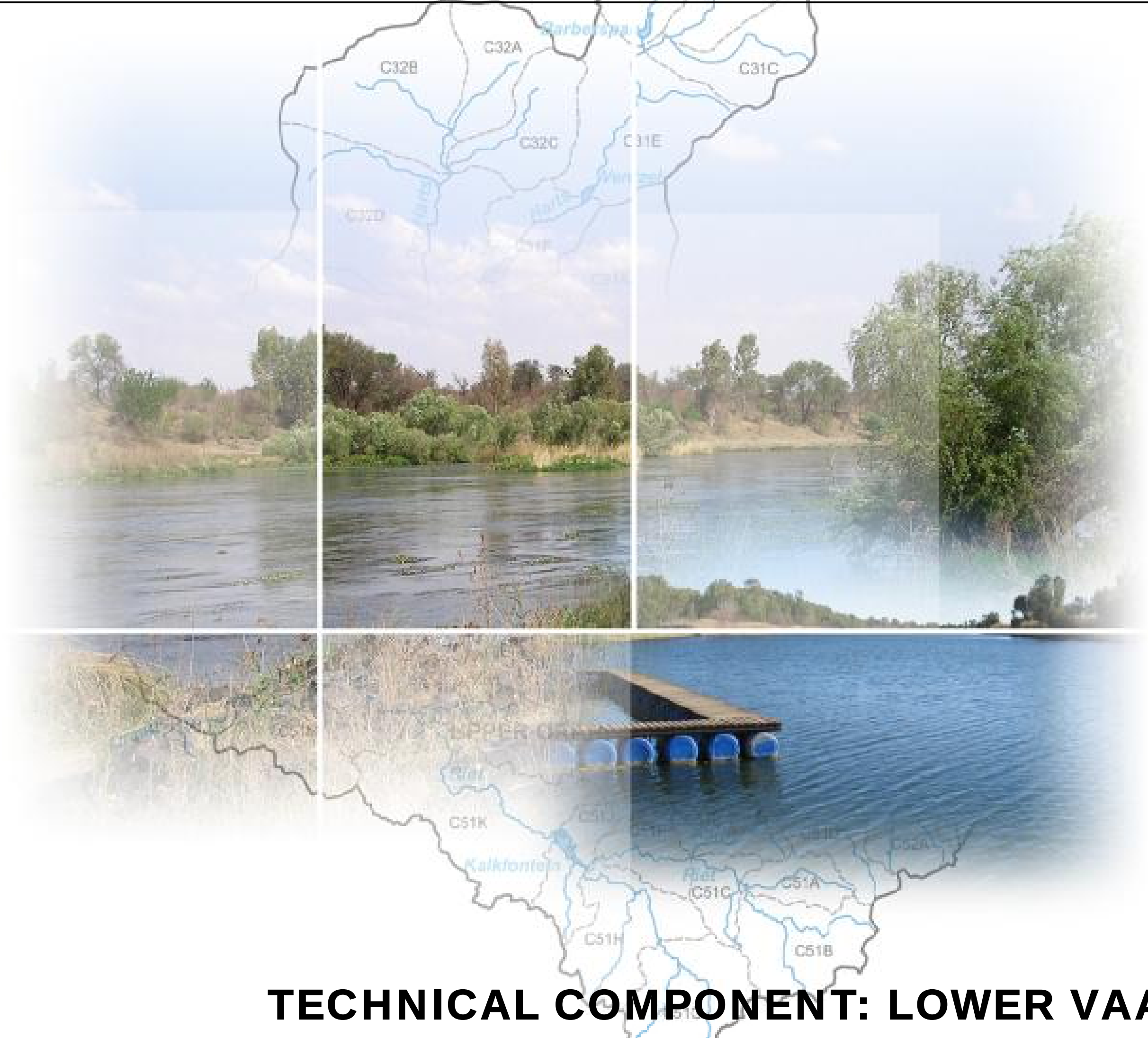
COMPREHENSIVE RESERVE DETERMINATION

INTEGRATED VAAL RIVER SYSTEM

SURFACE WATER

ECOLOGICAL WATER REQUIREMENTS



TECHNICAL COMPONENT: LOWER VAAL

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EXECUTIVE SUMMARY

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.

The CD: RDM initiated the Comprehensive Reserve Determination Study for the Lower Vaal Water Management Area (WMA), North West Province. 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 a comprehensive level of detail. 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.

This report provides the results of step 4 (Quantify Ecological Water Requirements) of the 8-step Reserve determination process for the rivers of the Lower Vaal catchment area.

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.

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 and almost no surface flows, 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 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.

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 and almost no surface flows, 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 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 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.

The results of the Ecoclassification per EWR site is summarised in Table C. All the EWR sites were assessed on a comprehensive level of detail.

Table C: Summary of Ecoclassification

EWR site	River	Quaternary catchment	Reference MAR (Mm^3/a)	PES	EIS	REC
EWR16	Vaal	C91A	3242.508	E	Moderate	D (Instream)
EWR17	Harts	C33C	147.854	D	Moderate	D
EWR18	Vaal	C92B	3347.193	C/D	Moderate	C/D
EWR19	Riet	C51L	403.864	D	High	D

*The reference flows refers to the natural flow

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 D. The final flow requirements are expressed as a percentage of the natural MAR in Table E.

Table D: 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 E: 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**

EWR Sites	EC	Maintenance Low Flows (% nMAR)	Drought Low Flows (% nMAR)	High Flows (% nMAR)	Long Term Mean (% nMAR)
	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 Mm3/a during the period of projection – Reserved in the Middle Vaal WMA.

A reservation applies to the transfer of 18 Mm3/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.

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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 the Lower Vaal Water Management Area (WMA), North West Province. 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 a comprehensive level of detail.

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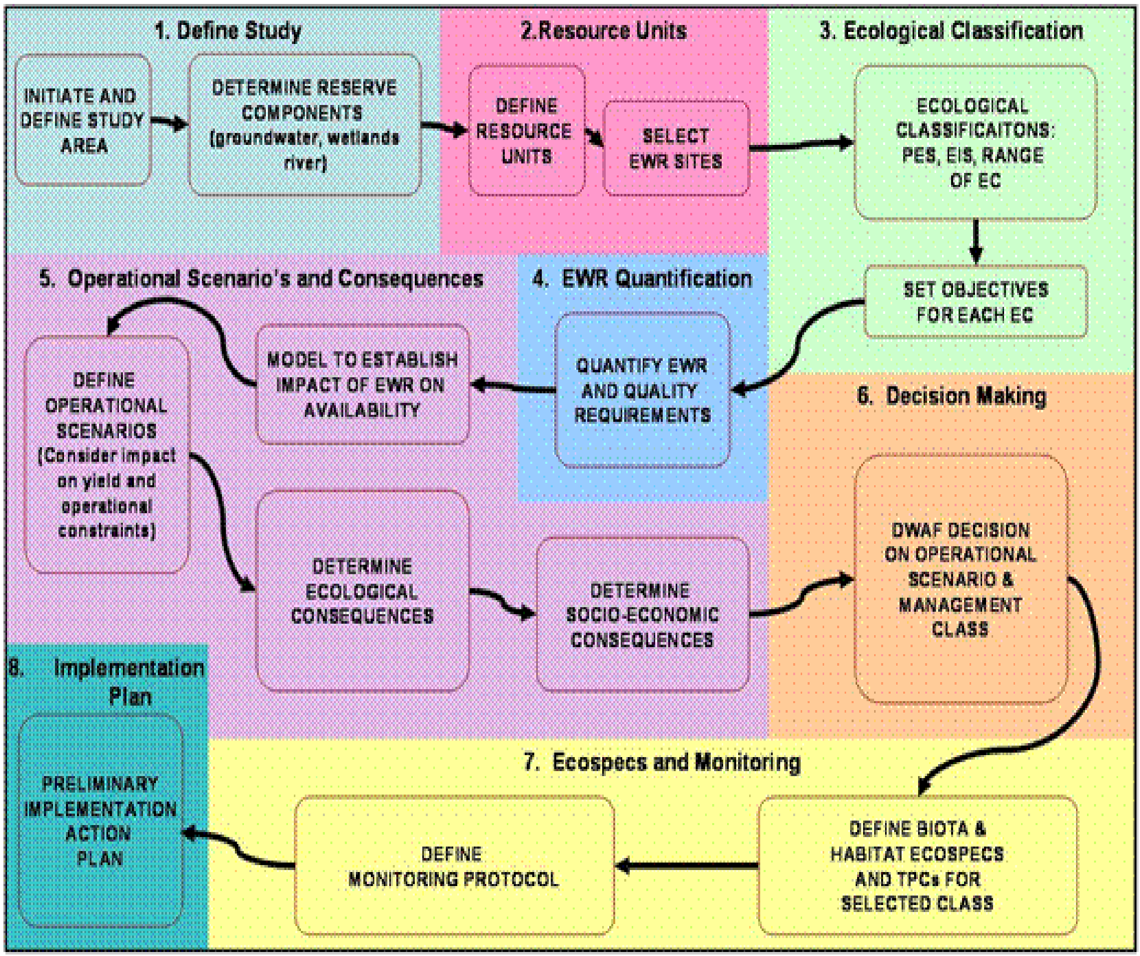

Figure 1.1: Generic procedure for the determination of the ecological Reserve

1.2 STUDY AREA

The study area for the Comprehensive Reserve determination is the Lower Vaal and Upper Orange WMAs (part of WMA 10 and 13) (Figure 1.2). 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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PRIMARY CATCHMENT	SUB-CATCHMENT	QUARTENARY CATCHMENTS	AVERAGE GROSS AREA (km^2)
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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 1.2 and shown in Figure 1.2.

Table 1.2: 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

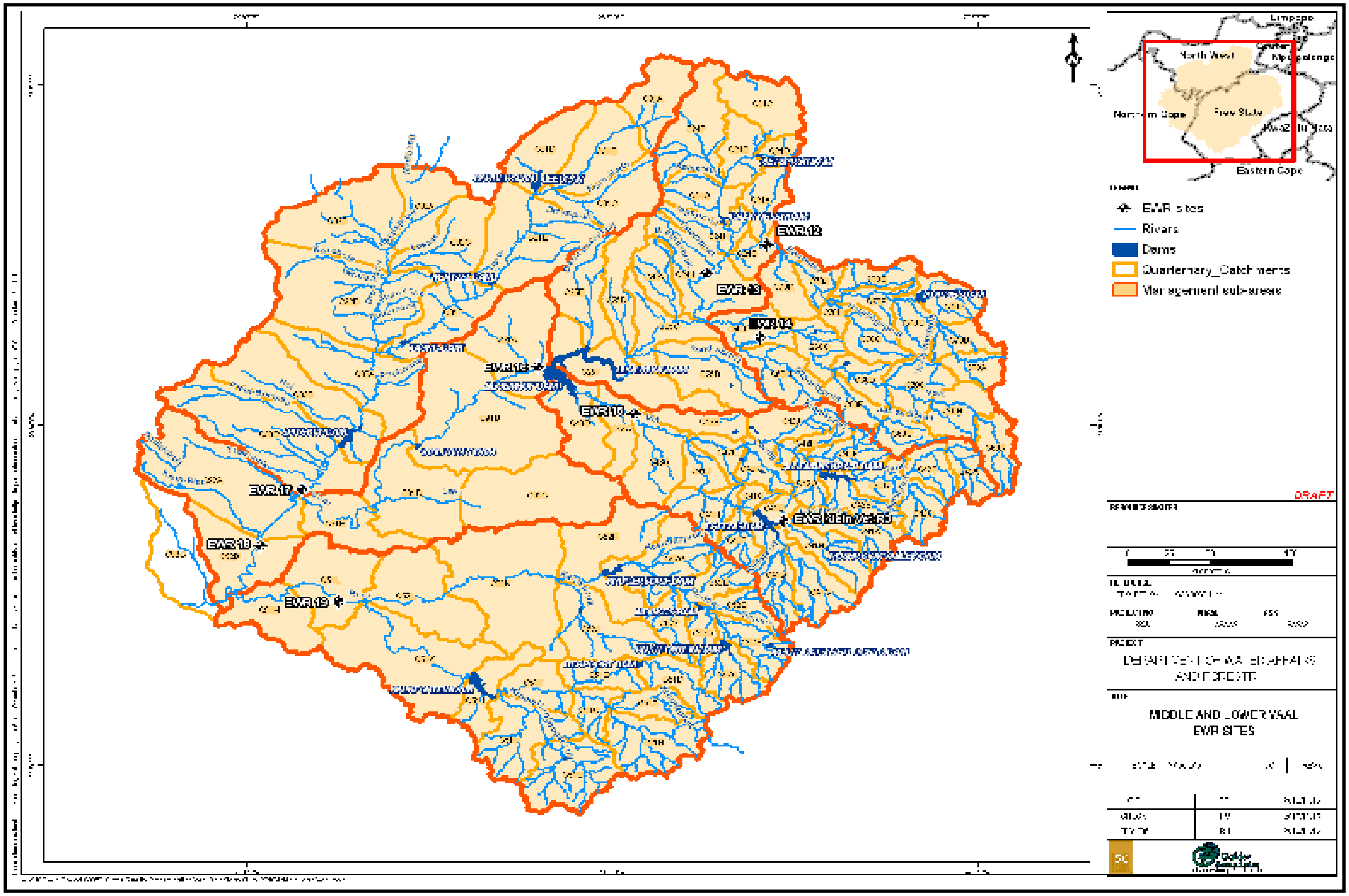


Figure 1.2: Resource Units and selected EWR sites for the Lower and Middle Vaal catchment

1.3 METHODOLOGY FOR SETTING RIVERINE EWRs

SPATSIM (Spatial and Time Series Information Modelling) (Hughes and Forsythe, 2006) was used as a framework for the hydrological information used within the process, and to capture the EWR results.

1.3.1 Comprehensive EWR sites

During the Ecological Water Requirement (EWR) scenario assessment of the Lower Vaal, the EWR sites were identified as having more flows than natural with:

- EWR 16 and EWR 18 having higher base flows in winter, with a loss of or masked summer floods due to the Vaal Dam, Vaal Barrage and Bloemhof Dam; and
- EWR 17 and EWR 19 having less flow all year round.

1.3.2 Low flows

The Habitat Flow Stressor Response method (HFSR) (IWR S2S, 2004) was used to set low flows, a method adjusted from the Building Block Methodology (BBM; King and Louw, 1998). The objective is to supply a relationship between an index of stress (0 to 10) and habitat availability during different flow conditions. This information is required for the determination of required stresses for different Ecological Categories (ECs). The information on habitat collated during the course of the study, as well as the hydraulics, was used to determine the stress indices. These indices form the basis for the determination of low flows for the EWR scenarios using the Habitat Flow Stressor Response method.

1.3.3 High flows

The approach to set high flows is a combination of the Downstream Response to Imposed Flow Transformation (DRIFT; Brown and King, 2001) approach and BBM. The high flows are determined as follows:

- Flood ranges for each flood class and the geomorphology and riparian vegetation functions are identified and tabled by the relevant specialists.
- These are provided to the instream specialists who indicate;
  - which instream function these floods cater for,
  - whether additional instream functions apart from the generic list are required,
  - whether any instream functions are not necessary and can be deleted from the list,
  - whether they require any additional flood classes to the ones identified.
- The number of floods for each flood class is identified as well as where (early, mid, late) in the season they should occur.
- The floods are evaluated by the hydrologist to determine whether they are realistic. A nearby gauge if available is used for this.
- The hydrologist then determines the daily average and documents the months in which the floods are required.

1.4 PURPOSE OF THIS REPORT

The activities and tasks for step 4 of the Reserve determination process were undertaken in accordance with the appropriate approaches and methodologies for rivers as prescribed by the CD: RDM of DWA, namely:

- The methodology as set out in DWAF (1999): Resource Directed Measures for Protection of Water Resources; Volume 3: River Ecosystems Version 1.0 (Revised water quality methodology, 2002).
- The revised methods as outlined in Louw and Hughes (2002), the Habitat Flow Stressor Response (HFSR) manual of IWR Source-to-Sea (2004) and the EcoClassification manual of Kleynhans *et al* (2005).
- EcoClassification and EcoStatus determination in River EcoClassification: Manual for EcoStatus Determination (version 2) of Kleynhans and Louw (2007).
- SPATSIM (Spatial and Time Series Information Modelling) (Hughes and Forsythe, 2006) was used as a framework to determine the EWR results.
- The Habitat Flow Stressor Response method (HFSR) (IWR S2S, 2004) was used to set low flows, a method adjusted from the Building Block Methodology (BBM; King and Louw, 1998).
- The ecological water requirements for the rapid EWR sites were estimated using the Hughes Desktop Reserve Model (DRM) (DWAF, 1999) for the Recommended Ecological Category (REC).
- The approach to set high flows is a combination of the Downstream Response to Imposed Flow Transformation (DRIFT; Brown and King, 2001) approach and BBM.

This report serves to document the results of the determination of the ecological water requirements for the rivers in the Lower Vaal Water Management Area which were finalised at several specialist meetings held during 15 – 19 September 2008 and 17 – 21 November 2009. The final results are provided per EWR site and include the following:

- Determination of stress indices for macroinvertebrates and fish
- Integrated stress indices
- Determination of ecological water requirements for low flows and floods
- Confidence in the results
- Conclusions and recommendations.

1.5 REPORT STRUCTURE

This report is structured into the following sections:

Section 1: Introduction

This section.

Section 2: Determination of stress indices

The stress indices for all physical and biological components at each comprehensive EWR site are provided.

Section 3: Determination of ecological water requirements

These chapters provide results of different EWR scenarios with respect to low and high flows for the respective comprehensive EWR sites. Aspects covered in these chapters are component and integrated/stress curves, generating stress requirements, general approach to high flows, final results and confidence in the final results.

Section 4: Conclusions and Recommendations

The results are summarised and recommendations are made.

Section 5: References

2 DETERMINATION OF STRESS INDICES

2.1 EWR 16: VAAL RIVER: DOWNSTREAM OF BLOEMHOF DAM

Stress indices are set for fish and macroinvertebrates to aid in the determination of low flow requirements. The stress index describes the consequences of flow reduction on flow dependant biota. It therefore describes the habitat conditions for fish and macroinvertebrate indicator species or guild for various low flows. These habitat conditions for different flows are rated from 10 (zero flows) to 0, which is optimum habitat for the indicator species.

2.1.1 Indicator species or group

Fish indicator species: Large semi-rheophilic species (BKIM)

Two indicator species were selected for this EWR site. As a result of the absence of any true rheophilic fish species in this system, ***Labeobarbus kimberleyensis*** (BKIM) was selected as a representative of large semi-rheophilic (LSR) species. This indicator is a semi-rheophilic species that is dependent on perennial flows (requiring water column for cover preferences) and specific flow-depth classes (Fast-Deep and to a lesser extent Fast-Shallow).

Macroinvertebrate indicator taxa

Flow dependant (FDI) and Water quality intolerant (WQI) macroinvertebrate taxa were selected on the basis of their sensitivity to changes in velocity and water quality. Only taxa that occur commonly at the site were selected and include:

- *Tricorythus* sp. requires velocities of > 0.6 m/s, but may persist at lower velocities (> 0.1 m/s). The indicator is a rheophilic species dependant on the perennial flow and is moderately sensitive to water quality conditions. These taxa are not expected to tolerate wide fluctuations in flow and water quality.

Riparian vegetation indicator species

Indicator species included:

- *Cyperus longus:* Obligate riparian sedge that occurs in both the marginal and lower zones. This sedge has narrow, dark-green leaves, which can feel quite rough and sharp. The flower spikes, which appear in October - February, are red-brown. Plants reach about 50cm in height. This species propagates by means of seeds, prefers wet but not inundated soil.

- *Phragmites australis: Phragmites australis*, Common reed, commonly forms extensive stands (known as reed beds), which may be as much as 1 square kilometre (0.39 sq mi) or more in extent. Where conditions are suitable it can spread at 5 metres (16 ft) or more per year by horizontal runners, which put down roots at regular intervals. It can grow in damp ground, in standing water up to 1metre deep, or even as a floating mat.

- *Imperata cylindrica*: perennial rhizomatous grass. It grows from 0.2–1 m tall. Roots are up to 1.2 meters deep, but 0.4 m is typical in sandy soil. It spreads both through small seeds, which are easily carried by the wind, and rhizomes.

2.1.2 Stress flow index

The stress flow index is generated in terms of habitat and biotic response and is discussed below.

<u>Habitat response</u>

Habitat response is used to derive the biota's response to provide a biota stress index and represents the instantaneous response of habitat to flow changes, based on a site specific 0 – 10 scale for instream biota where:

- 0 – Optimum habitat (fixed at the natural maximum baseflow – calculated using the wettest flow month discharge at the maintenance flow of 50% – 60% for the Vaal River at the EWR site).
- 10 **-** No flow (i.e., there can still be surface water in pools).

<u>Biota response</u>

The biota stress index is the instantaneous response of biota to change in habitat (and therefore flow), based on a scale of 0 – 10 where:

- 0 = Optimum habitat with least amount of stress possible for the indicator groups at the site (fixed at the natural maximum baseflow in the same way as for the habitat response).

- 10 = No flow (i.e., there can still be surface water in pools). The biota response will depend on the indicator groups present, i.e. rheophilics will be gone whereas semi-rheophilics will still be present and survive.

The fish species response index is calculated using the fish habitat rating for each of the discharges evaluated for assessing habitat response. The macroinvertebrate (FDI) index is derived by considering the habitat response and % occurrence of habitat conditions at different flows.

Integrated stress curve

The integrated stress curve represents the highest stress for fish (blue) and macroinvertebrates (red below black) at a specific flow. The highest discharge representing a specific stress is used to define the integrated stress curve. Figure 2.1 illustrates this graphically.

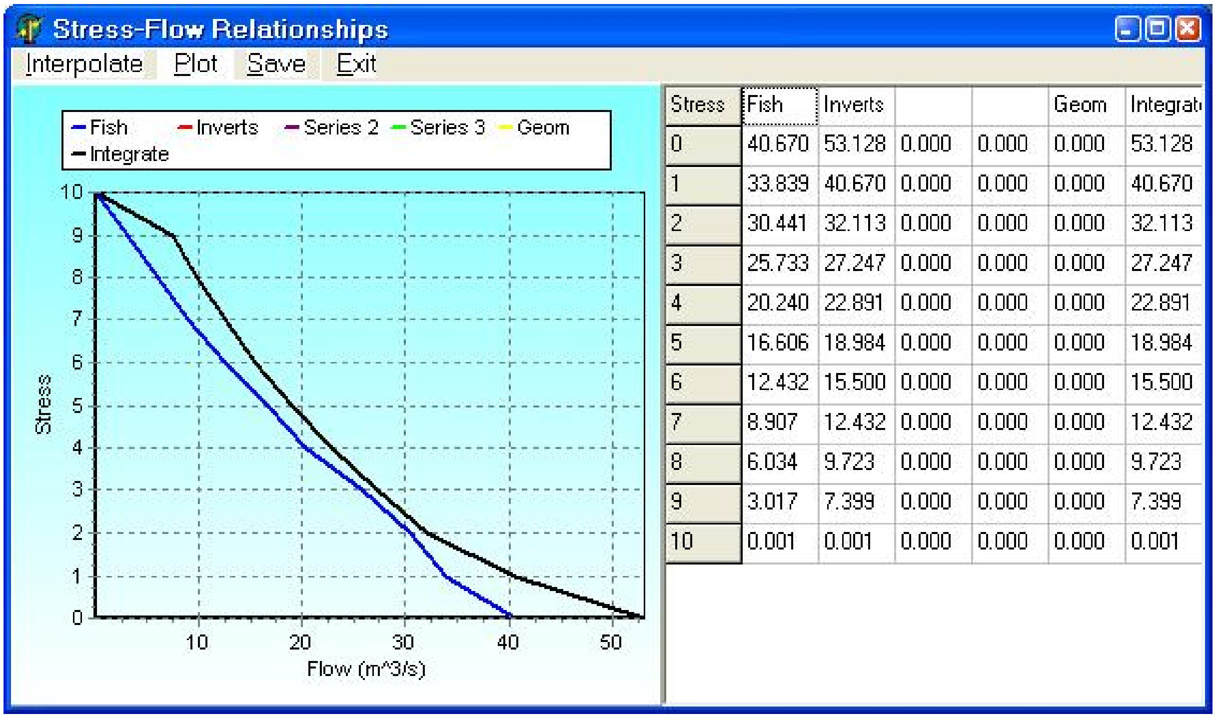


Figure 2.1: Component and integrated stress curves for EWR 16

Table 2.1 provides the summarised biotic response for the integrated stresses.

Table 2.1: Integrated stress and summarised habitat/biotic responses for fish and macroinvertebrates

Integrated stress	Flow m^3/s	Habitat and/or Biotic responses
0 (SSR)	53.128	Fish guild: All habitats optimal (5*).
1 (SSR)	40.670	SSR guild: Water quality and abundance is optimal, Cover and connectivity is good (4) while spawning and nursery habitats are moderate (3). LSR guild: All habitats are optimal.
2 (SSR)	32.113	SSR guild: Habitats as above with nursery and spawning habitats low (2). LSR guild: All habitats are slightly less than optima (4.5).
3 (SSR)	27.247	SSR guild: Connectivity, water quality spawning and nursery habitat as above. Abundance is good and cover moderate. LSR guild: All habitat is good (4 – 4.5). All FDI habitats in excess and taxa are very abundant and healthy.
4 (SSR)	22.891	SSR guild: Spawning and nursery habitats are very low (1) with rest of habitats moderate and water quality good. LSR guild: Spawning and nursery habitats are low (2.5) while rest of habitat occurrence is moderate and water quality good.
5 (SSR)	18.984	SSR guild: All habitat occurrence is moderate although spawning and nursery is very low (1). LSR guild: Connectivity and water quality is moderate while rest of habitats are low (2.5). Critical FDI habitats sufficient. Most rheophilic species persist, but slight (80 %) reduction.
6 (SSR)	15.500	Reduced FDI critical habitat. Most rheophilic species persist, but abundances reduced.
7 (SSR)	12.432	SSR guild: Spawning and nursery habitats are very rare (0.5) and rest of habitat occurrence is low. LSR guild: Spawning and nursery habitats are very rare, abundance and cover are very low (1.5) while connectivity and water quality is low.

Integrated stress	Flow m^3/s	Habitat and/or Biotic responses
		Critical FDI habitats limited. All life stages viable in limited areas, critical life stages of some sensitive rheophilic species at risk.
8 (LSR)	9.723	Fish guild habitats are as above. Critical FDI habitat very reduced. Critical life-stages of sensitive rheophilic species at risk or non-viable.
9 (LSR)	7.399	SSR guild: Spawning, nursery and abundance are very rare. Connectivity and cover is very low with low water quality. LSR guild: Spawning and nursery habitats are absent, with very low cover. Rest of habitat occurrence is very rare. No critical FDI habitat. Some rheophilic species persist, but most disappear. All life-stages of sensitive rheophilic species at risk or non-viable.
10	0.001	Only pool dwelling species present. Only hyporheic refugia, no surface water for FDIs. Indicator taxa no longer present.

* Suitability rating 0 (not suitable) – 5 (highly suitable)

2.2 EWR 17: HARTS RIVER: LLOYDS WEIR

Stress indices are set for fish and macroinvertebrates to aid in the determination of low flow requirements. The stress index describes the consequences of flow reduction on flow dependant biota. It therefore describes the habitat conditions for fish and macroinvertebrate indicator species or guild for various low flows. These habitat conditions for different flows are rated from 10 (zero flows) to 0, which is optimum habitat for the indicator species.

2.2.1 Indicator species or group

<u>Fish indicator species: Large semi-rheophilic species (BAEN)</u>

Two indicator species were selected for this EWR site. As a result of the absence of any true rheophilic fish species in this system, *Labeobarbus aeneus* (BAEN) was selected as a representative of large semi-rheophilic (LSR) species. This indicator is a semi-rheophilic species that is dependent on flows during the breeding season and has a high preference for fast shallow habitats (FS), moderate to high preferences for fast deep and slow deep habitats, and requires substrate cover preferences.

<u>Macroinvertebrate indicator taxa</u>

Flow dependant (FDI) and Water quality intolerant (WQI) macroinvertebrate taxa were selected on the basis of their sensitivity to changes in velocity and water quality. Only taxa that occur commonly at the site were selected and include:

- *Ephemeroptera (Leptophlebiidae)* an indicator species for the rheophilic macro-invertebrate community.

Riparian vegetation indicator species

Indicator species included:

- *Cynodon dactylon: O*ccurs on almost all soil types especially in fertile soil, e.g. loamy soil, and is often found in moist sites along rivers. The flower spikes, which appear in October **-** February, are red-brown. Plants reach about 30cm in height. This species propagates by means of seeds, thrives in wet but not inundated soil.

- *Phragmites australis:* Common reed, commonly forms extensive stands (known as reed beds), which may be as much as 1 square kilometre (0.39 sq mi) or more in extent. Where conditions are suitable it can spread at 5 metres (16 ft) or more per year by horizontal runners, which put down roots at regular intervals. It can grow in damp ground, in standing water up to 1 metre (3 ft 3 in) or so deep, or even as a floating mat.

- *Myriophyllum spicatum:* Aquatic plant which grows, submerged in the instream substrate. In aquatic areas where native aquatic plants are not well established, the ***M. spicatum*** can quickly spread. It can create dense mats that interfere with recreational activity. ***M. spicatum*** can grow from broken off stems which increases the rate in which the plant can spread and grow.

2.2.2 Stress flow index

The stress flow index is generated in terms of habitat and biotic response and is discussed below.

Habitat response

Habitat response is used to derive the biota's response to provide a biota stress index and represents the instantaneous response of habitat to flow changes, based on a site specific 0 – 10 scale for instream biota where:

- 0 – Optimum habitat (fixed at the natural maximum baseflow – calculated using the wettest flow month discharge at the maintenance flow of 50% – 60% for the Harts River at the EWR site).
- 10 **-** No flow (i.e., there can still be surface water in pools).

Biota response

The biota stress index is the instantaneous response of biota to change in habitat (and therefore flow), based on a scale of 0 – 10 where:

- 0 = Optimum habitat with least amount of stress possible for the indicator groups at the site (fixed at the natural maximum baseflow in the same way as for the habitat response).

- 10 = No flow (i.e., there can still be surface water in pools). The biota response will depend on the indicator groups present, i.e. rheophilics will be gone whereas semi-rheophilics will still be present and survive.

The fish species response index is calculated using the fish habitat rating for each of the discharges evaluated for assessing habitat response. The macroinvertebrate (FDI) index is derived by considering the habitat response and % occurrence of habitat conditions at different flows.

Integrated stress curve

The integrated stress curve represents the highest stress for fish (blue below black) and macroinvertebrates (red) at a specific flow. The highest discharge representing a specific stress is used to define the integrated stress curve. Figure 2.2 illustrates this graphically.

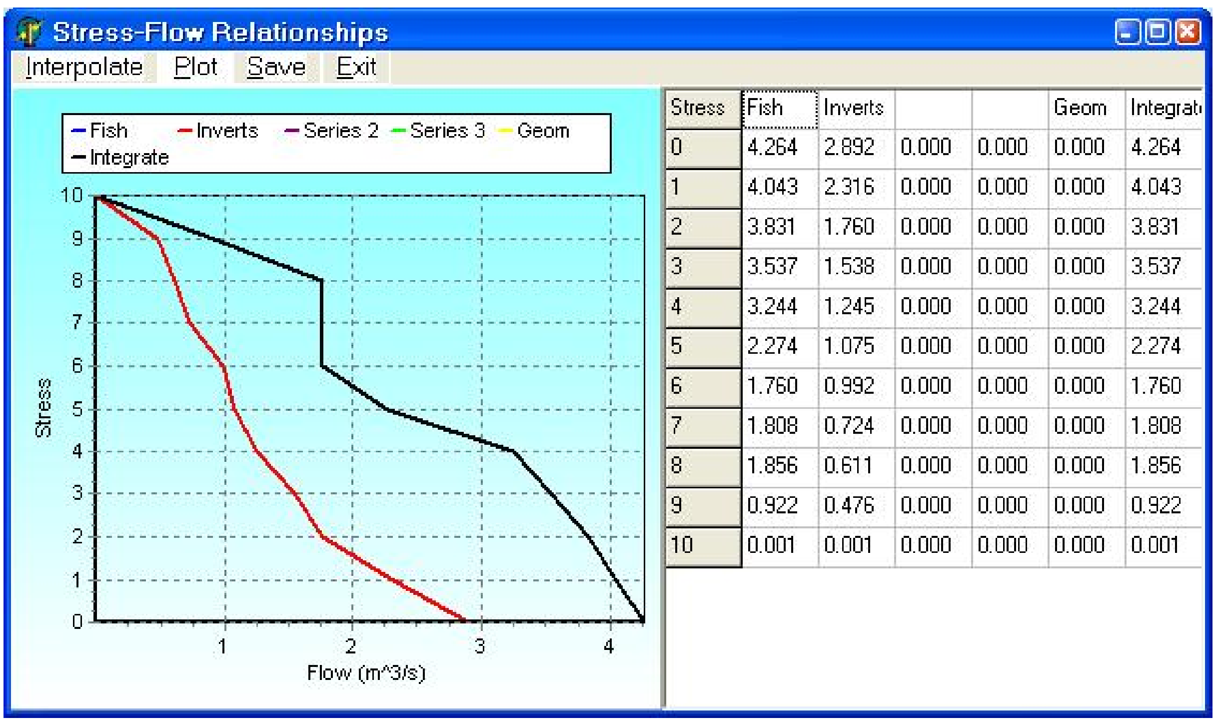


Figure 2.2: Component and integrated stress curves for EWR 17

Table 2.2 provides the summarised biotic response for the integrated stresses.

Table 2.2: Integrated stress and summarised habitat/biotic responses for fish and macroinvertebrates

Integrated stress	Flow m^3/s	Habitat and/or Biotic responses
0 (SSR)	4.264	Fish guild: All habitats optimal (5*).

Integrated stress	Flow m^3/s	Habitat and/or Biotic responses
1 (SSR)	4.043	SSR guild: Water quality and abundance is optimal, Cover and connectivity is good (4) while spawning and nursery habitats are moderate (3). LSR guild: All habitats are optimal.
2 (SSR)	3.831	SSR guild: Habitats as above with nursery and spawning habitats low (2). LSR guild: All habitats are slightly less than optima (4.5).
3 (SSR)	3.537	SSR guild: Connectivity, water quality spawning and nursery habitat as above. Abundance is good and cover moderate. LSR guild: All habitat is good (4 – 4.5). All FDI habitats in excess, and taxa are very abundant and healthy.
4 (SSR)	3.244	SSR guild: Spawning and nursery habitats are very low (1) with rest of habitats moderate and water quality good. LSR guild: Spawning and nursery habitats are low (2.5) while rest of habitat occurrence is moderate and water quality good.
5 (SSR)	2.274	SSR guild: All habitat occurrence is moderate although spawning and nursery is very low (1). LSR guild: Connectivity and water quality is moderate while rest of habitats are low (2.5). Critical FDI habitats sufficient. Most rheophilic species persist, but slight (80 %) reduction.
6 (SSR)	1.760	Reduced FDI critical habitat. Most rheophilic species persist, but abundances reduced.
7 (SSR)	1.808	SSR guild: Spawning and nursery habitats are very rare (0.5) and rest of habitat occurrence is low. LSR guild: Spawning and nursery habitats are very rare, abundance and cover are very low (1.5) while connectivity and water quality is low. Critical FDI habitats limited. All life stages viable in limited areas, critical life stages of some sensitive rheophilic species at risk.
8 (LSR)	1.856	Fish guild habitats are as above. Critical FDI habitat very reduced. Critical life-stages of sensitive rheophilic species at risk or non-viable.
9 (LSR)	0.922	SSR guild: Spawning, nursery and abundance are very rare. Connectivity and cover is very low with low water quality. LSR guild: Spawning and nursery habitats are absent, with very low cover. Rest of habitat occurrence is very rare. No critical FDI habitat. Some rheophilic species persist, but most disappear. All life-stages of sensitive rheophilic species at risk or non-viable.
10	0.01	Only pool dwelling species present. Only hyporheic refugia, no surface water for FDIs. Indicator taxa no longer present.

* Suitability rating 0 (not suitable) – 5 (highly suitable)

2.3 EWR 18: VAAL RIVER: SCHMIDTSDRIFT

Stress indices are set for fish and macroinvertebrates to aid in the determination of low flow requirements. The stress index describes the consequences of flow reduction on flow dependant biota. It therefore describes the habitat conditions for fish and macroinvertebrate indicator species or guild for various low flows. These habitat conditions for different flows are rated from 10 (zero flows) to 0, which is optimum habitat for the indicator species.

2.3.1 Indicator species or group

Fish indicator species: Large semi-rheophilic species (BKIM)

Two indicator species were selected for this EWR site. As a result of the absence of any true rheophilic fish species in this system, ***Labeobarbus kimberleyensis*** (BKIM) was selected as a representative of large semi-rheophilic (LSR) species. This indicator is a semi-rheophilic species that is dependent on perennial flows (requiring water column for cover preferences) and specific flow-depth classes (Fast-Deep and to a lesser extent Fast-Shallow).

Macroinvertebrate indicator taxa

Flow dependant (FDI) and Water quality intolerant (WQI) macroinvertebrate taxa were selected on the basis of their sensitivity to changes in velocity and water quality. Only taxa that occur commonly at the site were selected and include:

- *Coleoptera (Dytiscidae)* is a species dependant on the perennial flow and marginal vegetation.

Riparian vegetation indicator species

Indicator species included:

- *Cynodon dactylon: O*ccurs on almost all soil types especially in fertile soil, e.g. loamy soil, and is often found in moist sites along rivers. The flower spikes, which appear in October **-** February, are red-brown. Plants reach about 30cm in height. This species propagates by means of seeds, thrives in wet but not inundated soil.

- *Phragmites australis:* Common reed, commonly forms extensive stands (known as reed beds), which may be as much as 1square kilometre or more in extent. Where conditions are suitable it can spread at 5 metres or more per year by horizontal runners, which put down roots at regular intervals. It can grow in damp ground, in standing water up to 1 metre or so deep, or even as a floating mat.

- *Myriophyllum spicatum:* Aquatic plant which grows, submerged in the instream substrate. In aquatic areas where native aquatic plants are not well established, the *M. spicatum* can quickly spread. It can create dense mats that interfere with recreational activity. *M. spicatum* can grow from broken off stems which increases the rate in which the plant can spread and grow.

2.3.2 Stress flow index

The stress flow index is generated in terms of habitat and biotic response and is discussed below.

Habitat response

Habitat response is used to derive the biota's response to provide a biota stress index and represents the instantaneous response of habitat to flow changes, based on a site specific 0 – 10 scale for instream biota where:

- 0 – Optimum habitat (fixed at the natural maximum baseflow – calculated using the wettest flow month discharge at the maintenance % of 50 – 60% for the Vaal River at the EWR site).
- 10 **-** No flow (i.e., there can still be surface water in pools).

Biota response

The biota stress index is the instantaneous response of biota to change in habitat (and therefore flow), based on a scale of 0 – 10 where:

- 0 = Optimum habitat with least amount of stress possible for the indicator groups at the site (fixed at the natural maximum baseflow in the same way as for the habitat response).

- 10 = No flow (i.e., there can still be surface water in pools). The biota response will depend on the indicator groups present, i.e. rheophilics will be gone whereas semi-rheophilics will still be present and survive.

The fish species response index is calculated using the fish habitat rating for each of the discharges evaluated for assessing habitat response. The macroinvertebrate (FDI) index is derived by considering the habitat response and % occurrence of habitat conditions at different flows.

Integrated stress curve

The integrated stress curve represents the highest stress for fish (blue below black) and macroinvertebrates (red) at a specific flow. The highest discharge representing a specific stress is used to define the integrated stress curve. Figure 2.3 illustrates this graphically.

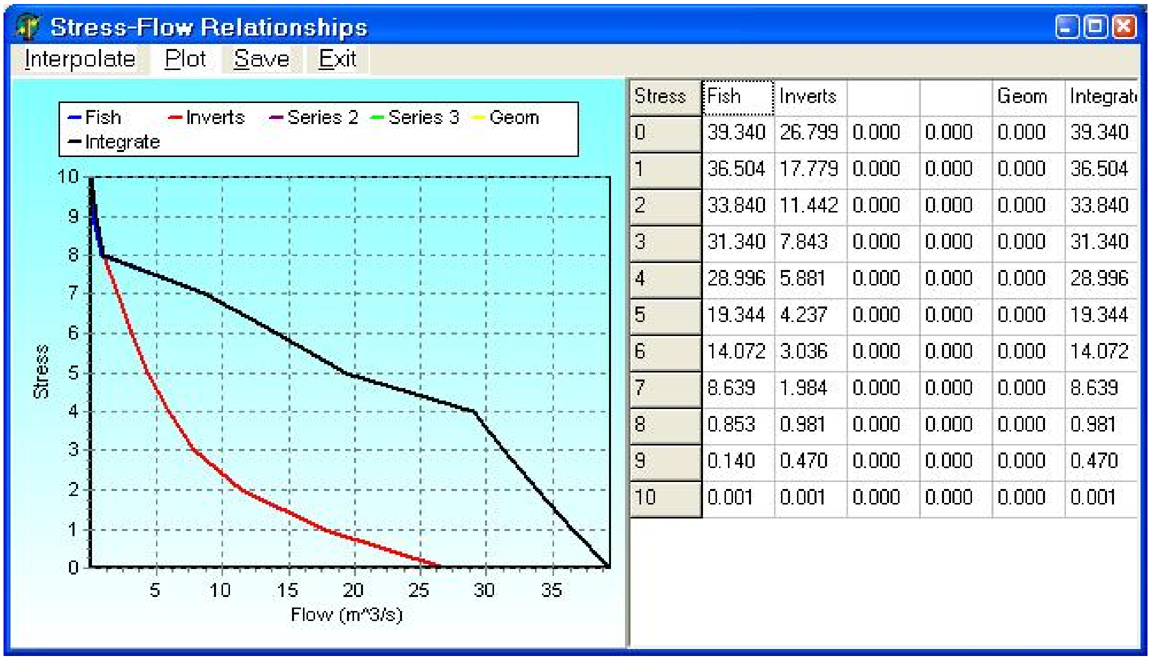


Figure 2.3: Component and integrated stress curves for EWR 18

Table 2.3 provides the summarised biotic response for the integrated stresses.

Table 2.3: Integrated stress and summarised habitat/biotic responses for fish and macroinvertebrates

Integrated stress	Flow m^3/s	Habitat and/or Biotic responses
0 (SSR)	39.340	Fish guild: All habitats optimal (5*).
1 (SSR)	36.504	SSR guild: Water quality and abundance is optimal, Cover and connectivity is good (4) while spawning and nursery habitats are moderate (3). LSR guild: All habitats are optimal.
2 (SSR)	33.840	SSR guild: Habitats as above with nursery and spawning habitats low (2). LSR guild: All habitats are slightly less than optima (4.5).
3 (SSR)	31.340	SSR guild: Connectivity, water quality spawning and nursery habitat as above. Abundance is good and cover moderate. LSR guild: All habitat is good (4 – 4.5). All FDI habitats in excess, and taxa are very abundant and healthy.
4 (SSR)	28.996	SSR guild: Spawning and nursery habitats are very low (1) with rest of habitats moderate and water quality good. LSR guild: Spawning and nursery habitats are low (2.5) while rest of habitat occurrence is moderate and water quality good.
5 (SSR)	19.344	SSR guild: All habitat occurrence is moderate although spawning and nursery is very low (1). LSR guild: Connectivity and water quality is moderate while rest of habitats are low (2.5). Critical FDI habitats sufficient. Most rheophilic species persist, but slight (80 %) reduction.
6 (SSR)	14.072	Reduced FDI critical habitat. Most rheophilic species persist, but abundances reduced.
7 (SSR)	8.639	SSR guild: Spawning and nursery habitats are very rare (0.5) and rest of habitat occurrence is low. LSR guild: Spawning and nursery habitats are very rare, abundance and cover are very low (1.5) while connectivity and water quality is low.

Integrated stress	Flow m^3/s	Habitat and/or Biotic responses
		Critical FDI habitats limited. All life stages viable in limited areas, critical life stages of some sensitive rheophilic species at risk.
8 (LSR)	0.981	Fish guild habitats are as above. Critical FDI habitat very reduced. Critical life-stages of sensitive rheophilic species at risk or non-viable.
9 (LSR)	0.470	SSR guild: Spawning, nursery and abundance are very rare. Connectivity and cover is very low with low water quality. LSR guild: Spawning and nursery habitats are absent, with very low cover. Rest of habitat occurrence is very rare. No critical FDI habitat. Some rheophilic species persist, but most disappear. All life-stages of sensitive rheophilic species at risk or non-viable.
10	0.001	Only pool dwelling species present. Only hyporheic refugia, no surface water for FDIs. Indicator taxa no longer present.

* Suitability rating 0 (not suitable) – 5 (highly suitable)

2.4 EWR 19: RIET RIVER AT LILLYDALE LODGE

Stress indices are set for fish and macroinvertebrates to aid in the determination of low flow requirements. The stress index describes the consequences of flow reduction on flow dependant biota. It therefore describes the habitat conditions for fish and macroinvertebrate indicator species or guild for various low flows. These habitat conditions for different flows are rated from 10 (zero flows) to 0, which is optimum habitat for the indicator species.

2.4.1 Indicator species or group

Fish indicator species: Large semi-rheophilic species (BAEN)

Two indicator species were selected for this EWR site. As a result of the absence of any true rheophilic fish species in this system, ***Labeobarbus kimberleyensis*** (BKIM) was selected as a representative of large semi-rheophilic (LSR) species. This indicator is a semi-rheophilic species that is dependent on perennial flows (requiring water column for cover preferences) and specific flow-depth classes (Fast-Deep and to a lesser extent Fast-Shallow).

Macroinvertebrate indicator taxa

Flow dependant (FDI) and Water quality intolerant (WQI) macroinvertebrate taxa were selected on the basis of their sensitivity to changes in velocity and water quality. Only taxa that occur commonly at the site were selected and include:

- *Ephemeroptera (Heptageniidae)* is a rheophilic species dependant on the perennial flow.

Riparian vegetation indicator species

Indicator species included:

- *Panicum coloratum:* Found on sandy or clay soils in river beds, drainage courses, around pans or in depressions. Occurs mainly on seasonally waterlogged soils, rarely on heavy clays that are waterlogged for long periods. A shortly rhizomatous, tufted (erect, geniculate or decumbent) perennial, sometimes with long spreading stolons. Plants reach about 30cm in height. This species propagates by means of seeds, thrives in wet but not inundated soil.

- *Phragmites australis:* Common reed, commonly forms extensive stands (known as reed beds), which may be as much as 1 square kilometre or more in extent. Where conditions are suitable it can spread at 5 metres or more per year by horizontal runners, which put down roots at regular intervals. It can grow in damp ground, in standing water up to 1 metre or so deep, or even as a floating mat.

- *Myriophyllum spicatum:* Aquatic plant which grows, submerged in the instream substrate. In aquatic areas where native aquatic plants are not well established, the ***M. spicatum*** can quickly spread. It can create dense mats that interfere with recreational activity. ***M. spicatum*** can grow from broken off stems which increases the rate in which the plant can spread and grow.

2.4.2 Stress flow index

The stress flow index is generated in terms of habitat and biotic response and is discussed below.

Habitat response

Habitat response is used to derive the biota's response to provide a biota stress index and represents the instantaneous response of habitat to flow changes, based on a site specific 0 – 10 scale for instream biota where:

- 0 – Optimum habitat (fixed at the natural maximum baseflow – calculated using the wettest flow month discharge at the maintenance flow of 50% – 60% for the Riet River at the EWR site).
- 10 **-** No flow (i.e., there can still be surface water in pools).

Biota response

The biota stress index is the instantaneous response of biota to change in habitat (and therefore flow), based on a scale of 0 – 10 where:

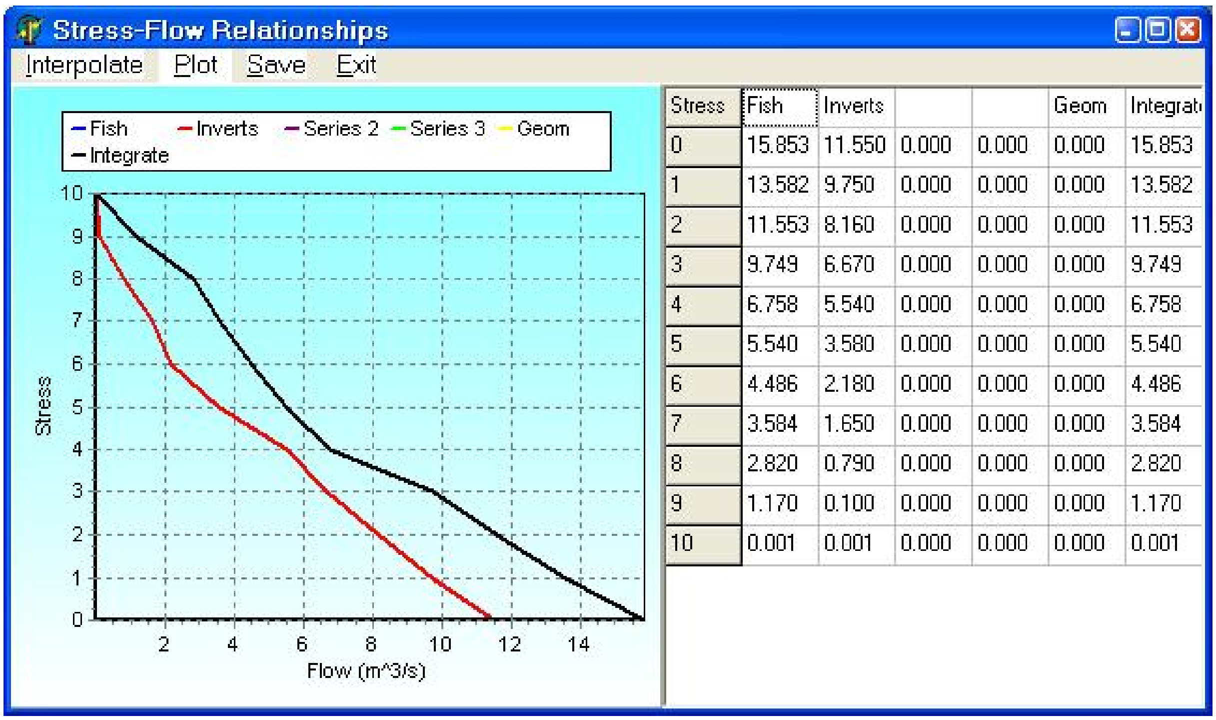
- 0 = Optimum habitat with least amount of stress possible for the indicator groups at the site (fixed at the natural maximum baseflow in the same way as for the habitat response).

- 10 = No flow (i.e., there can still be surface water in pools). The biota response will depend on the indicator groups present, i.e. rheophilics will be gone whereas semi-rheophilics will still be present and survive.

The fish species response index is calculated using the fish habitat rating (Appendix B) for each of the discharges evaluated for assessing habitat response. The macroinvertebrate (FDI) index is derived by considering the habitat response and % occurrence of habitat conditions at different flows.

Integrated stress curve

The integrated stress curve represents the highest stress for fish (blue below black) and macroinvertebrates (red) at a specific flow. The highest discharge representing a specific stress is used to define the integrated stress curve. Figure 2.4 illustrates this graphically.



Stress	Fish	Inverts			Geom	Integrat
0	15.853	11.550	0.000	0.000	0.000	15.853
1	13.582	9.750	0.000	0.000	0.000	13.582
2	11.553	8.160	0.000	0.000	0.000	11.553
3	9.749	6.670	0.000	0.000	0.000	9.749
4	6.758	5.540	0.000	0.000	0.000	6.758
5	5.540	3.580	0.000	0.000	0.000	5.540
6	4.486	2.180	0.000	0.000	0.000	4.486
7	3.584	1.650	0.000	0.000	0.000	3.584
8	2.820	0.790	0.000	0.000	0.000	2.820
9	1.170	0.100	0.000	0.000	0.000	1.170
10	0.001	0.001	0.000	0.000	0.000	0.001

Figure 2.4: Component and integrated stress curves for EWR 19

Table 2.4 provides the summarised biotic response for the integrated stresses.

Table 2.4: Integrated stress and summarised habitat/biotic responses for fish and macroinvertebrates

Integrated stress	Flow m^3/s	Habitat and/or Biotic responses
0 (SSR)	15.853	Fish guild: All habitats optimal (5*).
1 (SSR)	13.582	SSR guild: Water quality and abundance is optimal, Cover and connectivity is good (4) while spawning and nursery habitats are moderate (3).

Integrated stress	Flow m^3/s	Habitat and/or Biotic responses
		LSR guild: All habitats are optimal.
2 (SSR)	11.553	SSR guild: Habitats as above with nursery and spawning habitats low (2). LSR guild: All habitats are slightly less than optima (4.5).
3 (SSR)	9.749	SSR guild: Connectivity, water quality spawning and nursery habitat as above. Abundance is good and cover moderate. LSR guild: All habitat is good (4 – 4.5). All FDI habitats in excess and taxa are very abundant and healthy.
4 (SSR)	6.758	SSR guild: Spawning and nursery habitats are very low (1) with rest of habitats moderate and water quality good. LSR guild: Spawning and nursery habitats are low (2.5) while rest of habitat occurrence is moderate and water quality good.
5 (SSR)	5.540	SSR guild: All habitat occurrence is moderate although spawning and nursery is very low (1). LSR guild: Connectivity and water quality is moderate while rest of habitats are low (2.5). Critical FDI habitats sufficient. Most rheophilic species persist, but slight (80 %) reduction.
6 (SSR)	4.486	Reduced FDI critical habitat. Most rheophilic species persist, but abundances reduced.
7 (SSR)	3.584	SSR guild: Spawning and nursery habitats are very rare (0.5) and rest of habitat occurrence is low. LSR guild: Spawning and nursery habitats are very rare, abundance and cover are very low (1.5) while connectivity and water quality is low. Critical FDI habitats limited. All life stages viable in limited areas, critical life stages of some sensitive rheophilic species at risk.
8 (LSR)	2.820	Fish guild habitats are as above. Critical FDI habitat very reduced. Critical life-stages of sensitive rheophilic species at risk or non-viable.
9 (LSR)	1.170	SSR guild: Spawning, nursery and abundance are very rare. Connectivity and cover is very low with low water quality. LSR guild: Spawning and nursery habitats are absent, with very low cover. Rest of habitat occurrence is very rare. No critical FDI habitat. Some rheophilic species persist, but most disappear. All life-stages of sensitive rheophilic species at risk or non-viable.
10	0.001	Only pool dwelling species present. Only hyporheic refugia, no surface water for FDIs. Indicator taxa no longer present.

* Suitability rating 0 (not suitable) – 5 (highly suitable)

3 DETERMINATION OF THE ECOLOGICAL WATER REQUIREMENTS

This section provides the ecological water requirements as determined with the Habitat Flow Stressor Response approach for the low flows and the DRIFT/BBM approach for the flood requirements.

The results of the Ecoclassification per EWR site is summarised in Table 3.1. All the EWR sites were assessed on a comprehensive level of detail. Detail hydraulic results are provided in Appendix A.

Table 3.1: Summary of Ecoclassification

EWR site	River	Quaternary catchment	Reference MAR (Mm^3/a)	PES	EIS	REC
EWR16	Vaal	C91A	3242.508	E	Moderate	D (Instream)
EWR17	Harts	C33C	147.854	D	Moderate	D
EWR18	Vaal	C92B	3347.193	C/D	Moderate	C/D
EWR19	Riet	C51L	403.864	D	High	D

*The reference flows refers to the natural flow

The following approach was followed for the comprehensive assessments (EWR 16 to 19):

- Identify the flow data set (natural or present day) to be used as reference flows;
- Identify the maximum base flows for the low flow and high flows months;
- Create the stress-flow relationship obtained from the fish and macroinvertebrate specialists in SPATSIM;
- Generate initial EWRs with the Desktop Reserve Model (DRM) for the REC for low flows without floods;
- Output stress-duration curves for the ecological specialists to evaluate and specify how the desktop curves can be changed to match their ecological objectives;
- Modify the desktop EWRs to achieve the desired curve and set the low flow requirements;
- Determine the high flow requirements (floods) for the fish, macroinvertebrate, geomorphology and riparian vegetation specialists and check against daily flows (if available);
- Combine the flood requirements with the existing low flow requirements; and
- Generate the final EWRs and check for any exceedences of the reference flows.

3.1 HYDROLOGY ASSESSMENT

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.

3.2 HYDRAULIC ASSESSMENT

Four EWR sites were selected during the field surveys of the rivers of the Lower Vaal system (Appendix A). The hydraulic advantages and disadvantages per EWR site are provided in Table 3.2.

Table 3.2: Advantages and disadvantages of the EWR sites

River	Site	Advantages	Disadvantages
Vaal	EWR16	Easy access to the site. Single channel. Gauging weir for flow records.	Vegetation on both banks influences overall flow resistance at high flows. Downstream hydraulic structures may create an additional backwater effect under high flow condition.
Harts	EWR17	Easy access to the site. Single channel. Gauging weir for flow records.	Under high flows an additional flow resistance from the confluence backwater could occur.
Vaal	EWR18	Easy access to the site. Single channel. Gauging weir for flow records.	Vegetation on both banks influences overall flow resistance at high flows. Downstream hydraulic structures may create an additional backwater effect under high flow condition.
Riet	EWR19	Gauging weir for flow records.	Hydraulics is more complex. Large scale river bad substrates result to non-uniform flow with potential for non-horizontal water profile at low flows. There are instream vegetated islands that additionally complicate hydraulic modelling.

The stage-discharge data collected for the EWR sites are summarised in Table 3.3.

Table 3.3: Summary of hydraulic data collected at EWR sites

River	Site no.	Date	Discharge Q (m^3/s)	Max. flow depth, y (m)	Slope
Vaal	EWR 16	26.09.2007	40.89	2.94	0.00005
		25.08.2008	55.03	2.99	0.00005
Harts	EWR 17	25.08.2008	1.13	1.05	0.00124
		20.06.2008	0.89	0.96	0.00124
Vaal	EWR 18	20.06.2008	4.99	3.14	0.00010
		26.08.2008	2.11	3.00	0.00010
Riet	EWR 19	27.09.2007	5.26	0.84	0.00170
		24.06.2008	4.20	0.77	0.00277
		26.08.2008	2.55	0.67	0.00760

The above information was utilised during the Habitat Flow Stressor Response process to determine the stress indices for low flows and the flood requirements for the fish, macroinvertebrates, geomorphology and riparian vegetation.

3.3 EWR 16: VAAL RIVER: DOWNSTREAM OF BLOEMHOF DAM

3.3.1 Ecoclassification summary of EWR 16 Vaal River: Downstream of Bloemhof Dam

EWR 16: VAAL RIVER: DOWNSTREAM OF BLOEMHOF DAM

EIS: MODERATE
PES: E
Combination of flow and non-flow related impacts. Impacts mostly related to changes in flow regime due to Vaal Dam, Vaal River Barrage and Bloemhof Dam.
REC: D (instream)
Maintain the PES due to the **MODERATE** EIS rating. However note that there is *B. kimberleyensis* (near threatened) expected and *A. sclateri* expected which warrants improvement of the fish EC. Other fish are isolated within this reach of river due to regulations and no fish ladders.

AEC up: C/D
Changes in hydrology
- Lower winter base flow
- Increase November flows
- Allow first-flush freshet cues in November

Water quality management
- Reduce nutrients from agricultural runoff and WWTW's
- Reduced salts due to greater flows and flushing
- Increase flows

Fish
- Migratory barrier and the species missing need migratory corridor. Unless fishway built there will be no changes. Stuck between Vaal Harts weir and Bloemhof dam and a section of the river that species have been extinct – *Barbus anoplus*, *B. palidonosus*, and *B. trimaculatus*

AEC down:
None due to current PES

Driver	PES & REC Category	Trend	AEC up	AEC down
Hydrology	D	Stable	D	
Water quality	C	Upwards nutrients	B/C	
Geomorphology	D/E	Negative EC and nutrients	D/E	
Response components	**PES & REC Category**	**Trend**	**AEC up**	**AEC down**
Fish	E	Stable-negative	E	
Aquatic invertebrates	C/D	Stable	C	
Instream	D		D	
Riparian vegetation	F	Stable - negative	D	
Ecostatus	E		D	

The REC for EWR 16 situated on the Vaal River in quaternary catchment C91A is a D category. The reference flow used was the present day simulated flows with the mean annual runoff (MAR) of 1699.32 Mm^3.

3.3.2 Base flows

The maximum base flows for the wet and dry season were determined from the reference flow and is summarised in Table 3.4.

Table 3.4: Maximum base flows for EWR 16 in m3/s

High flow month	Maximum base flow	Low flow month	Maximum base flow	Measured		REC
				Aug	Sept	
February	143.236	August	15.053	55.03	40.89	D

Integrated stress index

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

The fish and macroinvertebrate flow requirements for different Ecological Categories (ECs) are provided in Table 3.5 and Tables 3.6. The results are plotted for the wet and dry season on stress duration graphs and compared to the Desktop Reserve Model (DRM) low flow estimates for the same range of ECs.

Summarised motivations for the final requirements are provided in Table 3.5.

Table 3.5: Fish species and integrates stress requirements for EWR 16

FISH: DURATIONS AND MOTIVATIONS TO BE USED FOR DETERMINING STRESS REQUIREMENTS.
Indicator: *Labeobarbus kimberleyensis* **Fish:** This indicator is a semi-rheophilic species that is dependent on perennial flows and specific flow-depth classes.
FISH STRESS REQUIREMENTS
DRY SEASON (August)
DROUGHT: **0%** at stress level of 10 where there is no fast deep habitat remaining. (At a stress of 10 semi-rheophilic species will be seriously threatened). **50%** at stress level 7, where fast-deep habitats comprises 4% of the discharge providing limited fast deep and slow-deep habitat for *L.kimberleyensis.*
MAINTENANCE (D): **50%** at stress level 7 providing limited fast deep habitat and limited habitat for gonadal development. **MAINTENANCE (C/D):** **50%** at stress level 5 providing moderate slow-deep habitats for over wintering and limited fast deep habitat for gonadal development.
WET SEASON (February)
DROUGHT: **0%** at stress level of 8 where fast-deep habitat comprises 3% of discharge. At this discharge there is zero breeding capability. (At a stress level of 8 semi-rheophilic species will struggle to survive). **50%** at stress level 3, providing limited fast-deep habitats for survival of *L.kimberleyensis* a semi- rheophilic species.
MAINTENANCE (D): **40**% at stress at level 3 providing habitat for gonadal development and fast deep habitats and water column cover including SS margins which provide for juvenile development. *Labeobarbus kimberleyensis* *Breeding will have commenced in November* ***Juvenile:*** Feeding and Growth: Mostly SS (< 0.3 m/s and 0.1 to 0.5m depth) and FS (> 0.3m/s and 0.1 to 0.5m depth). Cover: Cobbles & rocks overhanging vegetation. Duration 3-6 months. - 3 - 30%. ***Adult:*** FD (> 0.3m/s and > 0.5m depth), FS (> 0.3m/s and 0.1 to 0.5m depth) and SD (< 0.3 m/s and < 0.5m depth), and water column cover. Spawning season: October – January/February. Cue: increased temperature, flow and changes in water quality (e.g. conductivity) (3 - 30%).
MAINTENANCE (C/D): **30%** at stress level 3 providing adequate fast deep habitats for abundance, adequate slow deep habitats for water column cover and adequate depths and flows for spawning. **45** % at stress at level 2 providing adequate fast deep habitats for abundance, adequate slow deep habitats for water column cover and adequate depths and flows for spawning.

Labeobarbus kimberleyensis *Breeding will have commenced in November* ***Juvenile:*** Feeding and Growth: Mostly SS (< 0.3 m/s and 0.1 to 0.5m depth) and FS (> 0.3m/s and 0.1 to 0.5m depth). Cover: Cobbles & rocks overhanging vegetation. Duration 3-6 months. - 3 - 30%. ***Adult:*** FD (> 0.3m/s and > 0.5m depth), FS (> 0.3m/s and 0.1 to 0.5m depth) and SD (< 0.3 m/s and < 0.5m depth), and water column cover. Spawning season: October – January/February. Cue: increased temperature, flow and changes in water quality (e.g. conductivity) (3 - 30%).

Table 3.6: Invertebrate taxa and integrates stress requirements for EWR 16

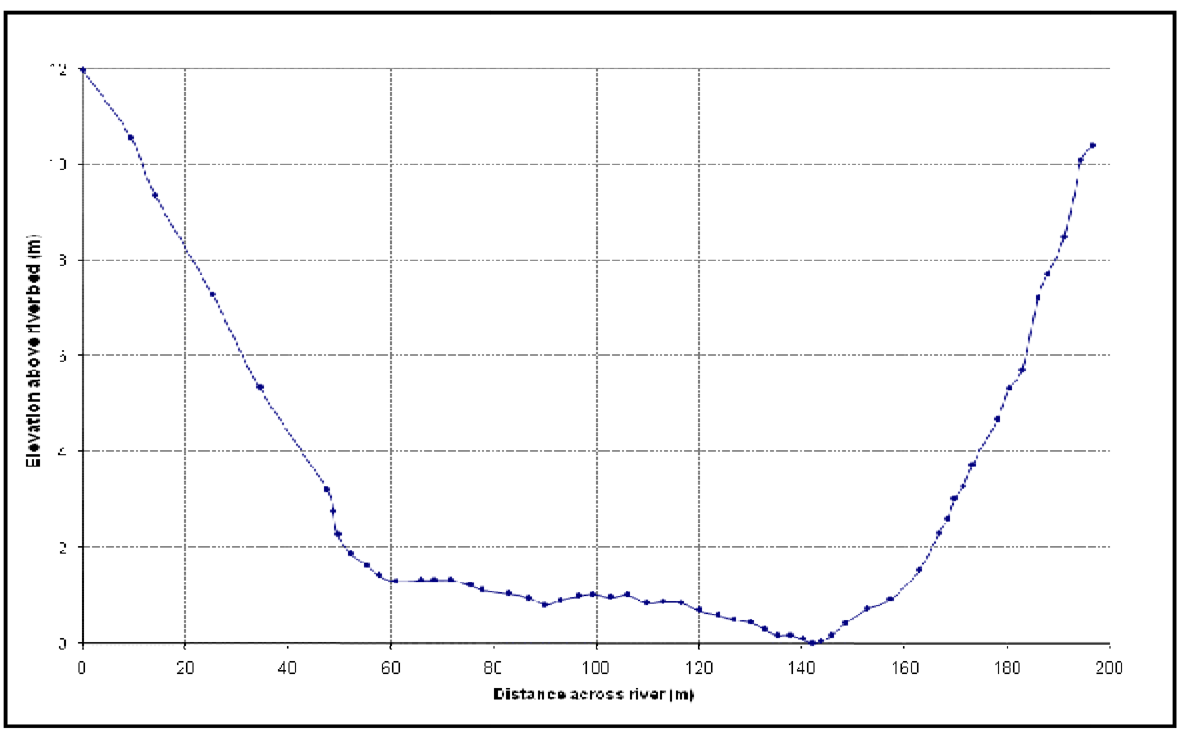
INVERTEBRATES:DURATIONS AND MOTIVATIONS TO BE USED FOR DETERMINING STRESS REQUIREMENTS.
Indicator: *Trichoptera* (Hydropsychidae) **Invertebrate:** The indicator is a rheophilic species dependant on the perennial flow.
INVETEBRATE STRESS REQUIREMENTS
DRY SEASON (August)
DROUGHT: For a drought duration of 10% there is enough SIC habitat with fast enough velocities (0.3 m/s) and depth (>10 cm) to ensure the survival of the highly flow dependent caddisflies *Trichoptera* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. The river should never stop flowing as this would result in the complete elimination of the rheophilic invertebrate community (0% duration)
MAINTENANCE (D): The river has enough flow to ensure a healthy population of the caddisflies *Trichoptera* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. This should be for duration of 30%. **MAINTENANCE (C):** The river has enough flow to ensure a healthy population of the caddisflies, *Trichoptera* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. This should be for a duration of 30%.
WET SEASON (February)
DROUGHT: There is enough SIC habitat with fast enough velocities (0.3 m/s) and depth (>10 cm) to ensure the survival of the highly flow dependent caddisflies *Trichoptera* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. This should be for a duration of not less than 10%. Higher drought flows <u>(greater depths, velocities and amount of cobbles)</u> are required in the summer months to ensure sustainability and gender equity in the *Trichoptera* population. The river should never stop flowing as this would result in the complete elimination of the rheophilic invertebrate community (0% duration)
MAINTENANCE (D): The river has enough flow to ensure a healthy population of the caddisflies, *Trichoptera* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. The value set is the minimum level to ensure a viable breeding community This should be for a duration of 30%. **MAINTENANCE (C):** The river has enough flow to ensure a healthy population of the mayfly, *Trichoptera* sp., which was selected as an indicator for the rheophilic macro-invertebrate community. The value set is the minimum level to ensure a viable breeding community. This should be for a duration of 30%.

The vegetation indicators used were *Imperata cylindrica Cyperus denudatus* and *Cyperus longus.* The resulting conditions of the vegetation indicators to the required low flows are described below. In conclusion, the low flows would maintain the PES and REC of the riparian vegetation (Table 3.7).

Table 3.7: Verification of the low flow requirements to maintain the vegetation EC

PES and REC: RIPARIAN VEGETATION EC F (ECOSTATUS E)
Dry Season maintenance Flows do not vary much between high and low flow and are sufficient to activate the lower limits of *Imperata cylindrica* on the marginal zone, and facilitate survival of Cyperoid *species*. **Dry Season drought** *Imperata cylindrica* and *Cyperus denudatus* rhizome level remains activated for survival. Water level is just below both species rooting level. Water level is deep enough to prevent the spread of *P. australis* into the channel. **Wet Season maintenance** This flow inundates the marginal zone sedges, which is sufficient to sustain summer functionality e.g. flowering. **Wet Season drought** Sufficient to activate the lower limits of Cyperoid rhizomes on the marginal zone, and facilitate survival of *C. longus*. *P. australis* may migrate towards the middle of the instream channel in very dry conditions if the water level of the instream channel drops to below 1m.
AEC up: RIPARIAN VEGETATION EC: D (ECOSTATUS E)
Dry Season maintenance Due to the canalisation of the river at this site the maintenance flows will not significantly alter the status from the present ES. The status in this area is determined mainly by the vast number and percentage cover of exotic species. **Wet Season maintenance** Same effect as dry season base flow slight inundation at rhizome level of current sedges.

The maximum wet season base flow was used as the departure point with no stress and the stress-flow relationships were determined for the fish and macroinvertebrates using the hydraulic profile for EWR 16 and the associated available habitats under various stress levels from 0 (maximum base flow) to 10 (no flow). Figure 3.3 shows the hydraulic profile for EWR16.



To produce the final results (Figure 3.5), the DRM results for the specific category are modified according to specialists' requirements (Figure 3.1 and 3.2). There are a range of options one can use to make these modifications, such as changing the total volume required for the year, changing specific monthly volumes, changing durations of either drought or maintenance flows, changing the seasonal distribution and changing the category rules and shape factors. The final dry and wet season stress duration curves for EWR 16 is shown in Figure 3.5.

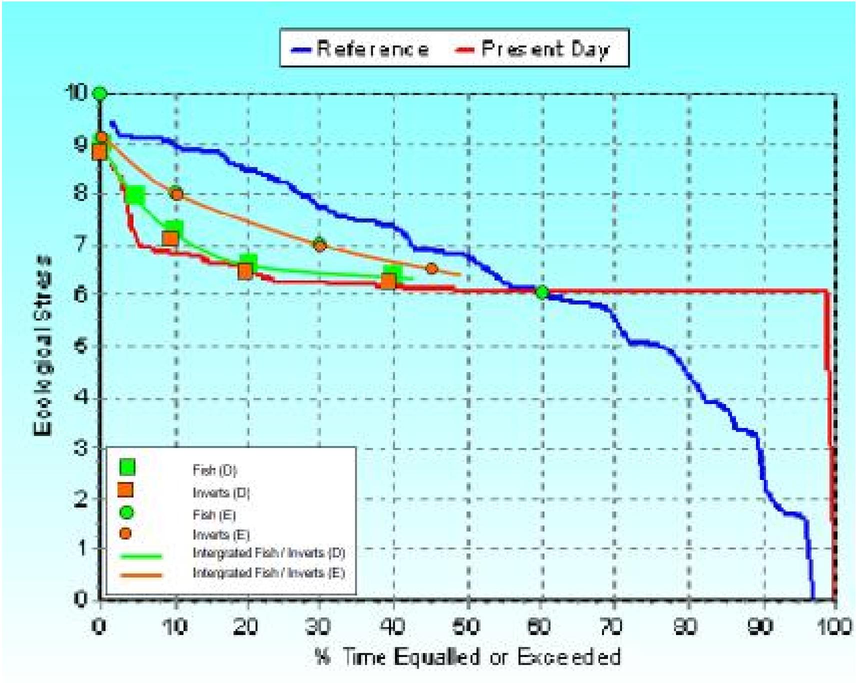


Figure 3.2: Final stress duration curves for EWR 16 (August)

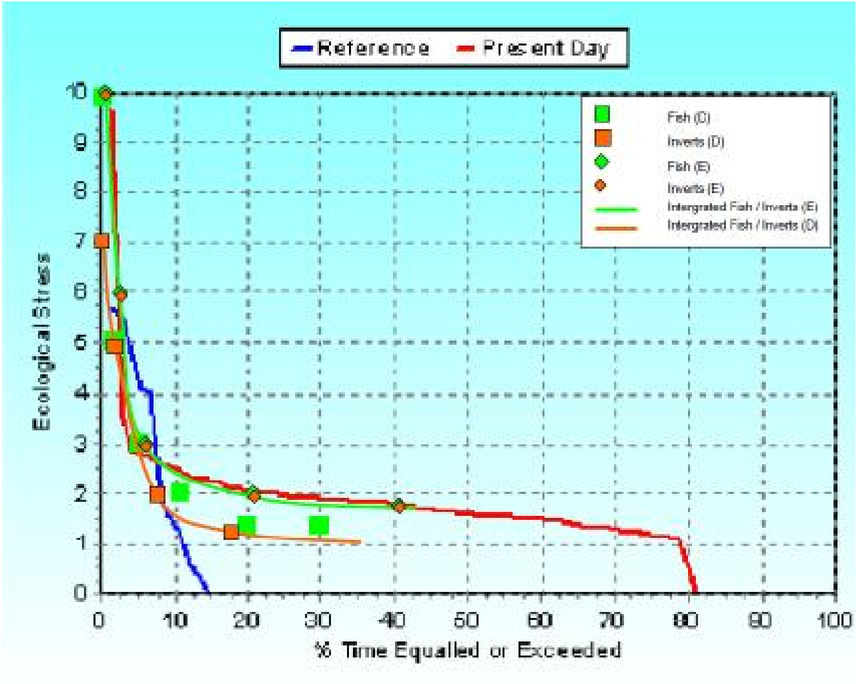


Figure 3.3: Final stress duration curves for EWR 16 (February)

3.3.3 Flood requirements

The flood requirements for EWR 16 were specified by the fish, macroinvertebrates, geomorphology and riparian vegetation specialists and include small freshets to provide specific cues as well as larger floods for clearing of the river channel. The high flow classes are identified as follows:

- The geomorphologist and riparian vegetation specialist identify the range of flood classes required and list the functions of each flood.
- The instream specialists then indicate which of the instream flooding functions are addressed by the floods identified for geomorphology and riparian vegetation.
- Any of the floods required by the instream biota and not addressed by the floods already identified, must then be described (in terms of ranges and functions) for the instream biota.

Results are provided in Table 3.8 and detailed motivations provided in Table 3.9.

Table 3.8: Identification of instream functions for EWR 16

FLOOD CLASS	FLOOD RANGE (m3/s)	Motivations	Fish flood functions							Invertebrate flood functions				
			Migration cues	Migration habitat (depth etc)	Clean spawning substrate	Create spawning habitat	Create nursery areas	Resetting water quality	Inundate vegetation for spawning	Breeding and hatching cues	Clear fines	Scour substrate	Reach or inundate specific areas	Reset water quality
I	70 (daily average)	**Macroinvertebrates**: Flushing of riffles, water quality improvements and additional marginal vegetation biotopes. **Fish:** First flush is for flushing sediments from riffle areas, improving water quality, moving exotic macrophytes and inundation of marginal vegetation for nursery areas. Cues for migration in Jan and Feb.	x	x	x	x	x	x	x	x	x	x	x	x
II														
III														
IV	500 (daily avg)	**Geomorphology:** Effective discharge for fines (>50%) and important for gravel activation and movement; activate the bed and mobilize fines to maintain the condition of the reach. **Vegetation**: Floods are unlikely to have much effect on the vegetation at this site. Very severe floods may remove some of the exotic vegetation; however the areas where vegetation is removed are most likely to be re-colonized by exotics which currently make up the bulk of the vegetation communities. Regular light flooding may serve to prevent terrestrialisation of the lower and marginal zones, but may also increase erosion in the denuded areas.			x	x								

The number of high flow events required for each EC is provided in Table 3.9. No observed daily data was available to check flood requirements against.

Table 3.9: EWR 16: The recommended number of high flow events required

FLOOD CLASS	FLOOD RANGE (m^3/s)	INVERTEBRATES	FISH	VEGETATION	GEOMORPHOLOGY	FINAL (Frequency)	MONTHS	DAILY AVERAGE	DURATION
PES: E									
I	70 (daily average)	2	4			4	Nov, Jan, Feb, Mar	50	5
II									
III									
IV	500 (daily average)				1:3		Feb		
AEC up: D (REC)									
I	70 (daily average)	3	5			5	Nov, Dec, Jan, Feb, Mar	50	5
II									
III									
IV	500 (daily average)			1:2	1:2		Feb		

3.3.4 Final ecological water requirements

The final ecological water requirements were generated by the DRM in SPATSIM using the stress duration curves and the integrated flood requirements and is summarised in Table 3.10.

Table 3.10:Final EWRs for EWR 16

Desktop version:		2.10	**Reference flow used Present day MAR (MCM)**	1699.3
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	6.333	4.905		
NOVEMBER	6.794	5.262	50	5
DECEMBER	6.971	5.400	50	5
JANUARY	8.266	6.403	50	5
FEBRUARY	11.052	2.646	50	5
MARCH	8.974	6.952	50	5
APRIL	7.086	5.489		
MAY	5.710	4.423		
JUNE	4.717	3.654		
JULY	4.669	3.617		
AUGUST	4.460	3.454		
SEPTEMBER	5.632	4.363		
TOTAL MCM	211.092	149.204	163.814	
% OF REFERENCE	12.42	8.78	9.64	

3.4 EWR 17: HARTS RIVER AT LLOYDS WEIR

3.4.1 Ecoclassification summary of EWR 17 Harts River at Lloyds Weir

EWR 17: HARTS RIVER AT LLOYDS WEIR

EIS: MODERATE
PES: D
Combination of flow and non-flow related impacts. Impacts mostly related to changes in flow regime due to upstream irrigation and urbanisation. Coupled to this are water quality issues from return irrigation
REC: D
Maintain the PES due to the **MODERATE** EIS rating. However note that there is rare and endangered *Labeobarbus kimberleyensis* and *Austroglanis sclateri* expected which warrants improvement of the fish EC. Migration stopped by Spitskop Dam.

AEC up: C

- Greater flows in March compared to natural
- Water quality management will be slow as 70 years of soils nutrients and salts to be flushed out
- Need a large flood to remove instream vegetation.

AEC down:

- None due to current PES

Driver	PES & REC Category	Trend	AEC up	AEC down
Hydrology	D/E	Stable	D	
Water quality	D	Stable – Nutrients up	D	
Geomorphology	D	Stable	D	
Response components	**PES & REC Category**	**Trend**	**AEC up**	**AEC down**
Fish	D	Stable	C/D	
Aquatic invertebrates	C/D	Stable	C	
Instream	D	Stable	C/D	
Riparian vegetation	D	Stable	D	
Ecostatus	D	Stable	D	

The REC for EWR 17 situated on the Harts River in quaternary catchment C33C is a D category. The reference flow used was the natural simulated flows with the mean annual runoff (MAR) of 147.85 Mm^3.

3.4.2 Base flows

The maximum base flows for the wet and dry season were determined from the reference flow and is summarised in Table 3.11.

Table 3.11: Maximum base flows for EWR 17 in m3/s

High flow month	Maximum base flow	Low flow month	Maximum base flow	Measured		REC
				Jun	Aug	
March	15.549	September	0.171	0.89	1.13	D

<u>Integrated stress index</u>

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

The fish and macroinvertebrate flow requirements for different Ecological Categories (ECs) are provided in Table 3.12 and Table 3.13. The results are plotted for the wet and dry season on stress duration graphs and compared to the Desktop Reserve Model (DRM) low flow estimates for the same range of ECs. Summarised motivations for the final requirements are provided in Table 3.1.

Table 3.12: Fish species and integrates stress requirements for EWR 17

FISH: DURATIONS AND MOTIVATIONS TO BE USED FOR DETERMINING STRESS REQUIREMENTS.
Indicator: *Labeobarbus aeneus* **Fish:** This indicator is a semi-rheophilic species that is dependent on perennial flows and specific flow-depth classes.
FISH STRESS REQUIREMENTS
DRY SEASON (August)
DROUGHT: **0%** at stress level of 10 where habitat consists primarily of slow shallow habitats, no fast flowing or deep habitats remaining. (At a stress of 10 semi-rheophilic species will be seriously threatened). **50%** at stress level 7, where slow-deep habitat comprises 71% of the discharge providing adequate cover and some fast-deep habitat have appeared.
MAINTENANCE (D): **50%** at stress level 5 providing abundant slow-deep habitat as well as limited fast shallow and fast-deep habitats for gonadal development. **MAINTENANCE (C/D):** **60%** at stress level 4 providing abundant slow-deep habitats for over wintering as well as fast shallow and fast-deep habitats for gonadal development.
WET SEASON (February)
DROUGHT: **0%** at stress level of 9 where no fast-deep or fast-shallow habitat is available. At this discharge there is zero opportunity for this species to breed. (In the absence of either fast-deep or fast-shallow habitats population of semi-rheophilic species will struggle to reproduce). **50%** at stress level 4, providing sufficient slow deep and fast deep habitats for *L. aeneus*.
MAINTENANCE (D): **40**% at stress at level 3 providing habitat for gonadal development and fast deep habitats and water column cover including SS margins which provide for juvenile development. *Labeobarbus aeneus* *Breeding will have commenced in November* ***Juvenile:*** Feeding and Growth: Mostly SS (< 0.3 m/s and 0.1 to 0.5m depth) and FS (> 0.3m/s and 0.1 to 0.5m depth). Cover: Cobbles & rocks overhanging vegetation. Duration 3-6 months. - 3 - 30%. ***Adult:*** FD (> 0.3m/s and > 0.5m depth), FS (> 0.3m/s and 0.1 to 0.5m depth) and SD (< 0.3 m/s and < 0.5m depth), and water column cover. Spawning season: October – January/February. Cue: increased temperature, flow and changes in water quality (e.g. conductivity) (3 - 30%).
MAINTENANCE (C/D): **30%** at stress level 3 providing adequate fast deep habitats for abundance, adequate slow deep habitats for water column cover and adequate depths and flows for spawning. **45** % at stress at level 2 providing adequate fast deep habitats for abundance, adequate slow deep habitats for water column cover and adequate depths and flows for spawning. *Labeobarbus aeneus* *Breeding will have commenced in November* ***Juvenile:*** Feeding and Growth: Mostly SS (< 0.3 m/s and 0.1 to 0.5m depth) and FS (> 0.3m/s and 0.1 to 0.5m depth). Cover: Cobbles & rocks overhanging vegetation. Duration 3-6 months. - 3 - 30%. ***Adult:*** FD (> 0.3m/s and > 0.5m depth), FS (> 0.3m/s and 0.1 to 0.5m depth) and SD (< 0.3 m/s and < 0.5m depth), and water column cover. Spawning season: October – January/February. Cue: increased temperature, flow and changes in water quality (e.g. conductivity) (3 - 30%).***Adult:*** FD (> 0.3m/s and > 0.5m depth), FS (> 0.3m/s and 0.1 to 0.5m depth) and SD (< 0.3 m/s and < 0.5m depth), and water column cover. Spawning season: October – January/February. Cue: increased temperature, flow and changes in water quality (e.g. conductivity) (3 - 30%).

Table 3.13: Invertebrate taxa and integrates stress requirements for EWR 17

INVERTEBRATES:DURATIONS AND MOTIVATIONS TO BE USED FOR DETERMINING STRESS REQUIREMENTS.
Indicator: *Ephemeroptera* (Leptophlebiidae) **Invertebrate:** The indicator is a rheophilic species dependant on the perennial flow.
INVETEBRATE STRESS REQUIREMENTS
DRY SEASON (August)
DROUGHT: For a drought duration of 10% there is enough SIC habitat with fast enough velocities (0.3 m/s) and depth (>10 cm) to ensure the survival of the highly flow dependent mayflies *Ephemeroptera* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. The river should never stop flowing as this would result in the complete elimination of the rheophilic invertebrate community (0% duration)
MAINTENANCE (D): The river has enough flow to ensure a healthy population of the mayflies *Ephemeroptera* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. This should be for duration of 30%. **MAINTENANCE (C):** The river has enough flow to ensure a healthy population of the mayflies, *Ephemeroptera* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. This should be for a duration of 30%.
WET SEASON (February)
DROUGHT: There is enough SIC habitat with fast enough velocities (0.3 m/s) and depth (>10 cm) to ensure the survival of the highly flow dependent mayflies *Ephemeroptera* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. This should be for a duration of not less than 10%. Higher drought flows <u>(greater depths, velocities and amount of cobbles)</u> are required in the summer months to ensure sustainability and gender equity in the *Trichoptera* population. The river should never stop flowing as this would result in the complete elimination of the rheophilic invertebrate community (0% duration)
MAINTENANCE (D): The river has enough flow to ensure a healthy population of the mayflies, *Ephemeroptera* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. The value set is the minimum level to ensure a viable breeding community This should be for a duration of 30%. **MAINTENANCE (C):** The river has enough flow to ensure a healthy population of the mayflies, *Ephemeroptera* sp., which was selected as an indicator for the rheophilic macro-invertebrate community. The value set is the minimum level to ensure a viable breeding community. This should be for a duration of 30%.

The vegetation indicators used were *Imperata cylindrica, Cyperus denudatus* and *Cyperus longus.* The resulting conditions of the vegetation indicators to the required low flows are described below. In conclusion, the low flows would maintain the PES and REC of the riparian vegetation (Table 3.14).

Table 3.14: Verification of the low flow requirements to maintain the vegetation EC

PES and REC: RIPARIAN VEGETATION EC D (ECOSTATUS D)
Dry Season maintenance Flows do not vary much between high and low flow and are sufficient to activate the lower limits of *C. dactylon* on the marginal zone, and facilitate survival of *P. australis*. **Dry Season drought** *C. dactylon* rhizome level remains activated for survival. Water level is just below both species rooting level. Water level is deep enough to prevent the extensive spread of *P. australis* into the channel.

Wet Season maintenance This flow inundates the marginal zone sedges, which is sufficient to sustain summer functionality e.g. flowering. **Wet Season drought** Sufficient to activate the lower limits of *C. dactylon* on the marginal zone, and facilitate its survival. *P. australis* may migrate towards the middle of the instream channel in very dry conditions if the water level of the instream channel drops to below 1m. *Myriophyllum spicatum* is also likely to thrive in the lower flow conditions choking the instream channel.
AEC up: RIPARIAN VEGETATION EC: D (ECOSTATUS D)
Dry Season maintenance Due to the canalisation of the river at this site the maintenance flows will not significantly alter the status from the present ES. The status in this area is determined mainly by the vast number and percentage cover of exotic species. **Wet Season maintenance** Same effect as dry season base flow slight inundation at rhizome level of current sedges.

The maximum wet season base flow was used as the departure point with no stress and the stress-flow relationships were determined for the fish and macroinvertebrates using the hydraulic profile for EWR 17 and the associated available habitats under various stress levels from 0 (maximum base flow) to 10 (no flow). Figure 3.8 shows the hydraulic profile for EWR 17.

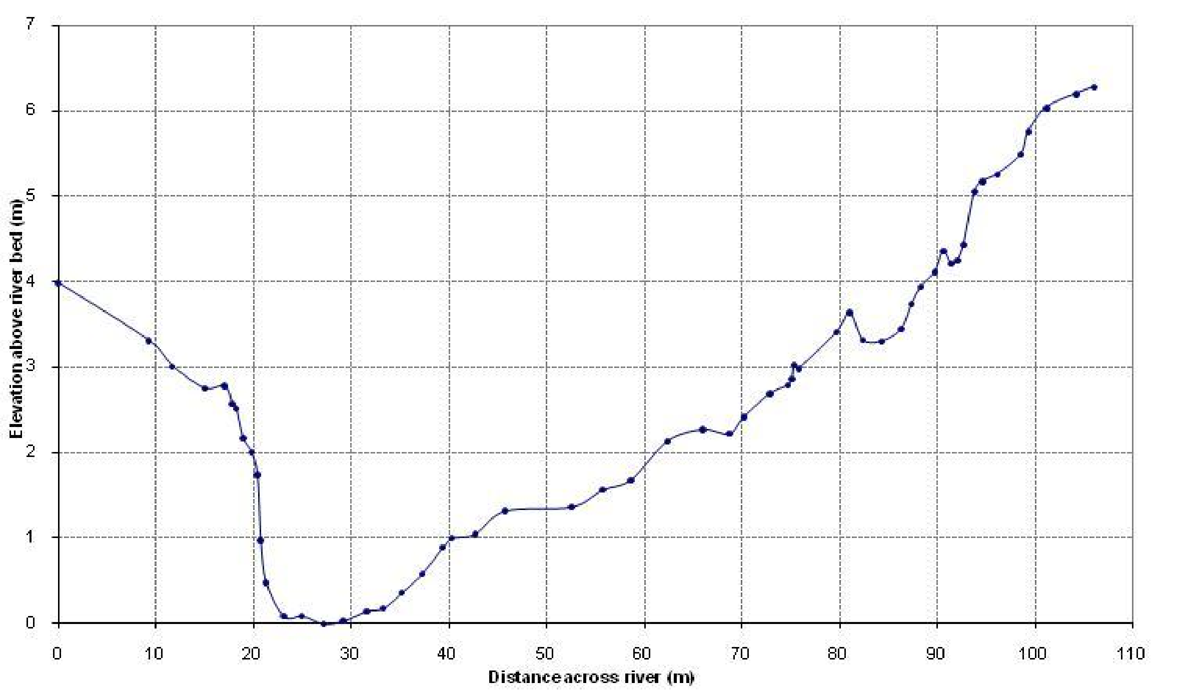


Figure 3.4: Hydraulic profile for EWR 17

Final low flow requirements

To produce the final results (Figure 3.10), the DRM results for the specific category are modified according to specialists' requirements (Figure 3.6 and 3.7). There are a range of options one can use to make these modifications, such as changing the total volume required for the year, changing specific monthly volumes, changing durations of either drought or maintenance flows, changing the seasonal distribution and changing the category rules and shape factors. The final dry and wet season stress duration curves for EWR 17 is shown in Figure 3.10.

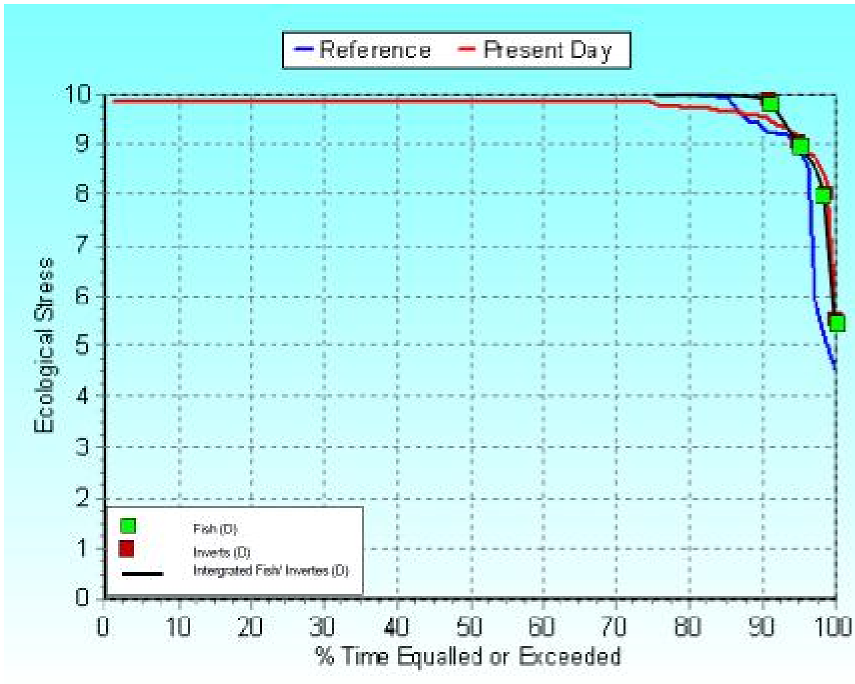


Figure 3.5: Final stress duration curves for EWR 17 (September)

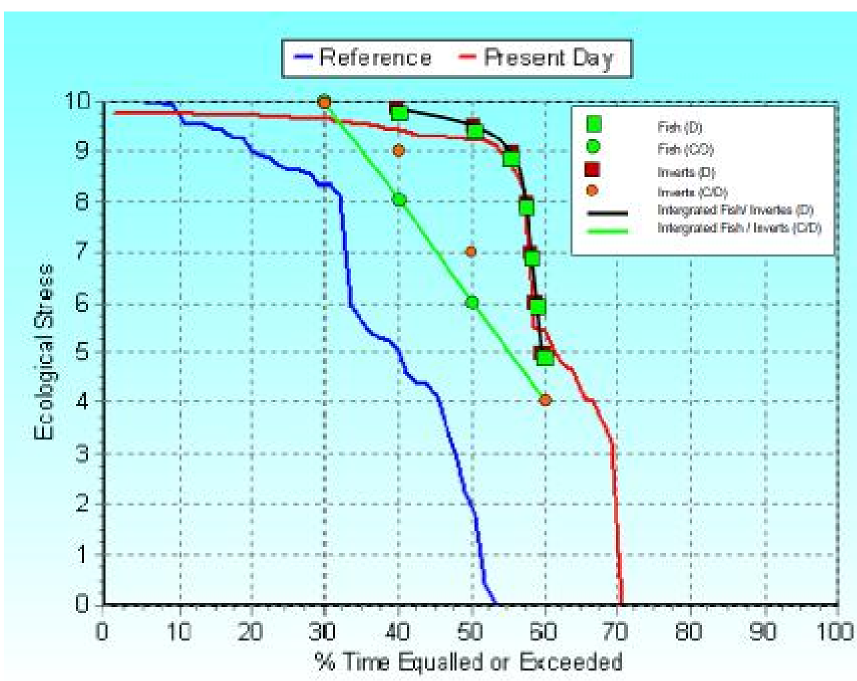


Figure 3.6: Final stress duration curves for EWR 17 (March)

3.4.3 Flood requirements

The flood requirements for EWR 17 were specified by the fish, macroinvertebrates, geomorphology and riparian vegetation specialists and include small freshets to provide specific cues as well as larger floods for clearing of the river channel. The high flow classes are identified as follows:

- The geomorphologist and riparian vegetation specialist identify the range of flood classes required and list the functions of each flood.
- The instream specialists then indicate which of the instream flooding functions are addressed by the floods identified for geomorphology and riparian vegetation.
- Any of the floods required by the instream biota and not addressed by the floods already identified, must then be described (in terms of ranges and functions) for the instream biota.

Results are provided in Table 3.15 and detailed motivations provided in Table 3.16.

Table 3.15: Identification of instream functions for EWR 17

FLOOD CLASS	FLOOD RANGE (m3/s)	Motivations	Fish flood functions							Invertebrate flood functions				
			Migration cues	Migration habitat (depth etc)	Clean spawning substrate	Create spawning habitat	Create nursery areas	Resetting water quality	Inundate vegetation for spawning	Breeding and hatching cues	Clear fines	Scour substrate	Reach or inundate specific areas	Reset water quality
I	4.5 (daily average)	**Geomorphology:** One of the important discharge classes for movement of fines through the channel. **Macroinvertebrates**: Flushing of riffles, water quality improvements and additional marginal vegetation biotopes.	x	x	x	x	x	x	x	x	x	x	x	x
II	10 (daily avg)	**Fish**: First flush is for flushing sediments from riffle areas, improving water quality, moving exotic macrophytes and inundation of marginal vegetation for nursery areas. Cues for migration in Nov to March. **Geomorphology:** An important discharge class for the movement of fines from the bed of the channel.	x	x	x	x	x	x	x	x	x	x	x	x
III	25 (daily avg)	**Riparian vegetation:** Inundates much of the marginal zone thereby preventing terrestrialisation of this community			x	x		x				x	x	x
IV	120 (daily avg)	**Geomorphology:** 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 characteristics of reaches upstream of the site, but confidence is extremely low because the hydraulics and exact sediment sizes of these upstream areas are not known. **Vegetation**: Inundates the entire marginal zone and the majority of the lower zone once again preventing terretrialisation. May remove some of the instream exotic aquatic plants. This effect will however be temporary												

The number of high flow events required for each EC is provided in Table 3.16. No observed daily data was available to check flood requirements against.

Table 3.16: EWR 16: The recommended number of high flow events required

FLOOD CLASS	FLOOD RANGE (m^3/s)	INVERTEBRATES	FISH	VEGETATION	GEOMORPHOLOGY	FINAL (Frequency)	MONTHS	DAILY AVERAGE	DURATION
PES and REC: D									
I	4.5 (daily average)	2			3	3	Nov, Mar	3	5
II	10 (daily avg)		4		2	4	Nov - Mar	8	7
III	25 (daily avg)			1:3		1	Nov		
IV	120 (daily avg)			1:10		1	Feb		
AEC up: D									
I	4.5 (daily average)	2			4	4	Nov, Mar	3	5
II	10 (daily avg)		4		2	4	Nov - Mar	8	7
III	25 (daily avg)			1:3		1	Nov		
IV	120 (daily avg)			1:10		1	Feb		

3.4.4 Final ecological water requirements

The final ecological water requirements were generated by the DRM in SPATSIM using the stress duration curves and the integrated flood requirements and is summarised in Table 3.17.

Table 3.17: Final EWRs for EWR 17

Desktop version:		2.10	Reference flow used Virgin MAR (MCM)	147.85
BFI index	0.124	**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	1.500	0.001		
NOVEMBER	2.000	0.001	3 8	5 7
DECEMBER	2.500	0.001	8	7
JANUARY	3.000	0.001	8	7
FEBRUARY	4.000	0.001	8	7
MARCH	5.000	0.001	3 8	5 7
APRIL	4.000	0.001		
MAY	3.000	0.001		
JUNE	2.500	0.001		
JULY	2.000	0.001		
AUGUST	1.500	0.001		
SEPTEMBER	1.000	0.001		
TOTAL MCM	83.851	0.032	19.320	
% OF REFERENCE	56.71	0.02	13.07	

3.5 EWR 18: VAAL RIVER SCHMIDTSDRIFT

3.5.1 Ecoclassification summary of EWR 18 Vaal River Schmidtsdrift

EWR 18: VAAL RIVER SCHMIDTSDRIFT

EIS: MODERATE

PES: C/D

Combination of flow and non-flow related impacts. Impacts mostly related to changes in flow regime due to Vaal Dam, Vaal River Barrage and Bloehhof Dam as well as return irrigation water quality (Vaal Hartz).

REC: C/D

Maintain the PES due to the **HIGH** EIS rating. However note that there is rare and endangered *Labeobarbus kimberleyensis* found, and *Austroglanis sclateri* expected which warrants improvement of the fish EC. Other fish are isolated within this reach of river due to regulations and no fish ladders.

AEC up: C

Changes in hydrology

- Allow more moderate flows
- Allow freshet cues in summer in October and November

Riparian vegetation

- Reduce impacts of diamond mining and rehabilitate mined areas

Water quality management

- Reduce discharge standards of nutrients for WWTW
- Implement water quality guidelines/objectives
- Reduce nutrients by less into system and greater flows as above
- Greater flows mean less salts due to dilution

AEC down: D

Changes in hydrology

- • Reduce moderate flows
- • No freshet cues in summer in October and November

Riparian vegetation

- Greater impacts of diamond mining and no rehabilitation

Water quality management

- Greater nutrients from WWTW
- Implement water quality guidelines/objectives
- More salts due to less flows for dilution.

Driver	**PES & REC Category**	**Trend**	**AEC up**	**AEC down**
Hydrology	C	Stable	C	D
Water quality	C	Decrease nutrients, higher salts	C	D
Geomorphology	C/D	Stable	C/D	D
Response components	**PES & REC Category**	**Trend**	**AEC up**	**AEC down**
Fish	C	Negative	C	D
Aquatic invertebrates	C/D	Stable	C	D
Instream	C/D	Stable	C	D
Riparian vegetation	C/D	Negative	C/D	D
Ecostatus	C/D	Stable - negative	C	D

The REC for EWR 18 situated on the Vaal River in quaternary catchment C92B is a C/D category. The reference flow used was the present day simulated flows with the mean annual runoff (MAR) of 1177.28 Mm^3.

3.5.2 Base flows

The maximum base flows for the wet and dry season were determined from the reference flow and is summarised in Table 3.18.

Table 3.18: Maximum base flows for EWR 18 in m3/s

High flow month	Maximum base flow	Low flow month	Maximum base flow	Measured		REC
				Jun	Aug	
February	273.934	August	15.698	4.99	2.11	C/D

Integrated stress index

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

The fish and macroinvertebrate flow requirements for different Ecological Categories (ECs) are provided in Table 3.19 and Tables 3.20. The results are plotted for the wet and dry season on stress duration graphs and compared to the Desktop Reserve Model (DRM) low flow estimates for the same range of ECs.

Summarised motivations for the final requirements are provided in Table 3.23.

Table 3.19: Fish species and integrates stress requirements for EWR 18

FISH: DURATIONS AND MOTIVATIONS TO BE USED FOR DETERMINING STRESS REQUIREMENTS.
Indicator: *Labeobarbus kimberleyensis* **Fish:** This indicator is a semi-rheophilic species that is dependent on perennial flows and specific flow-depth classes.
FISH STRESS REQUIREMENTS
DRY SEASON (August)
DROUGHT: **0%** at stress level of 8 where fast-deep habitat comprises 5% of the discharge. (At stress levels of 8 and higher semi-rheophilic species will be seriously threatened). **50%** at stress level 7 where fast-deep habitats comprises 7% of the discharge providing limited fast deep and slow-deep habitat for *L.kimberleyensis.*
MAINTENANCE (D): **50%** at stress level 7 providing limited fast deep habitat and limited habitat for gonadal development. **MAINTENANCE (C/D):** **50%** at stress level 5 providing moderate slow-deep habitats for over wintering and limited fast deep habitat for gonadal development.
WET SEASON (February)
DROUGHT: **0%** at stress level of 8 where fast-deep habitat comprises 5% of discharge. At this discharge there is zero breeding capability. (At a stress level of 8 semi-rheophilic species will struggle to survive). **30%** at stress level 5, providing adequate fast-deep habitats for survival of *L.kimberleyensis* a semi- rheophilic species.
MAINTENANCE (D): **40**% at stress at level 3 providing habitat for gonadal development and fast deep habitats and water column cover including SS margins which provide for juvenile development. *Labeobarbus kimberleyensis* *Breeding will have commenced in November* ***Juvenile:*** Feeding and Growth: Mostly SS (< 0.3 m/s and 0.1 to 0.5m depth) and FS (> 0.3m/s and 0.1 to 0.5m depth). Cover: Cobbles &

rocks overhanging vegetation. Duration 3-6 months. - 3 - 30%. ***Adult:*** FD (> 0.3m/s and > 0.5m depth), FS (> 0.3m/s and 0.1 to 0.5m depth) and SD (< 0.3 m/s and < 0.5m depth), and water column cover. Spawning season: October – January/February. Cue: increased temperature, flow and changes in water quality (e.g. conductivity) (3 - 30%).
MAINTENANCE (C/D): **30%** at stress level 3 providing adequate fast deep habitats for abundance, adequate slow deep habitats for water column cover and adequate depths and flows for spawning. **45** % at stress at level 2 providing adequate fast deep habitats for abundance, adequate slow deep habitats for water column cover and adequate depths and flows for spawning. *Labeobarbus kimberleyensis* *Breeding will have commenced in November* ***Juvenile:*** Feeding and Growth: Mostly SS (< 0.3 m/s and 0.1 to 0.5m depth) and FS (> 0.3m/s and 0.1 to 0.5m depth). Cover: Cobbles & rocks overhanging vegetation. Duration 3-6 months. - 3 - 30%. ***Adult:*** FD (> 0.3m/s and > 0.5m depth), FS (> 0.3m/s and 0.1 to 0.5m depth) and SD (< 0.3 m/s and < 0.5m depth), and water column cover. Spawning season: October – January/February. Cue: increased temperature, flow and changes in water quality (e.g. conductivity) (3 - 30%).

Table 3.20: Invertebrate taxa and integrates stress requirements for EWR 18

INVERTEBRATES:DURATIONS AND MOTIVATIONS TO BE USED FOR DETERMINING STRESS REQUIREMENTS.
Indicator: *Coleoptera* (Dytiscidae) **Invertebrate:** The indicator is a species dependant on the perennial flow and marginal vegetation.
INVETEBRATE STRESS REQUIREMENTS
DRY SEASON (August)
DROUGHT: For a drought duration of 10% there is enough VEG habitat with enough inundated vegetation to ensure the survival of the vegetation dependent beetles *Coleoptera* sp., which was selected as an indicator species. The river should never stop flowing as this would result in the complete elimination of the rheophilic invertebrate community (0% duration)
MAINTENANCE (D): The river has enough flow and inundated vegetation to ensure a healthy population of the beetle *Coleoptera* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. This should be for duration of 30%. **MAINTENANCE (C/D):** The river has enough flow and inundated vegetation to ensure a healthy population of the beetle *Coleoptera* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. This should be for duration of 30%.
WET SEASON (February)
DROUGHT: There is enough VEG habitat with enough inundated vegetation survival of the highly inundated vegetation dependent beetle *Coleoptera* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. This should be for a duration of not less than 10%. Higher drought flows (greater depths, velocities and amount of inundated vegetation) are required in the summer months to ensure sustainability and gender equity in the *Coleoptera* population. The river should never stop flowing as this would result in the complete elimination of the rheophilic invertebrate community (0% duration)
MAINTENANCE (D): The river has enough flow to ensure a healthy population of the beetle, *Coleoptera* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. The value set is the minimum level to ensure a viable breeding community This should be for a duration of 30%. **MAINTENANCE (C):** The river has enough flow to ensure a healthy population of the beetle, *Coleoptera* sp., which was selected as an indicator for the rheophilic macro-invertebrate community. The value set is the minimum level to ensure a viable breeding community. This should be for a duration of 30%.

The vegetation indicators used were *Imperata cylindrica*, *Cyperus denudatus* and *Cyperus longus.* The resulting conditions of the vegetation indicators to the required low flows are described below. In conclusion, the low flows would maintain the PES and REC of the riparian vegetation (Table 3.21).

Table 3.21: Verification of the low flow requirements to maintain the vegetation EC

PES and REC: RIPARIAN VEGETATION EC C/D (ECOSTATUS C/D)
Dry Season maintenance Flows do not vary much between high and low flow and are sufficient to activate the lower limits of *C. dactylon* on the marginal zone, and facilitate survival of *P. australis*. **Dry Season drought** *C. dactylon* rhizome level remains activated for survival. Water level is just below both species rooting level. Water level is deep enough to prevent the extensive spread of *P. australis* into the channel. **Wet Season maintenance** This flow inundates the marginal zone sedges, which is sufficient to sustain summer functionality e.g. flowering. **Wet Season drought** Sufficient to activate the lower limits of *C. dactylon* on the marginal zone, and facilitate its survival. *P. australis* may migrate towards the middle of the instream channel in very dry conditions if the water level of the instream channel drops to below 1m. *Myriophyllum spicatum* is also likely to thrive in the lower flow conditions choking the instream channel.
AEC up: RIPARIAN VEGETATION EC: C/D (ECOSTATUS C/D)
Dry Season maintenance Due to the canalisation of the river at this site the maintenance flows will not significantly alter the status from the present ES. The status in this area is determined mainly by the vast number and percentage cover of exotic species. **Wet Season maintenance** Same effect as dry season base flow slight inundation at rhizome level of *C.dactylon*.
AEC down: RIPARIAN VEGETATION EC: D (ECOSTATUS C/D)
Dry Season maintenance Reduced from PES flow requirements. The lower limit of sedges on the marginal zone likely to expand towards the instream channel in some areas but due to the canalisation of the river, this is unlikely to occur in most areas. There may be fatality of the outer zones of the marginal zone due to desiccation of the soil. Very dry conditions may allow water level to drop enough for *P. australis* to invade further into the channel. *Myriophyllum spicatum* is also likely to thrive in the lower flow conditions choking the instream channel. **Wet Season maintenance** Will inundate marginal zone sufficiently to maintain vigour and density of the marginal zone.

The maximum wet season base flow was used as the departure point with no stress and the stress-flow relationships were determined for the fish and macroinvertebrates using the hydraulic profile for EWR 18 and the associated available habitats under various stress levels from 0 (maximum base flow) to 10 (no flow). Figure 3.13 shows the hydraulic profile for EWR 18.

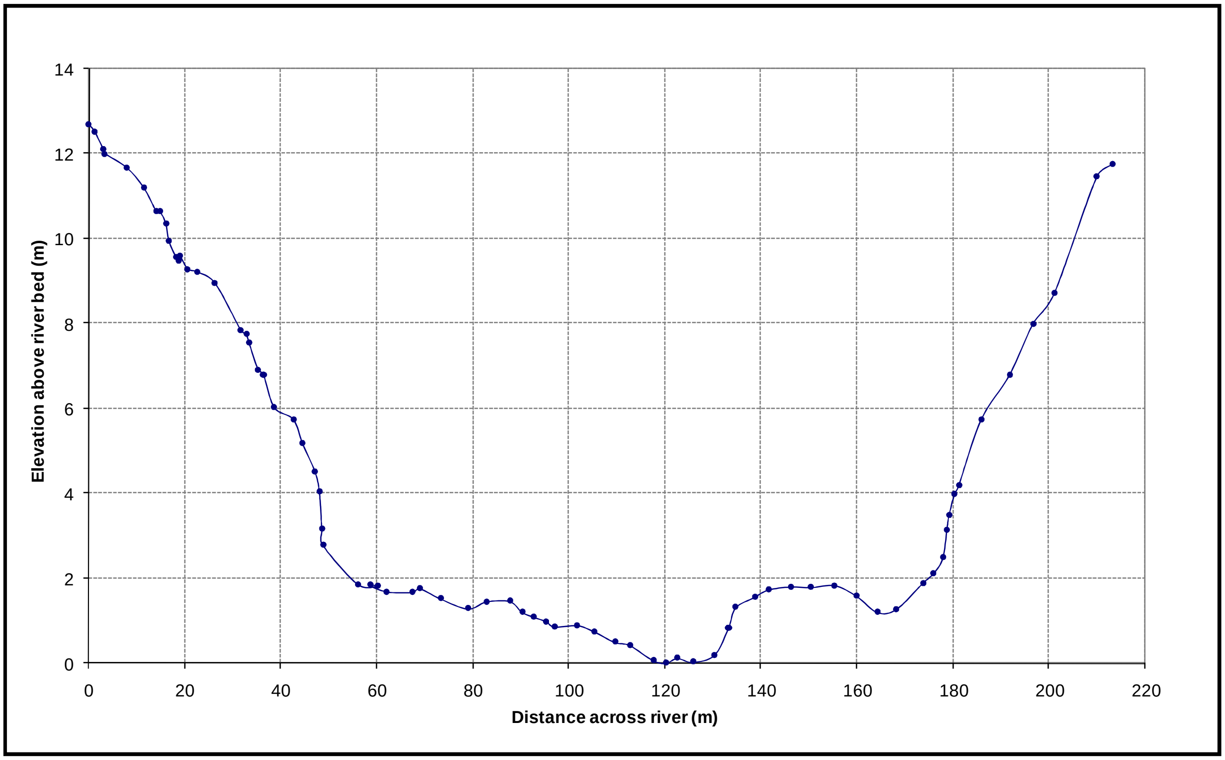


Figure 3.7: Hydraulic profile for EWR 18

To produce the final results (Figure 3.15), the DRM results for the specific category are modified according to specialists' requirements (Figure 3.11 and 3.12). There are a range of options one can use to make these modifications, such as changing the total volume required for the year, changing specific monthly volumes, changing durations of either drought or maintenance flows, changing the seasonal distribution and changing the category rules and shape factors. The final dry and wet season stress duration curves for EWR 18 is shown in Figure 3.15.

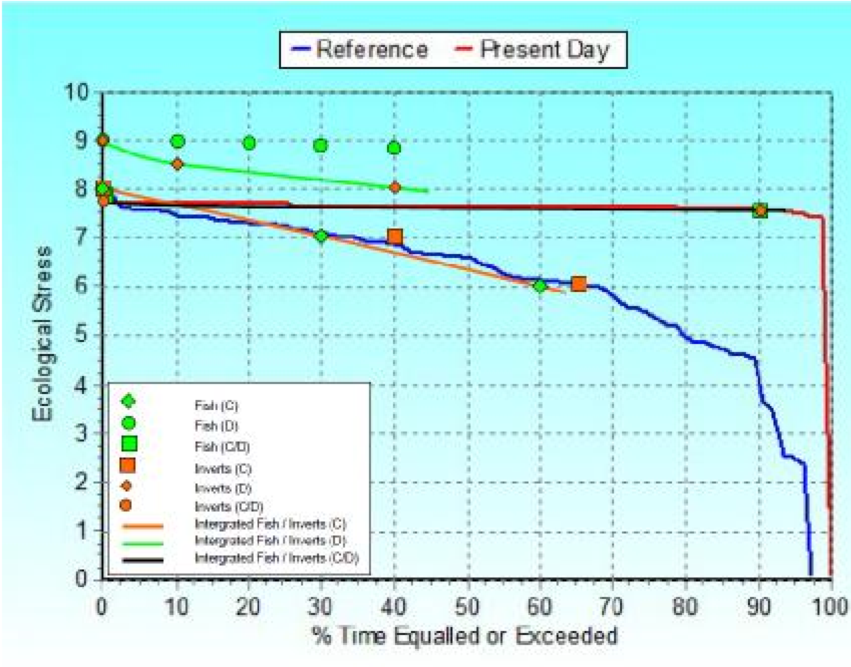


Figure 3.8: Final stress duration curves for EWR 18 (August)

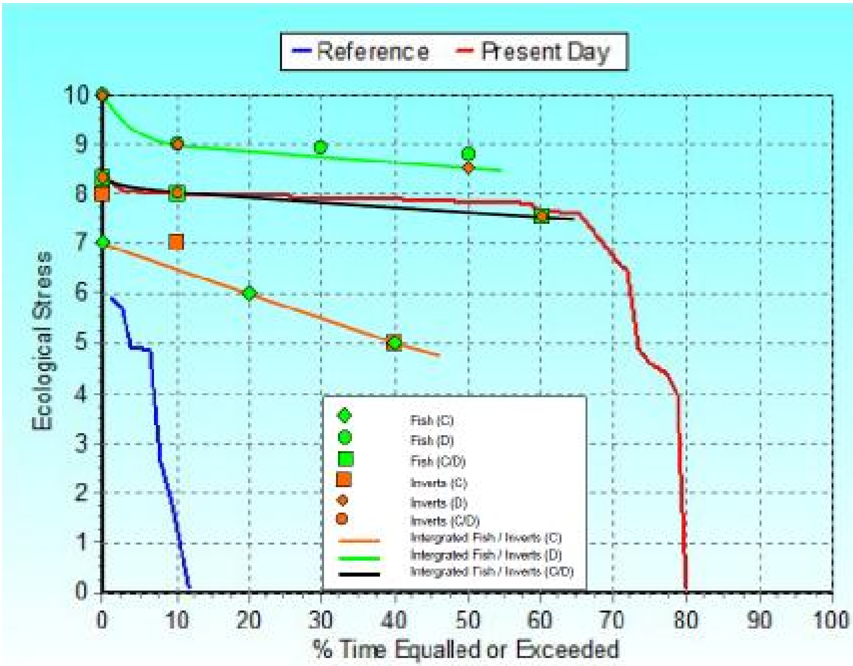


Figure 3.9: Final stress duration curves for EWR 18 (February)

3.5.3 Flood requirements

The flood requirements for EWR 18 were specified by the fish, macroinvertebrates, geomorphology and riparian vegetation specialists and include small freshets to provide specific cues as well as larger floods for clearing of the river channel. The high flow classes are identified as follows:

- The geomorphologist and riparian vegetation specialist identify the range of flood classes required and list the functions of each flood.
- The instream specialists then indicate which of the instream flooding functions are addressed by the floods identified for geomorphology and riparian vegetation.
- Any of the floods required by the instream biota and not addressed by the floods already identified, must then be described (in terms of ranges and functions) for the instream biota.

Results are provided in Table 3.22 and detailed motivations provided in Table 3.23.

Table 3.22: Identification of instream functions for EWR 14

FLOOD CLASS	FLOOD RANGE (m3/s)	Motivations	Fish flood functions							Invertebrate flood functions				
			Migration cues	Migration habitat (depth etc)	Clean spawning substrate	Create spawning habitat	Create nursery areas	Resetting water quality	Inundate vegetation for spawning	Breeding and hatching cues	Clear fines	Scour substrate	Reach or inundate specific areas	Reset water quality
I	35 (daily average)	**Fish:** First flush is for flushing sediments from riffle areas, improving water quality, moving exotic macrophytes and inundation of marginal vegetation for nursery areas. Cues for migration in Nov to March. **Macroinvertebrates:** Flushing of riffles, water quality improvements and additional marginal vegetation biotopes.	x	x	x	x	x	x	x	x	x	x	x	x
II														
III	120 (daily avg)	**Geomorphology:** This flow class would flush out some of the fines from the channel and clean substrates for instream biota. **Riparian vegetation:** Required to prevent the terrestrialization of marginal and lower zone riparian vegetation	x	x	x	x	x	x	x			x	x	x
IV	560(daily avg)	**Geomorphology:** 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 occasional floods would thus activate the bed of the channel.												

The number of high flow events required for each EC is provided in Table 3.23. No observed daily data was available to check flood requirements against.

Table 3.23: EWR 18: The recommended number of high flow events required

FLOOD CLASS	FLOOD RANGE (m^3/s)	INVERTEBRATES	FISH	VEGETATION	GEOMORPHOLOGY	FINAL (Frequency)	MONTHS	DAILY AVERAGE	DURATION
PES and REC: C/D									
I	35 (daily average)	2	4			4	Nov, Jan, Feb, Mar	35	7
II									
III	120 (daily avg)			1:1	1:1		Nov-Feb	120	
IV	560(daily avg)				1:3				
AEC up: C									
I	35 (daily average)	3	5			4	Nov, Dec, Jan, Feb, Mar	35	7
II									
III	120 (daily avg)			1:1	1:1		Nov-Feb	120	
IV	560(daily avg)				1:2				
AEC down: D									
I	35 (daily average)	2	3			3	Jan, Feb, Mar	35	7
II									
III	120 (daily avg)			1:1	1:1		Nov-Feb	120	
IV	560(daily avg)				1:3				

3.5.4 Final ecological water requirements

The final ecological water requirements were generated by the DRM in SPATSIM using the stress duration curves and the integrated flood requirements and is summarised in Table 3.24.

Table 3.24: Final EWRs for EWR 18

Desktop version:		2.10	Reference flow used Present day MAR (MCM)	1177.3
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	1.950	35 120	7
JANUARY	4.454	2.414	35 120	7
FEBRUARY	5.989	3.239	35 120	7
MARCH	5.131	2.776	35	7
APRIL	3.910	2.123		
MAY	2.412	1.319		
JUNE	1.650	0.912		
JULY	1.361	0.756		
AUGUST	1.235	0.688		
SEPTEMBER	1.412	0.784		
TOTAL MCM	94.929	50.709	162.190	
% OF REFERENCE	2.84	1.51	4.85	

3.6 EWR 19: RIET RIVER AT LILYDALE LODGE

3.6.1 Ecoclassification summary of EWR 19 Riet River at Lilydale Lodge

EWR 19 RIET RIVER AT LILYDALE LODGE

EIS: HIGH
PES: D
The low PES is due to the issues not being flow related. These issues are mainly due to intense irrigated agriculture upstream and instream dams that supply domestic water supply. Returns flows from irrigation result in poor water quality (salts and nutrients)
REC: D
Maintain the PES due to the **HIGH** EIS rating. However note that there is rare and endangered *Austroglanis sclateri* expected which warrants improvement of the fish EC.

AEC up: C

- Releases from dams for first flushes (far upstream therefore smaller impacts)
- Release and less irrigation usage for more water seasonally as well as moderate flows
- Water quality improvement – less fertilizers, salts less able to mange as this is diffuse and may years of accumulation in the soils.
- If eucalypt trees removed then recruitment of indigenous plants

AEC down:

- None due to current PES

Driver	PES & REC Category	Trend	AEC up	AEC down
Hydrology	D	Stable	D	
Water quality	D	Stable – Nutrients increasing	C/D	
Geomorphology	C	Stable	C	
Response components	**PES & REC Category**	**Trend**	**AEC up**	**AEC down**
Fish	D	Stable	C	
Aquatic invertebrates	C	Stable	C	
Instream	D	Stable	C	
Riparian vegetation	C/D	Stable	C	
Ecostatus	D	Stable	C	

The REC for EWR 19 situated on the Riet River in quaternary catchment C51L is a D category. The reference flow used was the present day simulated flows with the mean annual runoff (MAR) of 247.67 Mm^3.

3.6.2 Base flows

The maximum base flows for the wet and dry season were determined from the reference flow and is summarised in Table 3.25.

Table 3.25: Maximum base flows for EWR 19 in m3/s

High flow month	Maximum base flow	Low flow month	Maximum base flow	Measured		REC
				Sept	Aug	
February	42.809	August	1.440	5.26	2.55	D

<u>Integrated stress index</u>

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

The fish and macroinvertebrate flow requirements for different Ecological Categories (ECs) are provided in Table 3.26 and Table 3.27. The results are plotted for the wet and dry season on stress duration graphs and compared to the Desktop Reserve Model (DRM) low flow estimates for the same range of ECs.

Summarised motivations for the final requirements are provided in Table 3.26.

Table 3.26: Fish species and integrates stress requirements for EWR 19

FISH: DURATIONS AND MOTIVATIONS TO BE USED FOR DETERMINING STRESS REQUIREMENTS.
Indicator: *Labeobarbus kimberleyensis* **Fish:** This indicator is a semi-rheophilic species that is dependent on perennial flows and specific flow-depth classes.
FISH STRESS REQUIREMENTS
DRY SEASON (August)
DROUGHT: **0%** at stress level of 10 where fast-deep and slow deep habitats are absent. (In the absence of fast-deep and slow-deep habitats *L. kimberleyensis* will be severely threatened). **50%** at stress level 8 where fast-deep habitats comprises 5% of the discharge providing limited fast deep and slow-deep habitats for *L.kimberleyensis.*
MAINTENANCE (D): **50%** at stress level 7 providing limited fast deep habitat and limited habitat for gonadal development. **MAINTENANCE (C/D):** **50%** at stress level 5 providing moderate slow-deep habitats for over wintering and limited fast deep habitat for gonadal development.
WET SEASON (February)
DROUGHT: **0%** at stress level of 9 where fast-deep habitat comprises < 5% of discharge. At this discharge there is zero breeding capability. (At a stress level of 9 semi-rheophilic species will struggle to survive). **30%** at stress level 5, providing limited fast-deep habitats for reproduction in *L.kimberleyensis* a semi- rheophilic species.
MAINTENANCE (D): **40**% at stress at level 3 providing habitat for gonadal development and fast deep habitats and water column cover including SS margins which provide for juvenile development. *Labeobarbus kimberleyensis* *Breeding will have commenced in November* ***Juvenile:*** Feeding and Growth: Mostly SS (< 0.3 m/s and 0.1 to 0.5m depth) and FS (> 0.3m/s and 0.1 to 0.5m depth). Cover: Cobbles & rocks overhanging vegetation. Duration 3-6 months. - 3 - 30%. ***Adult:*** FD (> 0.3m/s and > 0.5m depth), FS (> 0.3m/s and 0.1 to 0.5m depth) and SD (< 0.3 m/s and < 0.5m depth), and water column cover. Spawning season: October – January/February. Cue: increased temperature, flow and changes in water quality (e.g. conductivity) (3 - 30%).
MAINTENANCE (C/D): **30%** at stress level 3 providing adequate fast deep habitats for abundance, adequate slow deep habitats for water column cover and adequate depths and flows for spawning. **45** % at stress at level 2 providing adequate fast deep habitats for abundance, adequate slow deep habitats for water column cover and adequate depths and flows for spawning. *Labeobarbus kimberleyensis* *Breeding will have commenced in November* ***Juvenile:*** Feeding and Growth: Mostly SS (< 0.3 m/s and 0.1 to 0.5m depth) and FS (> 0.3m/s and 0.1 to 0.5m depth). Cover: Cobbles & rocks overhanging vegetation. Duration 3-6 months. - 3 - 30%. ***Adult:*** FD (> 0.3m/s and > 0.5m depth), FS (> 0.3m/s and 0.1 to 0.5m depth) and SD (< 0.3 m/s and < 0.5m depth), and water column cover. Spawning season: October – January/February. Cue: increased temperature, flow and changes in water quality (e.g. conductivity) (3 - 30%).

Table 3.27: Invertebrate taxa and integrates stress requirements for EWR 19

INVERTEBRATES:DURATIONS AND MOTIVATIONS TO BE USED FOR DETERMINING STRESS REQUIREMENTS.
Indicator: *Ephemeroptera* (Heptageniidae) **Invertebrate:** The indicator is a rheophilic species dependant on the perennial flow.
INVETEBRATE STRESS REQUIREMENTS
DRY SEASON (August)
DROUGHT: For a drought duration of 10% there is enough SIC habitat with fast enough velocities (0.3 m/s) and depth (>10 cm) to ensure the survival of the highly flow dependent mayflies *Ephemeroptera* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. The river should never stop flowing as this would result in the complete elimination of the rheophilic invertebrate community (0% duration)
MAINTENANCE (C): The river has enough flow to ensure a healthy population of the mayflies *Ephemeroptera* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. This should be for duration of 30%. **MAINTENANCE (C/B):** The river has enough flow to ensure a healthy population of the mayflies, *Ephemeroptera* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. This should be for a duration of 30%.
WET SEASON (February)
DROUGHT: There is enough SIC habitat with fast enough velocities (0.3 m/s) and depth (>10 cm) to ensure the survival of the highly flow dependent mayflies *Ephemeroptera* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. This should be for a duration of not less than 10%. Higher drought flows (greater depths, velocities and amount of cobbles) are required in the summer months to ensure sustainability and gender equity in the *Trichoptera* population. The river should never stop flowing as this would result in the complete elimination of the rheophilic invertebrate community (0% duration)
MAINTENANCE (C): The river has enough flow to ensure a healthy population of the mayflies, *Ephemeroptera* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. The value set is the minimum level to ensure a viable breeding community This should be for a duration of 30%. **MAINTENANCE (C/B):** The river has enough flow to ensure a healthy population of the mayflies, *Ephemeroptera* sp., which was selected as an indicator for the rheophilic macro-invertebrate community. The value set is the minimum level to ensure a viable breeding community. This should be for a duration of 30%.

The vegetation indicators used were *Imperata cylindrica Cyperus denudatus* and *Cyperus longus.* The resulting conditions of the vegetation indicators to the required low flows are described below. In conclusion, the low flows would maintain the PES and REC of the riparian vegetation (Table 3.28).

Table 3.28: Verification of the low flow requirements to maintain the vegetation EC

PES and REC: RIPARIAN VEGETATION EC C/D (ECOSTATUS D)
Dry Season maintenance Flows do not vary much between high and low flow and are sufficient to activate the lower limits of *P. coloratum* on the marginal zone, and facilitate survival of *P. australis*. **Dry Season drought** *P. coloratum* rhizome level remains activated for survival. Water level is just below both species rooting level. Water level is deep enough to prevent the extensive spread of *P. australis* into the channel.

Wet Season maintenance This flow inundates the marginal zone sedges, which is sufficient to sustain summer functionality e.g. flowering. **Wet Season drought** Sufficient to activate the lower limits of *P. coloratum* on the marginal zone, and facilitate its survival. *P. australis* may migrate towards the middle of the instream channel in very dry conditions if the water level of the instream channel drops to below 1m. *Myriophyllum spicatum* is also likely to thrive in the lower flow conditions choking the instream channel.	
AEC up: RIPARIAN VEGETATION EC: C (ECOSTATUS D)	
Dry Season maintenance The maintenance flows will not significantly alter the status from the present ES. The status in this area is determined mainly by the vast number and percentage cover of exotic species. **Wet Season maintenance** Same effect as dry season base flow slight inundation at rhizome level of *P. coloratum*.	

The maximum wet season base flow was used as the departure point with no stress and the stress-flow relationships were determined for the fish and macroinvertebrates using the hydraulic profile for EWR 19 and the associated available habitats under various stress levels from 0 (maximum base flow) to 10 (no flow). Figure 3.18 shows the hydraulic profile for EWR 19.

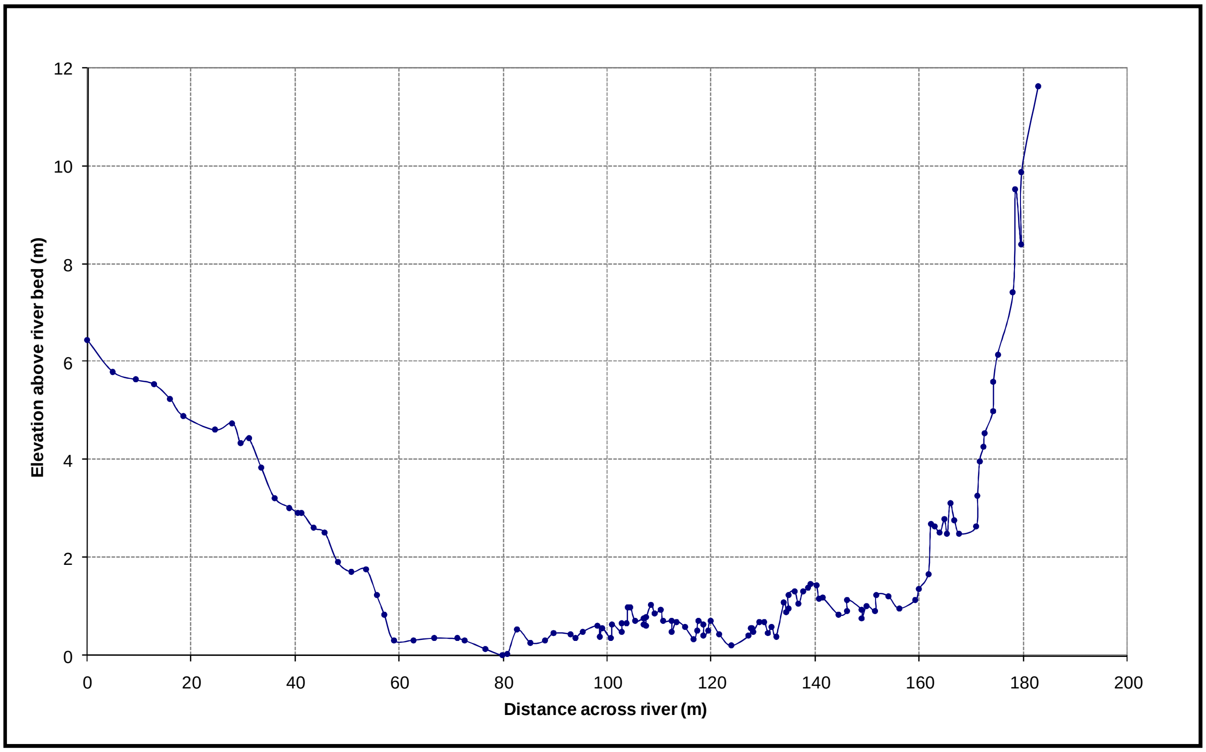


Figure 3.10: Hydraulic profile for EWR 19

To produce the final results (Figure 3.20), the DRM results for the specific category are modified according to specialists' requirements (Figure 3.16 and 3.17). There are a range of options one can use to make these modifications, such as changing the total volume required for the year, changing specific monthly volumes, changing durations of either drought or maintenance flows, changing the seasonal distribution and changing the category rules and shape factors. The final dry and wet season stress duration curves for EWR 19 is shown in Figure 3.20.

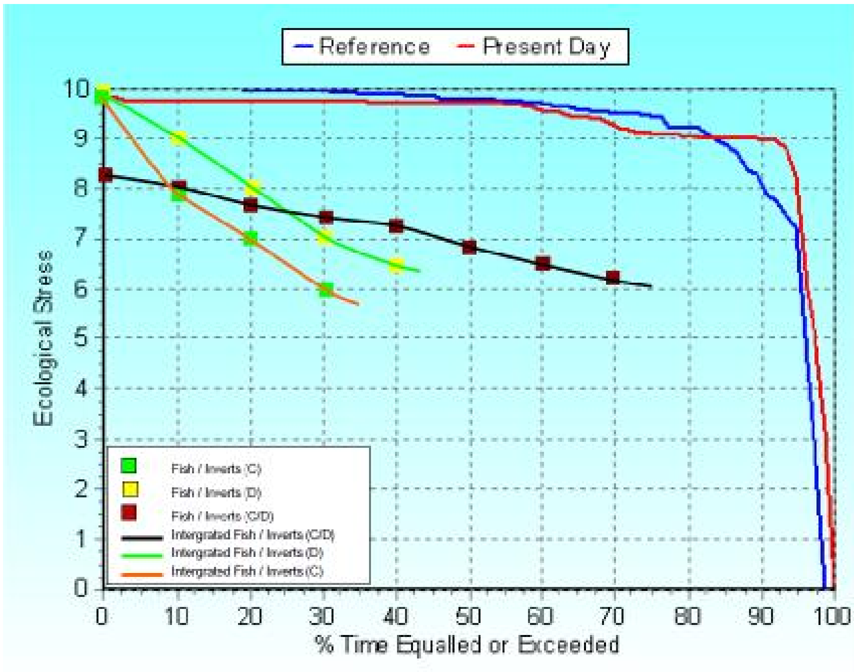


Figure 3.11: Final stress duration curves for EWR 19 (August)

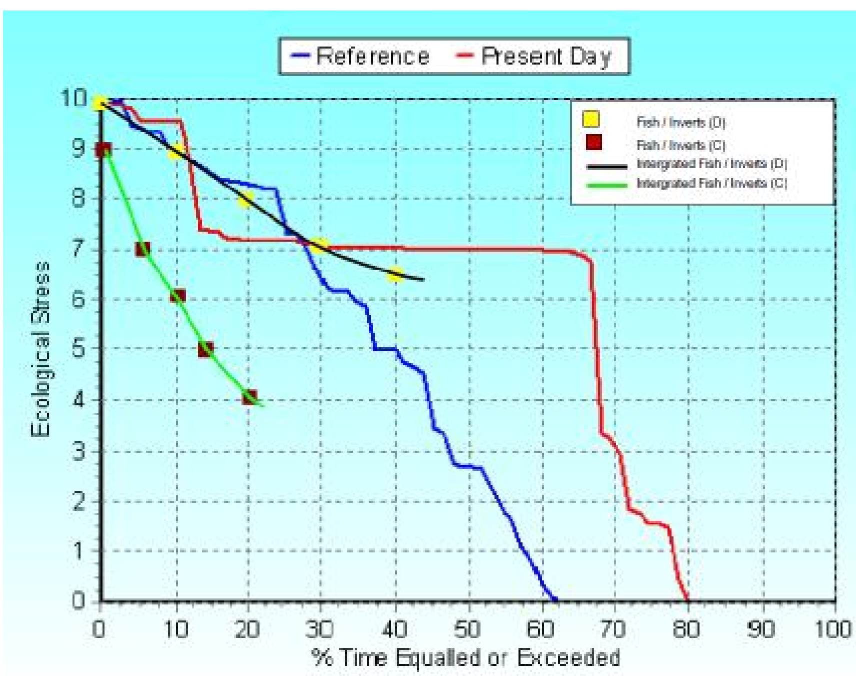


Figure 3.12: Final stress duration curves for EWR 19 (February)

3.6.3 Flood requirements

The flood requirements for EWR 19 were specified by the fish, macroinvertebrates, geomorphology and riparian vegetation specialists and include small freshets to provide specific cues as well as larger floods for clearing of the river channel. The high flow classes are identified as follows:

- The geomorphologist and riparian vegetation specialist identify the range of flood classes required and list the functions of each flood.
- The instream specialists then indicate which of the instream flooding functions are addressed by the floods identified for geomorphology and riparian vegetation.
- Any of the floods required by the instream biota and not addressed by the floods already identified, must then be described (in terms of ranges and functions) for the instream biota.

Results are provided in Table 3 29 and detailed motivations provided in Table 3.30.

Table 3.29: Identification of instream functions addressed for EWR 15

FLOOD CLASS	FLOOD RANGE (m3/s)	Motivations	Fish flood functions							Invertebrate flood functions				
			Migration cues	Migration habitat (depth etc)	Clean spawning substrate	Create spawning habitat	Create nursery areas	Resetting water quality	Inundate vegetation for spawning	Breeding and hatching cues	Clear fines	Scour substrate	Reach or inundate specific areas	Reset water quality
I	4 (daily average)	**Geomorphology:** 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.	x		x			x		x	x			
II	25 (daily avg)	**Fish:** First flush is for flushing sediments from riffle areas, improving water quality, moving exotic macrophytes and inundation of marginal vegetation for nursery areas. Cues for migration in Jan and Feb. **Macroinvertebrates:** Flushing of riffles, water quality improvements and additional marginal vegetation biotopes. **Geomorphology:** 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.	x	x	x	x	x	x	x	x	x	x	x	x
III														
IV	100 (daily avg)	**Geomorphology:** 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. **Riparian vegetation:** Inundates marginal zone and population. Inundates *Phragmites australis* and cyperoids lower limits to 50 cm at least, which will prevent in-channel migration.												
V	230(daily avg)	**Geomorphology:** 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.												

The number of high flow events required for each EC is provided in Table 3.5. No observed daily data was available to check flood requirements against.

Table 3.30: EWR 15: The recommended number of high flow events required

FLOOD CLASS	FLOOD RANGE (m^3/s)	INVERTEBRATES	FISH	VEGETATION	GEOMORPHOLOGY	FINAL (Frequency)	MONTHS	DAILY AVERAGE	DURATION
PES and REC: D									
I	4 (daily average)				5	5	Nov, Dec, Jan, Feb, Mar	4	3
II	25 (daily avg)	2	4		1	4	Nov, Jan, Feb, Mar	25	7
III									
IV	100 (daily avg)			1:2	1:2			100	10
V	230(daily avg)				1:5 +				
AEC up: C									
I	4 (daily average)				6	6	Nov, Dec, Jan, Feb, Mar, Apr	4	4
II	25 (daily avg)	3	5		1	5	Nov, Dec, Jan, Feb, Mar	25	7
III									
IV	100 (daily avg)				1:2			100	12
V	230(daily avg)				1:5 +				

3.6.4 Final ecological water requirements

The final ecological water requirements were generated by the DRM in SPATSIM using the stress duration curves and the integrated flood requirements and is summarised in Table 3.6.

Table 3.31: Final EWRs for EWR 19

Desktop version:		2.10	**Reference flow used Present day MAR (MCM)**	247.67
BFI index	0.161	**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	0.000		
NOVEMBER	1.179	0.012	4 25	4 7
DECEMBER	1.246	0.015	4 25	4 7
JANUARY	2.282	0.007	4 25	4 7
FEBRUARY	4.736	0.087	4 25	4 7
MARCH	4.504	0.011	4 25	4 7
APRIL	2.822	0.000	4	4
MAY	1.344	0.000		
JUNE	0.616	0.000		
JULY	0.392	0.000		
AUGUST	0.450	0.000		
SEPTEMBER	0.565	0.000		
TOTAL MCM	54.274	0.330	62.167	
% OF REFERENCE	13.44	0.08	15.39	

3.7 SUMMARY OF FINAL RESULTS

The natural MARs as provided by PDNA are given in Table 3.21. The final flow requirements are expressed as a percentage of the natural MAR in Table 3.22.

Table 3.32: 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 3.33: Summary of results as a percentage of the reference MAR

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

4 EXTRAPOLATION

No formal extrapolation activities were undertaken in the project.

5 CONCLUSIONS

5.1 Water quality

The Vaal River at Vaalharts weir (C9H008) displays high salts (479 mg/ℓ) and 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 (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 Weir.

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 soil types 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).

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 processes.

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).

5.2 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 neighboring countries resort under national control. The following reservations are made in the National Water Resource Strategy with respect to water transfers into 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 Mm3/a during the period of projection.

A reservation applies to the transfer of 18 Mm3/a from the Upper Orange WMA to the Douglas Weir in the Lower Vaal 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).

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APPENDIX A
HYDRAULICS ASSESSMENT