (C3H016) was unacceptable at 1 322 mg/ℓ and shows an increasing trend. The Harts River contributes significant amounts of salts to the lower Vaal River.

The water quality in the Vaal River at Schmidtsdrift (C9H024) was unacceptable because of the high salts (EC, 117 mS/m; ~820 mg TDS/ℓ) and high nutrients, especially high ammonia (0.147 mg/ℓ).

A summary of the Water Quality (WQ) PES is shown in Figure 44.

11.9.6 Irrigation and salinisation

Irrigation use about 82 % of the total water requirements in the WMA. Over 85 % of the requirements for irrigation are in the Harts sub-area, mainly at the Vaalharts irrigation scheme, with the balance being along the Vaal River. The Vaalharts irrigation scheme serves the purpose of beneficially utilising lower quality water discharged from the Upper Vaal water management area and thus prevents the accumulation of salinity in the lower reaches of the Lower Vaal WMA.

Water in the Harts River downstream of the Vaalharts irrigation scheme is of exceptional high salinity as a result of saline leachate from the irrigation fields, and needs to be carefully managed through blending with fresher water

Because of salinisation problems experienced at the Vaalharts irrigation scheme an efficient subsurface drainage system was installed, resulting in large quantities of irrigation effluent being returned to the river and which could potentially be re-used downstream. The resultant balance at the downstream end of the water management area is reflected as a surplus for the Lower Vaal water management area, and not as a transfer to the Lower Orange water management area (DWAF, 2003b).

Water quality in the lower reaches of the Vaal River is also impacted upon by irrigation return flows from the Harts River as well as from the Riet/Modder River further downstream, necessitating further blending with low salinity water from the Orange River at the Douglas.

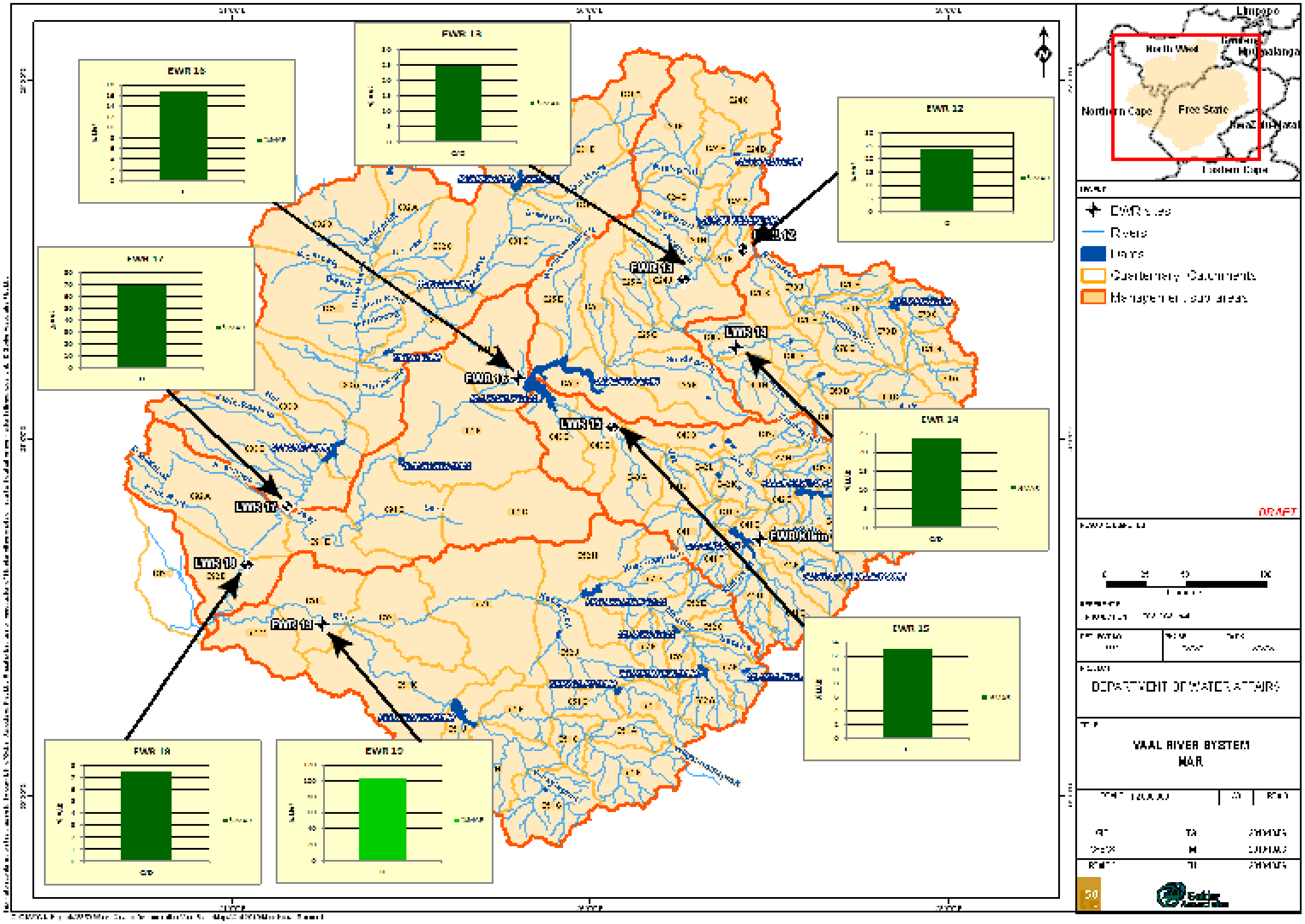


Figure 43: Summary of the MAR at the EWR sites within the Middle and Lower Vaal Catchments

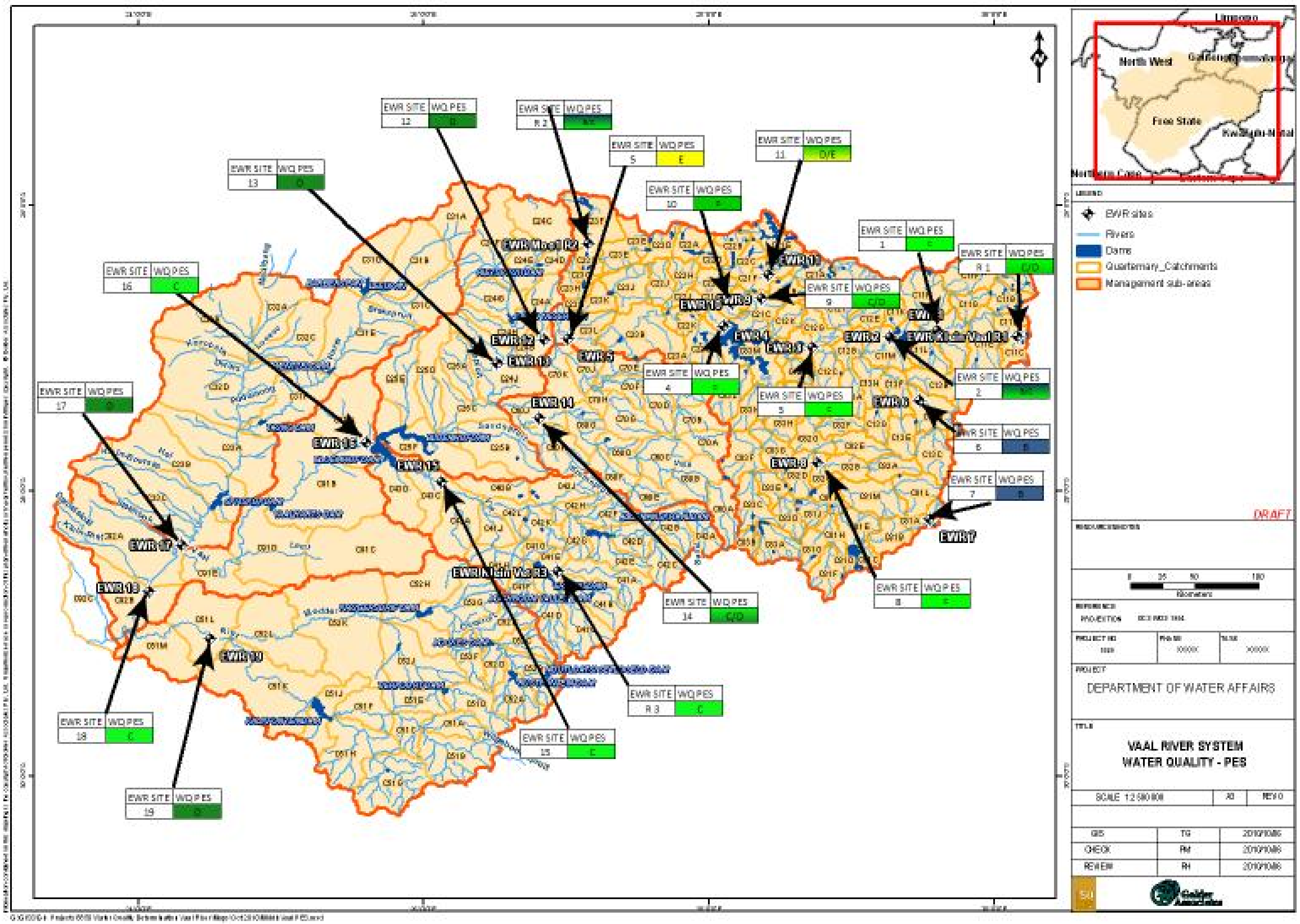


Figure 44: Summary of the Water Quality PES of the EWR sites within the Middle and Lower Vaal Catchments

In arid and semi-arid regions irrigation tends to degrade soil and water quality through salt accumulation with devastating effects on some crops. A recent study in the Lower Vaal WMA showed that the addition of salts to the soils as a result of farming practices varied between 79 t/ha and 280 t/ha, with irrigation water being the major contributor of salt. Soils had been irrigated for periods of between 17 to 53 years. However, predictions showed that if the current practices are sustained for the next 50 years the osmotic potential of 6 soils will decline to below the threshold of -100 kPa for maize. In two of these soils the threshold of -280 kPa for wheat will also be exceeded. Hence salt-induced water stress could reduce the yield of maize and even wheat significantly in future if appropriate precautionary measures are not introduced (Van Rensburg et al., 2008).High dissolved salts concentrations in the Vaal River could be the tipping factor that may shift the algal composition in favour of undesirable highly toxic cyanobacterium species (notably Cylindrospermopsis sp.) that was already observed in the lower part of the Vaal River and Orange River (Van Ginkel, 2004).

11.9.7 Eutrophication and Algal blooms

Spitskop Dam is classified as an eutrophic system and toxic cyanobacterial blooms have been recorded. The occurrence of cyanobacterial species, Cylindrospermopsis sp., is a major concern because of the potent toxin produced by these algae and the difficulty to remove it from the water during water treatment process.

During 2000 the first major cyanobacterial outbreak in the Orange River downstream of the confluence of the Vaal and the Orange River was recorded. The findings of a study during this event indicated that the problem species (Cylindrospermopsis sp.) originated in the Spitskop Dam. During high flows the cyanobacterial species were transported downstream causing problems for all the treatment works that was designed to handle high turbidity in the supply waters and not cyanobacterial or algal blooms (Van Ginkel, 2004).

11.9.8 Water Transfers and hydrology

The bulk of the surface water found in the water management area is in the Vaal River, most of which is transferred along the river from the Upper Vaal water management area and via the Middle Vaal water management area, to the Lower Vaal water management area. Water is also transferred into the water management area at Douglas Weir, from the Upper Orange water management area, for water quality management purposes.

The only direct international obligation affecting the water resources of the Vaal River System is in the Lower Vaal WMA, in particular the Molopo River catchment.

The transfer of water between water management areas and arrangements with neighbouring countries resort under national control. The following reservations are made in the National Water Resource Strategy with respect to water transfers in to and out of the Lower Vaal water management area: Currently 500 Mm^3/a is transferred from the Middle Vaal water management area to the Lower Vaal water management area. As an upper scenario this may increase to about 555 Mm^3/a during the period of projection – Reserved in the Middle Vaal WMA.

A reservation applies to the transfer of 18 Mm^3/a from the Upper Orange WMA to the Douglas Weir in the Lower Vaal WMA – Reserved in the Upper Orange WMA. The Lower Vaal WMA also forms part of the Vaal River System which extends over several water management areas. As water resource management in the Vaal River System impacts to some degree on water quantity and quality in all the inter-linked water management areas, management of water resources in the Vaal River System is to be controlled at a national level (DWAF, 2003 c).

12 DEVELOPMENT OF OPERATIONAL SCENARIOS

12.1 Overview and objective

The Ecological Water Requirement (quantity) scenarios developed are as sets of possible flows to achieve different river states (or Ecological Categories) for each EWR. This process did not consider whether these flows could be supplied or managed. To provide decision makers with more comprehensive information, it is necessary to examine each of the scenarios and their full range of implications. Thereafter, a process was followed to devise an optimised scenario (if necessary) that would have the least overall impact on the users and the ecology. All these operational scenarios were tested to determine the resulting state of the river, and the water quality consequences of each flow scenario were supplied.

The objectives of this task were to develop a range of operational scenarios that result in different impacts on different users. The impacts of incorporating the EWR on the ecology, system yield, services and overall economic activities could then be assessed.

12.2 Method

The purpose of this step (step 5) in the 8 step Reserve process is to predict the driver and biotic responses to each operational scenario, including natural and present day hydrology and derive the ecological categories for each EWR site. All information generated during steps 3 (ecoclassification) and step 4 (determination of Ecological Water Requirement) is used during this step.

The following steps were followed to determine the ecological consequences of the operational flow scenarios.

- The operational scenarios (DWA, 2010a) were modelled using the WRPM and a time series was provided for each scenario at each EWR site.
- The time series was converted to a flow duration table and both was provided to the physico chemical and geomorphology specialists.
- The impacts of these time series of the operational scenarios were analysed by the physico chemical and geomorphology specialists by completion of the Physico-chemical Assessment Index (PAI) and Geomorphology Assessment Index (GAI) models to predict the driver ecological category.
- The riparian vegetation specialist then assessed the response on the marginal and other riparian zones and supplied this information to the instream biotic specialists (macroinvertebrates and fish).
- Where required, the riparian vegetation specialist ran the Vegetation Response Assessment Index (VEGRAI) model to predict the ecological category for each operational scenario.

The following in-stream biotic assessment was then undertaken:

- Each time series was converted into a stress duration table and provided on a graph for the same months as evaluated during the EWR workshop.
- The requirements set for the low flow EWR scenarios for both fish and macroinvertebrates were copied onto these graphs.
- The operational scenarios were then compared to the EWRs set for the various ecological categories.
- If it was not obvious what the resulting category was, the stress and habitat implications for the operational scenario were investigated and the responses modelled in the Fish Response Assessment Index (FRAI) and Macro invertebrate response Assessment Index (MIRAI) to determine the ecological category.
- The VEGRAI, MIRAI and FRAI results were then used as input to the Ecostatus model to determine the resulting ecological category per operational scenario.

12.3 Results

Table 49 provides a summary of the operational scenarios that were modelled using the WRPM. Detailed information regarding the operational scenarios is documented in report RDM/C000/00/CON/0607.

Table 49: Summary of the operational scenarios evaluated

Sc No	Dev Level	EWR Status	Scenario description	Reasoning
1	2008	Excluded	Base scenario representing the status quo.	This is a new PRESENT DAY. This scenario was not evaluated, but differences from the old PD were noted and reasoning was provided.
4	2008	Included	Based on Scenario 1. EWR Scenario: With exception of EWR 4 and EWR 5, all EWRs in Vaal and one EWR in Thukela downstream of Driel Barrage were included.	Although EWRs are provided as a demand, it was still evaluated. One EWR site (e.g. in the Lower Vaal), could drive the requirements and result in unacceptable situations at EWR sites in the Upper Vaal (too much flow e.g.). NB: The EWR was included as a priority demand and this has a knock on effect on other users, and the operation rules of dams. This is relevant for all scenarios where dams are included.
5	2020	Excluded	Sc 1 representing the future 2020 development conditions excluding the EWRs. Includes VRESSAP pipeline from Vaal Dam to Eastern Sub-system. Includes proposed Polihali Dam and conveyance infrastructure. Includes proposed re-use of mine water. Includes projected possible transfer to the	Key scenarios. Includes most likely future developments and illustrates resulting flows at EWR sites. NO EWRs were included as a demand in the system. Basically, this is the WHAT IF scenarios, i.e., what if we manage the system in this manner without providing EWRs – will the EcoStatus change and if so, how much.

Sc No	Dev Level	EWR Status	Scenario description	Reasoning
			Crocodile catchment.	
6	2020	Included	Based on Sc 5. EWR Scenario: With exception of EWR 4 and EWR 5, all EWRs in Vaal and one EWR in Thukela downstream of Driel Barrage were included.	Combination of Sc 5 and Sc 4.
7	Full utilization (Future development scenario)	Excluded	Scenario representing the full utilization of available water. Based on current infrastructure. Includes VRESSAP pipeline from Vaal Dam to Eastern Sub-system.	This is also a future scenario, but brings in new developments apart from the VRESSAP pipeline. Full utilisation means that there is allocated water, or water available in dams, which have not been used yet.
8	Full utilization (Future development scenario)	Included	Based on Sc 7. EWR Scenario: With exception of EWR 4 and EWR 5, all EWRs in Vaal and one EWR in Thukela downstream of Driel Barrage were included.	Combination of Sc 7 and Sc 4.

13 ECOLOGICAL CONSEQUENCES OF THE OPERATIONAL SCENARIOS

13.1 Overview and objectives

Ecological and water quality consequences of the various operational scenarios were assessed and are described in the sections below. The ecological evaluation is based on an assessment of the impact on the status or ECs recommended for each component. Information on the water quality assessment as a key driver is provided below, followed by the overall assessment.

13.2 Results

A summary of the scenario consequences are shown in Table 50.

A summary of the ecological consequences per scenario for the main stem of the Vaal EWR (Figure 45) and for the tributaries are indicated in Figure 46. In summary the following are conclusions (Figure 35):

- Negative economic impacts (in terms of GDP and employment) may occur as a consequence of applying the Ecological Reserve in the Renoster, Vals and Vet Rivers
- Main stem of Vaal all scenario's meet PES and REC
- Tributaries Scenarios, 4, 7 and 8 meet PES and REC

- Water quality driver and management plans for nutrients and salts – aquatic ecosystem adapted
- Extra flows but main stem altered for many years
- Tributaries less water and water quality issues

Table 50: Scenario consequences

Main Stem	Sc 1 PD REC	Sc 4	Sc 5	Sc 6	Sc 7	Sc 8
16 Bloemhof	E	E	E	E	E	E
18 Schimdtsdrift	C/D	C	C/D	C	C/D	C
Tributaries						
17 Harts	D	D	D	D	D	D
19 Riet	D	C	D	C	D	C

At the presentation to the Department of Water Affairs Management Team on the 7 October 2010 the following was agreed for the future Reserve management for the Lower Vaal (Table 51).

Table 51: Final recommendations per EWR site

EWR site	Recommendation
16 Vaal (Bloemhof)	Sign off for instream REC=D as the current overall PES=E due to non-flow related impacts. Conditions to improve the Riparian Zone should be included.
17 Harts	Sign off for PES=REC=D
18 Vaal (Schmitsdrift)	Sign off for REC=C/D
19 Riet	Sign off for REC=D with a recommendation that the flow measurements at the gauging weir must be improved.

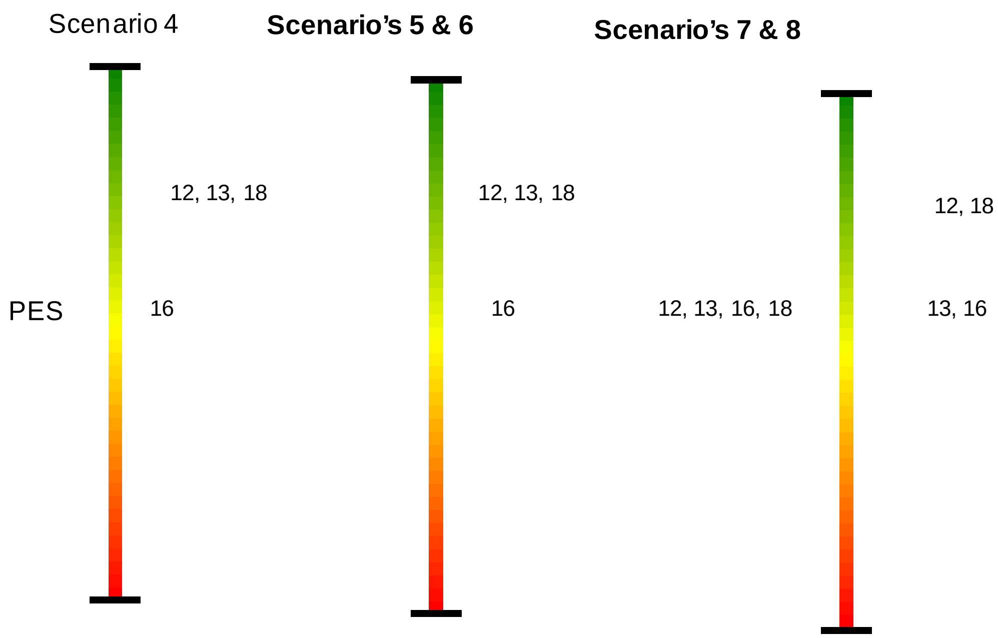


Figure 45 Summary of ecological consequences per scenario for the main stem of the Vaal EWR sites

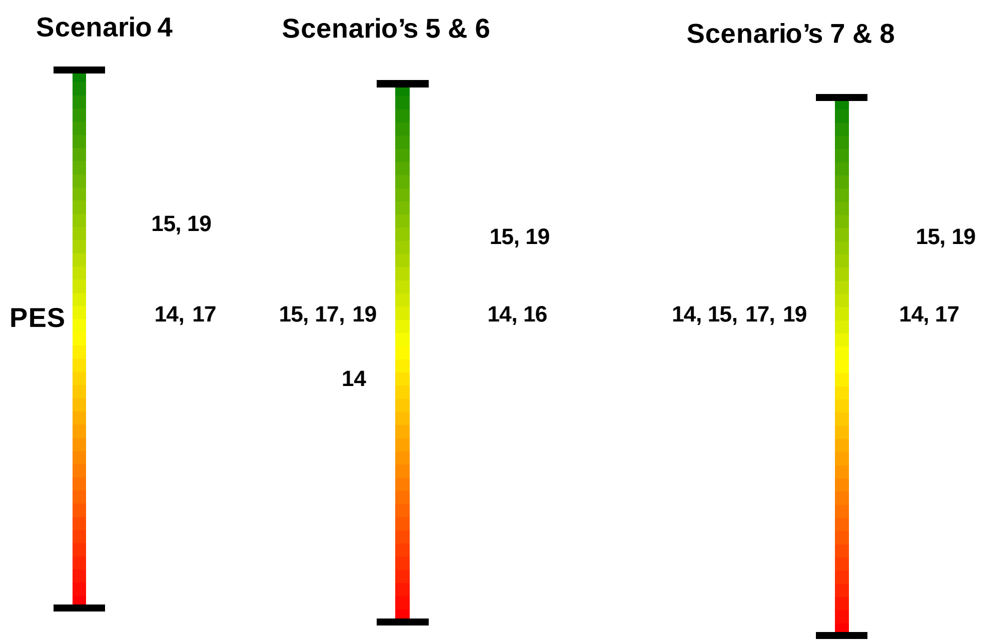


Figure 46: Summary of ecological consequences per scenario for the tributaries of the Vaal EWR sites

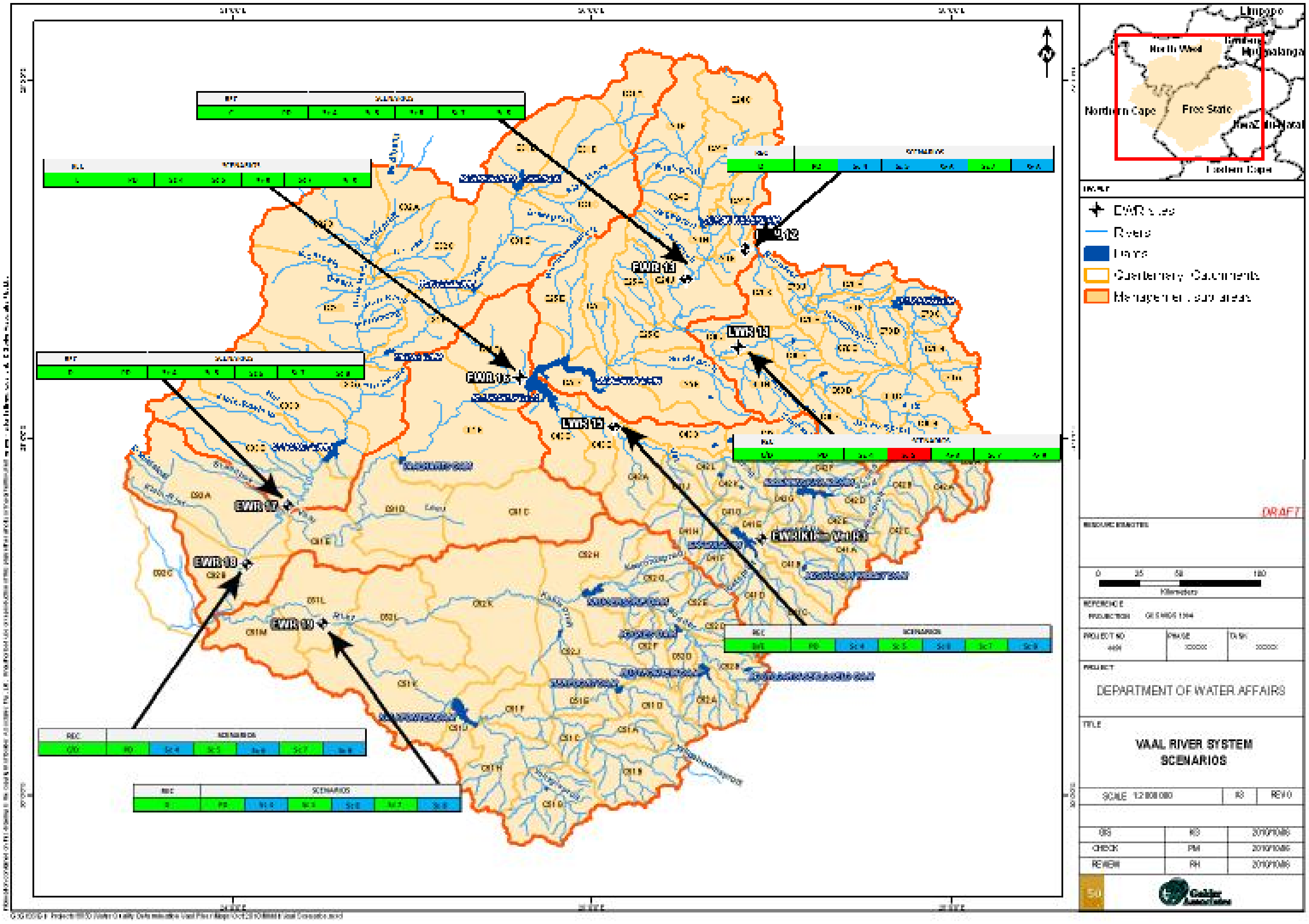


Figure 47: Summary of the Ecological Consequences for the Lower Vaal Catchment

14 SOCIO-ECONOMICS AND GOODS AND SERVICES

14.1 Introduction

Based on a similar approach used for the socio-economic impact assessment for the Upper Vaal WMA (as undertaken by Conningarth), the Lower Vaal WMAs were partitioned into defined economic zones. Several EWR sites were identified and establish along the Vaal River in the Upper, Middle and Lower Vaal WMAs within these economic zones in order to measure present day water use and to make predictions on future water use. These EWR sites were evaluated and identified according to criteria which included hydraulics, land use, regulation and accessibility. Eight EWR sites were then identified within the Middle and Lower Vaal WMAs and present day water use for various water users estimated. From the relevant socio-economic data collected for irrigated agriculture, mining and manufacturing and population within each WMA baseline economic indicators such Gross Domestic Product (GDP), employment and household income were generated for each economic zone using Water Multipliers. These baseline results were then adapted to account for water use (demand) at each of the eight EWR sites.

To assess the socio-economic impacts of either applying or not applying the Ecological Reserve, eight plausible water allocation scenarios were identified by the Project Team. Although all eight scenarios were analysed as part of the overall study, Scenario 8 (which included the EWR) was assessed relative to Scenario 7 specifically for the socio-economic component of the Project. The remaining scenarios were used to assess the impact of alternative options for the inclusion of the EWRs.

For the ecosystems services assessment, 5 water allocation Scenarios were assessed according to impacts on the following river resources:

- Fish;
- Riparian vegetation;
- Recreation; and
- Water quality.

Each resource was scored per Scenario according to whether utilization of the resource remained at current/present day levels or either increased or declined at each EWR site.

14.2 Approach

The methodology used to assess the impacts on Ecosystems Services is similar to the approach used in the Thukela Water Project: Reserve Determination Module (Mander *et al*., 2007). These are described in greater detail in the following section.

A description of the 8 water allocation scenarios used for the purposes of this study is provided in Table 3. Although all eight scenarios were analysed as part of the overall study, scenarios 7 (which excluded the EWRs) and 8 (which included the EWR) were assessed specifically for the socio-economic component of the Project as the water requirements were met for scenarios the remaining scenarios (and there was therefore no impact). The remaining scenarios were used to assess the impact of alternative options for the inclusion of the EWRs. For the ecosystems services assessment, impacts for scenarios 4, 5, 6, 7 and 8 were analyzed against the base Scenario (Scenario 1).

The evaluation of economic impacts takes into consideration the potential impacts of a particular development on the economic environment of a study area (which can be delineated according to impact intensity). More specifically, the way in which the direct benefits and costs of an intervention could affect the local, regional, or national economy can be assessed. The intervention can be in the form of new investment in infrastructure, new development, and adoption of a new policy or services, expansion of current operations. The types of economic impacts stimulated by an intervention are generally positive (in an economic sense) and include creation of additional jobs, generation of business sales and value-added, improved quality of life, an increase in disposable income, and growth of government revenue. For the purposes of this study, the economic intervention arises as a result of different water allocation scenarios, the economic impacts of which can be assessed per water allocation scenario. Three types of economic impacts are generally assessed:

The **direct** economic effects are generated when the new business creates new jobs and purchases goods and services to operate the new facility. Direct impact results in an increase in job creation, production, business sales, and household income;

The **indirect** economic effects occur when the suppliers of goods and services to the new businesses experience larger markets and potential to expand. Indirect impacts result in an increase in job creation, Gross Geographic Product (GGP), and household income; and

The **induced** economic effects represent further shifts in spending on food, clothing, shelter and other consumer goods and services as a consequence of the change in workers and payroll of directly and indirectly affected businesses. This leads to further business growth/decline throughout the local economy.

The work consisted of defining the relevant economics zones per WMA, collecting data for major water users per WMA, inputting these data into the relevant macro-economic models and finally interpreting and assessing the results.

Two models were used to calculate the macro-economic impacts of water use in the different economic zones. This was necessitated by the difference in water sources in the two main economic zone types. In the tributaries the irrigation water is drawn from local sources with a large percentage, if not all, of the required demand for the mining and other urban requirements pumped from the main stem. The approach for this study was based on a similar approach used for the Upper Vaal WMA study where a particular WMA is partitioned into various economic zones. For this study, the economic zones were only used to calculate the baseline or present day economic impacts.

On the main stem the irrigation water, together with the rest of the water, is sourced from the river. A decision was taken by the project team that water demand quantities drawn from the main stem will be supplied by external sources if needed.

On the main stem of the river and for the urban, mining and industrial requirements on the tributaries, the South African Inter-industry Model (SAFRIM) was used to calculate the impact on the introduction of the EWR. For the irrigation from the tributaries the WIM was used to calculate the impact on the introduction of the EWR.

Ecosystem services are the outputs of ecological systems that generate quality of life or well being for people. An ecosystem service is a product that emerges from processes or features within largely natural environments, which enhances human wellbeing and is directly used by people. No longer is capital, skills or labour major constraints to human development - environmental quality is often the limiting factor. Natural capital and associated ecosystem services are now becoming scarce. This study also investigated the anticipated impacts of the various water allocation scenarios on several ecosystem goods and services. These goods and services were partitioned into several resources categories: fish, riparian vegetation, recreation and water quality

14.3 Results

Of the initial eight water allocation scenarios identified by the Project Team, the economic impacts of Scenarios 7 and 8 were modelled for several tributaries of the Vaal. Present day GDP and employment figures per EWR site were calculated using present day water abstraction at each EWR site and economic water multiplier for each economic zone within the Lower Vaal WMAs. The relevant economic zones were:

- Vaal River main-stem;
- Harts;
- Modder; and
- Riet.

Water use data were collected for various water users within the Lower Vaal WMA. Major water users within these WMAs are:

- Irrigated agriculture;
- Mining and manufacturing; and
- Domestic and/or household consumption

Relevant data were collected for each user category and used to estimate water use. These data were then modelled using the SAFRIM and WIM methodology (consistent with the Upper Vaal study) producing baseline economic impacts based on the economic zones identified. The baseline results indicated that irrigated agriculture had a significant economic impact in the Lower Vaal WMA providing R524 million directly to GDP and 7,403 employment opportunities.

Possible further research into this could entail a financial and economic analysis of irrigated agriculture along these tributaries based on water allocation or costs scenarios the aim of which could be to assess the impacts of increasing water cost to irrigators and assessing at what levels costs affect profitability. Necessary trade-offs that could be made could also be identified by such a study. The traffic diagram below (Figure 48) provides a graphic representation of the overall socio-economic impacts of Scenario 8 in the Lower Vaal WMAs.

Figure 48: Traffic light diagram of overall socio-economic impacts of Scenarios 7 and 8 for Lower Vaal WMAs

The methodology used to assess the impacts on Ecosystems Goods and Services in this study was consistent with the approach used for the Upper Vaal WMA. Of the eight water allocation Scenarios identified, Scenarios 4, 5, 6, 7 and 8 were evaluated per EWR site. The approach investigated the impact of each Scenario on Fish, Riparian Vegetation, Recreation and Water Quality resources per EWR site. Overall it was found that by implementing the ER at each EWR site no negative impacts were found except for Scenario 5 at EWR site 14. These negative impacts were driven by impacts on fish species such as the, Smallmouth yellowfish (*Labeobarbus aeneus*), Orange-Vaal mudfish (*Labeo capensis*) and Moggel, (*Labeo umbratus*) and result from reduced flow levels leading to a decrease or disappearance of species from this reach. Scenario 5 cannot, therefore, be recommended as acceptable from an Ecosystems Goods and Services perspective based on these negative impacts. Scenario 6 had the highest overall score for each resource in both the Middle and Lower Vaal WMAs and on this basis must be recommended as the most acceptable Scenario from an Ecosystems Goods and Services perspective. The traffic diagram below (Figure 49) provides a graphic representation of the overall impacts of each Scenario on Ecosystems Goods and Services in the Lower Vaal WMAs.

Figure 49: Traffic light diagram of overall Ecosystems Goods and Services impacts of Scenarios 4, 5, 6, 7 and 8 for Lower Vaal WMAs

15 ECOLOGICAL SPECIFICATIONS (ECOSPECS) AND MONITORING

15.1 Introduction

EcoSpecs are clear and measurable specifications of ecological attributes (e.g. water quality, flow, biological integrity) that define the Ecological Category and serve as an input to Resource Quality Objectives. The ecospecs are intended to provide the quantifiable and enforceable descriptors of the RQOs as they pertain to the ecological objectives for a particular resource (in this case a particular river reach).

Threshholds of Potential Concern (TPCs) are points along a continuum of change in selected Ecospecs, which prompt management action. Such action may involve attention to the causes of change or a reassessment of the validity of the ecospecs or TPCs, as part of an adaptive management strategy.

Ecological water resource monitoring (EWRM) consists of the combined monitoring for Ecological Reserve Monitoring (ERM) and the River Health Programme (RHP). The EWRM therefore measures whether the ecological objectives set according to the Ecological Reserve Process and the RHP (in terms of Ecological Categories and EcoSpecs) is being met.

The purpose of monitoring is to:

- Determine whether the ecological objectives (in terms of Ecological Categories and EcoSpecs) are being met;
- Identify the possible cause of the problem; and
- Determine the required actions according to a Monitoring decision support system to be followed if the ecological objectives are not being met.

15.2 Ecospecs

The following table is a summary of the proposed monitoring frequency for the Ecological Reserve for the Lower Vaal EWR sites 16 to 19 (Table 52).

Table 52 Summary of proposed monitoring frequency for the Ecological Reserve for the Lower Vaal

Reserve component	Monitoring Frequency
Hydrology	Daily monitoring at closest DWA weir
Water Quality	Monthly, Quarterly (EC and Chlorophyll a)
Geomorphology	Every 2nd year: Daily hydrology and Fixed-point photography Every 5 – 10 years: Bed material composition; Cross-sections and Aerial photographs
Fish	Monitoring should be conducted twice annually. If only once annually

	then the intermediate dry –wet season would be preferred.
Macroinvertebrates	Wet and dry season sampling
Riparian Vegetation	Monitoring should be conducted annually during the wet season (Spring to early Summer). Monitoring may be reduced to one survey every two to three years, however, any significant, change should precipitate immediate surveys which should be conducted annually for at least three years in order to monitor the change and determine whether it was a stochastic event or the beginning of a trend

It is important to note that the proposed Rapid Habitat Monitoring Programme (RHAM) has not been tested in the Lower Vaal.

If this programme is to be implement then the suggested monitoring frequency in Table 52 would altered and the RHAM monitoring would be used a s screening approach. If the TPC are triggered then the proposed monitoring would click in.

16 CAPACITY BUILDING

The team members that received training in this project are included in Table 24.

Table 53 : List of team members that received capacity building in the Lower Vaal

Mentee/trainee	Mentor	Skills Developed
Dr Jennifer Molwantwa	Dr Ralph Heath	General process, water quality
Lindo Hlongwane	Mark Rountree	General process, geomorphology, GAI
Peter Kimburg	Dr Ralph Heath, Dr Neels Kleynhans, Dr Pieter Kotze, Dr Johan Engelbrecht	General process, fish, FRAI, Habitat Flow Stressor Response
Alvar Koning	Christa Thirion, Dr Rob Palmer, Dr Ralph Heath	General process, MARAI, macroinvertebrates, Habitat Flow Stressor Response
Adrian Hudson	James MacKenzie, Dr Ralph Heath	General process, VEGRAI,
Justin du Toit	Dr William Mullens (Conningarth), Rene Ford, Dr Ralph Heath, Greg Huggins	General process, socio-economics, goods and services

Mushoni Makatu	Prof Denis Hughes, Ken Haumann, Retha Stassen, Susan Swart, Dr Angelina Jordanova	General process, hydrology, HAI, Habitat Flow Stressor Response
Thulani Magagula	Prof Denis Hughes, Ken Haumann, Retha Stassen, Susan Swart, Dr Angelina Jordanova	General process, hydrology, HAI, Habitat Flow Stressor Response

The following are some learning's from members of the Golder Project Team whilst working on the socio-economic component of the Vaal Determination Study.

- The socio-economic and ecosystems services components of the Comprehensive Reserve Determination Study for the Vaal WMAs are relatively small but important components of the overall Reserve Determination Study in terms of their role in quantifying the broader social and ecosystems impacts. The overall Project Team were multidisciplinary and professionals in each of their respective fields. Important lessons learnt from being included in the Project Team include:

    - Communication amongst Project Team members: Given the scale and scope of Reserve Determination Study, effective communication amongst members of the Project Team has been vital to completing this work to an acceptably high standard. When the Project Team is large, however, communication becomes even more essential and on numerous occasions during this Project, difficulties in communicating had to be overcome.

    - Interdependence of Project components: Understanding how Project components are linked and how each component relates to one another is an important lesson learnt during this study. It is essential to understand the broader objectives of the Project and how the component one is responsible for may affect or influence the component of another Project Team Member.

    - Professional conduct and presentation: Interacting with Project Team members gives one an opportunity to learn about how to conduct and present oneself professionally and appropriately at Project Team meetings and workshops.

Members of the CD: RDM were part of the whole process from inception phase, site selection, workshops and review.

17 CONCLUSIONS AND RECOMMENDATIONS

17.1 Summary of Final Results

The natural and present day MARs as provided by WRP are given in Table 54. The final flow requirements are expressed as a percentage of either the natural or present day MAR in **Table 55**.

Table 54 : Natural and PD MARs (MCM) of the EWR sites

EWR site	NMAR (MCM)	PMAR (MCM)
EWR 16	3242.51	1699.32
EWR 17	147.85	124.72
EWR 18	3347.19	1177.28
EWR 19	403.86	247.67

Table 55 : Summary of results as a percentage of the natural and PD MAR

EWR site	EC	NMAR (MCM)	PMAR (MCM)	Maintenance low flows (%NMAR)	Drought low flows (%NMAR)	High flows (%NMAR)	Long term mean (%NMAR)	Maintenance low flows (%PMAR)	Drought low flows (%PMAR)	High flows (%PMAR)	Long term mean (%PMAR)
EWR 16	D Instream PES, REC	3242.51	1699.32	7.97	5.93	5.05	13.02	15.21	11.32	9.64	24.85
EWR 17	D PES, REC	147.85	124.72	59.17	0.35	13.34	72.51	70.14	0.41	15.81	85.95
EWR 18	C PES, REC	3347.19	1177.28	2.84	1.51	4.85	7.69	8.09	4.31	13.78	21.86
EWR 19	C/D PES, REC	403.86	247.67	13.44	0.08	28.91	42.35	21.91	0.13	47.14	69.05

17.1 Conclusions

The confidence in the flow requirements set at the different EWR sites within the Middle and Lower Vaal Catchment were generally Low. This was mainly due to an array of problems encountered during the EWR assessment and a summary of these various problems are provided below.

Hydrology

EWR 16 and 17:

For the application of the DRM the PD hydrology was used as reference hydrology because it was higher than natural during the dry season. Therefore the EWRs were set higher than natural and the DRM cannot accommodate this situation as the program will keep on decreasing the flows down to natural. As all flows that were set were less than PD, PD could therefore be used as the reference. This also meant that PD hydrology would guide the seasonal distribution of the EWRs which was acceptable as the objectives for these sites were to set a realistic flow regime considering the present conditions. This matched the overall objective of maintaining the PES which is a function of the PD hydrology at these sites.

EWR 18:

The modelled PD hydrology was of low confidence and there is a possibility that there is more water in the system that was modelled. This was due to various factors, amongst others the abstraction to the Vaal Gamagara transfer which was included in the modelling as the full allocation without verification of what was actually being used. Based on this information flows were set higher than present day modelled data during the wet season. This was done not because the objective was to improve the EC, but to maintain it, taking a more realistic present day hydrology into account. Any percentages comparing EWR to present day would therefore not be relevant as the specialists believed the present hydrology was underestimated during the wet season.

EWR 19:

The confidence in the Riet-Modder River hydrology was low due as there are indications that the simulations are inaccurate and not representative of present conditions in the river system and the transfers from the Orange River to improve water quality in the Riet River was excluded from modelling. Due to the uncertainty of the hydrology to improve the EcoStatus to a B, decreased dry season flows will be required as one of the main factors. Due to the low confidence in the modelled present day hydrology, there was no resolution to distinguish between a C and a B EcoStatus. Present day flows will therefore maintain the C EC, and flows lower than Present Day were set that would also maintain the C EC. For the application of the DRM the PD hydrology was used as reference hydrology. It is likely that as one moves towards natural, these decreased flows could result in a B EcoStatus if other non-flow related activities are also addressed.

Riparian vegetation

The riparian vegetation component was not surveyed along the hydraulic profile during the 2007-2008 Reserve determination study. In the absence of surveyed vegetation data assumptions had to be made regarding the presence of important vegetation indicators as well as inundation levels in order to check the low flow requirements, set by the instream biotic components, to ensure that the flows catered for any riparian vegetation (specifically marginal) requirements.

Hydraulic data

The cross-sections at EWR 16, 17 and 18 were placed through a pool. Therefore the lookup tables did not provide information for low flows below the depth of the pools. These depths are required to set low and drought flows in the fast flowing areas such as riffles. Furthermore, the biological surveys were undertaken at a multi-channel area with riffles further downstream. The biota found at the site and the habitats they require and utilize were not representative of the conditions in the pool. The cross-section and hydraulic data could not be used to set EWRs.

The locations of EWR 16, 17 and 18 did not allow for extrapolation from other EWR sites with better hydraulic information and therefore these sites were assessed based on available hydraulic information. More recent data collected in 2010 as part of the ORASECOM biomonitoring study (ORASECOM, 2011a and b) was however available and aided in furthering the understanding of the habitat responses to flow changes.

17.2 Recommendations

The issues can be addressed through Ecological Water Resources Monitoring (EWRM). As part of a EWRM programme the Rapid Habitat Assessment Method (RHAM) should be included as the application of this method will improve the confidence in hydraulic data especially at EWR 16, 17 and 18 and allow for more clarity on the hydrological issues of the Middle and Lower Vaal River. The RHAM was developed during 2007 - 2009 and it is recommended that a RHAM survey is undertaken at sites where applicable during EWRM. It is foreseen that due to the size and nature of the Vaal River, the RHAM for wadeable rivers might not be possible at all sites. The semi - wadeable (still to be tested) RHAM could be applicable. RHAM data may provide additional information on habitat suitability and the biota associated with this habitat. Due to the hydraulic data being unsuitable for use, it is not recommended that any additional improvements in confidence in determining the EWRs are attempted. This would require new cross-sections and new hydraulic modelling which is a serious investment. Detailed monitoring with photopoint monitoring at KNOWN flows is strongly recommended.

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