COMPREHENSIVE RESERVE DETERMINATION

INTEGRATED VAAL RIVER SYSTEM

SURFACE WATER

ECOLOGICAL WATER REQUIREMENTS

TECHNICAL COMPONENT: MIDDLE VAAL

REPORT NO.: RDM/WMA9 C000/01/CON/0210
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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 Middle Vaal Water Management Area (WMA), North West Province. The purpose of the Comprehensive Reserve Determination Study for the selected water resources of the Middle 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 Middle Vaal catchment area.

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

The Middle Vaal WMA covers a catchment area of 52 563 km^2, and includes parts of the Free State and North-West Provinces. It is situated in the north-western part of the country and forms part of the Orange River watercourse. The Vaal River flows in a westerly direction to the Lower Vaal WMA. It is the middle WMA within the Vaal River System, with water being transferred *via* the Vaal River through this WMA to Bloemhof Dam, from the Upper Vaal WMA to the Lower Vaal WMA. The WMA consists of the C24, C25, C41, C42, C43, C60 and C70 tertiary catchments.

The surface flow of the Vaal River, most of which originates in the Upper Vaal WMA, represents the bulk of the surface water in the Middle Vaal WMA. The Vaal River is fed by a number of tributaries of which the most significant are the Renoster, Schoonspruit, Vals and Vet Rivers. Vlei areas occur along the lower Vet River and in the upper Schoonspruit catchment. The surface water flows that originate within the WMA are highly seasonal and intermittent.

Selected Environmental Water Requirement (EWR) sites (EWR 12 – 15) are indicated in Table A. A rapid Reserve Determination was also undertaken on the Klein Vet River (Table A). The reason why this site was added was for potential extrapolation purposes.

Table A: Selected EWR sites for the Middle Vaal catchment

EWR Site number	EWR site name	River	EcoRegion (Level II)	Geomorphic zone	Altitude (m)	Quaternary catchment	Hydrological gauge
EWR12	Vaal River: Vermaasdrift	Vaal	11.01	E: Lower Foothills	1348	C24A	C2H007
EWR13	Vaal River: Regina bridge	Vaal	11.08	E: Lower Foothills	1285	C24J	C2H061
EWR14	Vals River: Proklameersdrift	Vals	11.07	E: Lower Foothills	1400	C60J/C60G	C6H003
EWR15	Vet River: Fisantkraal	Vet	11.08	E: Lower Foothills	1247	C43A	C4H002
Rapid EWR – RE-EWR 3	Klein-Vet, just downstream of Winburg	Klein Vet	11.03	E: Lower Foothills	1367	C41A	

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

The results of the Ecoclassification per EWR site is summarised in Table B. EWR sites 12 to 15 were assessed on a comprehensive level and the last site (Rapid EWR) were assessed on a rapid III level of detail.

Table B: Summary of Ecoclassification

EWR site	River	Quaternary catchment	Reference MAR (Mm^3/a)*	PES	EIS	REC
EWR12	Vaal	C24A	2546.4	D	Moderate	D
EWR13	Vaal	C24J	2654.3	C	High	C
EWR14	Vals	C60J/C60G	145.79	C/D	High	C/D
EWR15	Vet	C43A	413.04	D/E	Moderate	D
RE- EWR 3	Klein Vet	C41A	49.56	C	Moderate	C

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

Table C: Natural and PD MARs of the EWR sites

Site	Virgin MAR	Present MAR
EWR 12	2546.392	1574.637
EWR 13	2654.289	1638.37
EWR 14	145.794	118.04
EWR 15	413.036	253.15
Rapid EWR	49.564	

Ta**ble D: Summary of results as a percentage of the natural MAR**

EWR Sites	EC	Maintenance Low Flows (% nMAR)	Drought Low Flows (% nMAR)	High Flows (% nMAR)	Long Term Mean (% nMAR)
EWR 12	**D PES,REC**	**12.4**	**9.6**	**15.88**	**21.09**
EWR 13	**C PES,REC**	**11.6**	**0.05**	**5.05**	**17.33**
EWR 14	**C/D PES,REC**	**5.41**	**0.08**	**2.37**	**5.2**
EWR 15	**D/E PES,REC**	**5.44**	**2.37**	**12.76**	**12.96**

Water quality

The water quality of the Vaal River in the Middle Vaal WMA was generally poor due to high dissolved salts and high nutrients, e.g. the Vaal River at Orkney (C2H007) was characterised by unacceptable high EC (90 mS/m; ~630 mg TDS/ℓ), P concentration (0.224 mg/ℓ) and pH (9.11).

The water quality in the Renoster River (C7H006) and Sandspruit (C2H067) was fair in terms of salts (331 & 373 mg/ℓ), but poor in terms of nutrients, 0.080 and 0.118 mg PO4-P/ℓ respectively.

Koekemoerspruit (C2H139) and Skoonspruit (C2H073) are hotspot areas with unacceptable high salts concentrations, 1 760 and 987 mg/ℓ respectively. The salt load evidently originates from the mining activities and the high nutrients draining from the KOSH urban area.

Another problem area is the Sand River at Bloudrift (C4H016) with unacceptable high salts (2 415 mg/ℓ) from the Welkom-Virginia gold mines and very high nutrients (nitrate, 1.05; P, 0.50 mg/ℓ), evidently from poorly treated sewage effluent.

The water quality in the Vals River at Kroonstad (C6H007) was fair with ideal ammonia, sulphate and nitrate concentrations, acceptable pH (8.39), and salts (316 mg/ℓ), but with unacceptable high phosphate concentration (0.080 mg/ℓ). However, the Vals River at Bothaville (C6H002) was in a poor state with high salts concentration (837 mg/ℓ), probably originating mainly from seepage water and return flows from irrigation, unacceptable high pH (8.69) and phosphate concentration (0.90 mg/ℓ).

The water quality in Erfenis Dam (C4R002) was generally good except for the very high phosphate concentrations (0.126 mg/ℓ) that indicate a serious potential for algal productivity. However, the water quality in the lower section of the Vet River (C4H004) was poor with high salts (666 mg/ℓ) and high nutrients concentrations (phosphate, 0.088 mg/ℓ).

All the parameters in Heuningspruit at Dankbaar Mispah (C7H003) were ideal, except for the unacceptable P concentrations (0.194 mg/ℓ) that results in a poor quality.

Impacts of the mining activities and mine closure

The economy of the Middle Vaal WMA is dominated by the mining sector, with a contribution of 45.6 % to GGP, particularly gold mining. However, discharges from mines impact significantly on both the hydrology and water quality of the Middle Vaal system. The impacts from the gold mining activities on groundwater have been recognised as early as 1960 when localised dewatering became an issue at Stilfontein Gold Mine. Only more recently have the impacts on the quality of the groundwater and the interaction with the Vaal River becomes a concern. The largest volumes are abstracted at Stilfontein Gold Mine’s Margaret Shaft. Although Stilfontein’s underground operations has ceased for more than ten years, pumping at Margaret shaft continues for the safety of the downstream mines. The volume of water abstracted daily is estimated at 32 Mℓ/d. The water is utilized by a number of users and any excess is discharged to the Koekemoer Spruit. Groundwater is also abstracted from other operating shafts in the KOSH mining area for safety and the water is utilized as process water Due to the large quantities of water present in the mined Witwatersrand rocks, a large quantity of water (120 -150 Mℓ/d) is pumped to the surface for accessibility each day. This groundwater however has average conductivities of 500 mS/m (~3 500 mg/ℓ) and cannot be used for drinking or irrigation purposes.

Water quality in the Vaal River is of serious concern because of high salinity and nutrient content, which mainly results from urban and industrial return flows as well as mining activities in the Upper Vaal WMA. The closure of mines may have further water quality impacts.

Management of wastewater treatment works discharges

A large proportion of the sewage emanating from SA urban areas is not treated properly prior to discharge, because the sewer systems are incomplete, or sewage treatment plants are overloaded. Matjhabeng Local Municipality (Welkom, Odendaalsrus, Virginia, Hennenman, Allanridge and Ventersburg) with 11 sewage purification plants and the Moqhaka municipality (Kroonstad, Maokeng, Steynsrus and Viljoenskroon) have failed to present information to DWA for the Green Drop certification and are classified with zero Green Drop scores. These local municipalities have been implicated for polluting the local rivers and lakes with poorly treated sewage and occasionally raw sewage spills.

Municipal wastewater treatment plants, not complying with effluent standards and informal, unsewered human settlements along the river banks or in the close vicinity of the Vaal River, pose a threat to regional water quality, especially eutrophication (nutrient enrichment) and human health. There is a general non-compliance to phosphate RWQO throughout the WMA.

Sewage wastewater, by its nature, is teeming with microbes. Therefore, from a social perspective, the discharge of sewage effluent into the natural environment can have negative impacts on human health, primarily from bacteriological and other forms of pathogens that survive the biological treatment process and inadequate disinfection of the effluent. However, Municipal wastewater effluent is also one of the impacts that are most easy to mitigate because they are easily identified, measured, and susceptible to control by policies and regulation.

Eutrophication

The Vaal River in the Middle Vaal WMA experience regular algal blooms and has been classified as hypertrophic (nutrient over-enriched), that cause several problems to man and the environment. Eutrophication effects and problems are profound in the Vaal River and have become a matter of major concern to all water users. The impacts of eutrophication are ecological, social and economical. Infestations of alien vegetation are also found along the Vaal River.

Erfenis, Koppies and Allemanskraal Dams are classified as oligotrophic, however, toxic cyanobacterial incidents have been recorded. Bloemhof Dam is eutrophic and experience cyanobacterial blooms usually dominated by Microcystis spp. and Oscillatoria sp.

Cyanobacterial blooms (frequency and intensity) in the Vaal River are increasing. As cyanobacterial blooms become more common, the likelihood grows that people will be exposed to increased doses of toxins and the risk of animal die-offs grows as well.

Urbanisation

Over 75 % of the population in the WMA are classified as living in urban areas, and about 25 % as rural. Most of the population are concentrated in the main urban and mining centres of Klerksdorp, Orkney and Stilfontein in the Middle Vaal sub-area; Welkom and Virginia in the Sand-Vet sub-area, as well as Kroonstad (which is not a mining town) in the Rhenoster-Vals sub-area. South Africa’s freshwater resources are under increasing stress from a growing population and an expanding economy.

Water Transfers and availability

Substantial transfers take place from the Upper Vaal to the Middle Vaal (790 Mm3/a). However, there are no large control structures with respect to the regulation of flow in the Vaal River within the Middle Vaal WMA, and both the quantity and quality of water in the Vaal River are largely influenced by management practices in the Upper Vaal WMA. There are existing weirs on the Vaal River at Orkney and Balkfontein. Water from tributaries as well as from groundwater in the water management area is fully utilised, mainly for irrigation and for towns remote from the Vaal River.

Hydrology

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

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

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

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

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

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APPENDIX A: HYDRAULIC ASSESSMENT

ACRYNOMS

CD: RDM	Chief Directorate: Resource Directed Measures
D: NWRP	Directorate: National Water Resource Planning
D: RQS	Directorate: Resource Quality Services
DWAF	Department of Water Affairs and Forestry
EC	Ecological Category
EIS	Ecological Importance and Sensitivity
EWR	Ecological Water Requirements
GDP	Gross Domestic Product
GGP	Gross Geographic Product
IHI	Index of Habitat Integrity
NWA	National Water Act
PES	Present Ecological State
QHI	Quick Habitat Integrity
REC	Recommended Ecological Category
RU	Resource Unit
SCI	Socio Cultural Importance
ToR	Terms of Reference
WMA	Water Management Area

GLOSSARY

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

	used to refer to both the quantity and quality components.
INSTREAM FLOW REQUIREMENTS (IFR)	The flow patterns (magnitude, timing and duration) needed to maintain a riverine ecosystem in a particular condition. This term is used to refer to the quantity component only of Ecological Water Requirements.
MAINTENANCE FLOW	The flow required to meet the requirements of the riverine ecosystem at a particular site and maintain the resource base in a particular condition during "normal" climatic years. The distinction between "normal" and "drought" was based on an examination of monthly flow duration curves
PRESENT ECOLOGICAL STATE (PES)	The degree to which ecological conditions of an area have been modified from natural (reference) conditions. The measure is based on water quality variables, biotic indicators and habitat information collected 1 to 3 years prior to the assessment. Results are classified on a 6-poin scale, from Category A (*Largely Natural*) to Category F (*Critically Modified*).
REFERENCE CONDITION	Natural ecological conditions, prior to human development.
RESERVE	The quantity and quality of water required (a) to satisfy basic human needs by securing a basic water supply, as prescribed under the Water Services Act, 1997 (Act No. 108 of 1997), for people who are now or who will, in the reasonably near future, be (i) relying upon; (ii) taking water from; or (iii) being supplied from, the relevant water resource; and (b) to protect aquatic ecosystems under the National Water Act, 1998 (Act No. 36 of 1998) in order to secure ecologically sustainable development and use of the relevant water resource. The Reserve refers to the modified Ecological Water Requirement, where operational limitations, and stakeholder consultation are taken into account.

RESOURCE QUALITY OBJECTIVE	Quantitative and auditable statements about water quantity, water quality, habitat integrity and biotic integrity that specify the requirements (goals) needed to ensure a particular level of resource protection. This term takes into account the management *classes* and the requirements of other users. These components are not addressed in this project
RESOURCE UNIT	Stretches of river that are sufficiently ecologically distinct to warrant their own specification of Ecological Water Requirements, and that can be practically managed as a single unit.

1 INTRODUCTION

1.1 BACKGROUND

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

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

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

The CD: RDM initiated the Comprehensive Reserve Determination Study for the Middle Vaal Water Management Area (WMA), North West Province as part of the integrated Vaal River System Reserve study. The purpose of the Comprehensive Reserve Determination Study for the selected water resources of the Middle Vaal WMA is to determine the ecological and basic human needs water quantity and quality Reserve at a comprehensive level of confidence.

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 (see Figure 1.1) for the rivers of the Middle Vaal catchment area.

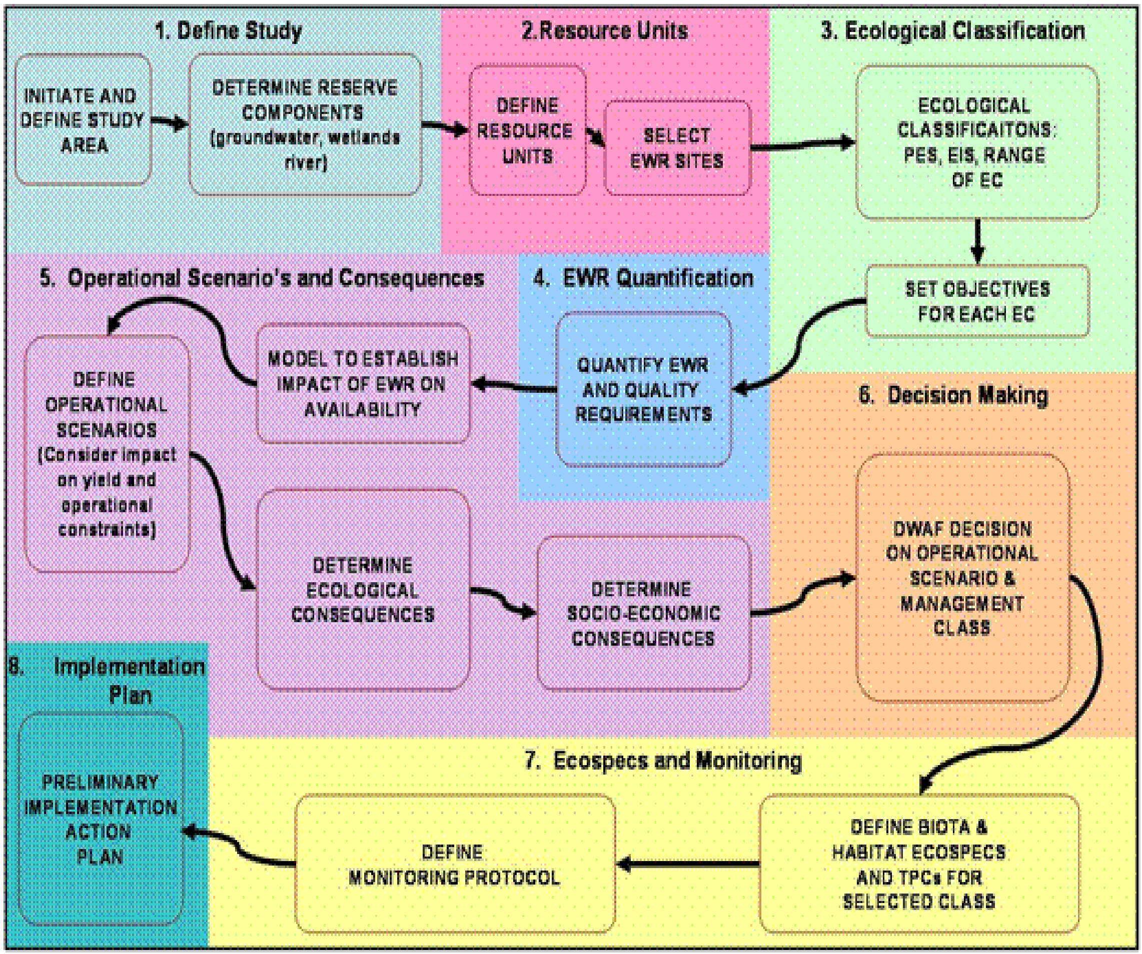


Figure 1.1: Generic procedure for the determination of the ecological Reserve

1.2 STUDY AREA

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

The Middle Vaal WMA covers a catchment area of 52 563 km^2, and includes parts of the Free State and North-West Provinces. It is situated in the north-western part of the country and forms part of the Orange River watercourse. The Middle Vaal River flows in a westerly direction to the Lower Vaal WMA. The WMA consists of the C24, C25, C41, C42, C43, C60 and C70 tertiary catchments.

The surface flow of the Middle Vaal River, most of which originates in the Upper Vaal WMA, represents the bulk of the surface water in the Middle Vaal WMA. The Vaal River is fed by a number of tributaries of which the most significant are the Renoster, Schoonspruit, Vals and Vet Rivers. Vlei areas occur along the lower Vet River and in the upper Schoonspruit catchment. The surface water flows that originate within the WMA are highly seasonal and intermittent.

Selected Ecological Water Requirement (EWR) sites (EWR 12 – 15) are indicated in Table 1.1 and in Figure 1.2. A rapid Reserve Determination was also undertaken on the Klein Vet River (Table 1.1). The reason why this site was added was for potential extrapolation purposes.

Table 1.1: Selected EWR sites for the Middle 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						
EWR12	Vaal River: Vermaasdrift	Vaal	C2-Vaal Orkne	S26.93615	E26.85025	11.01	E: Lower Foothills	1348	MRU Vaal F	C24A	C2H007
EWR13	Vaal River: Regina bridge	Vaal	C2-Vaal Orkne	S27.10413	E26.52185	11.08	E: Lower Foothills	1285	MRU Vaal G	C24J	C2H061
EWR14	Vals River: Proklameersdrift	Vals	C6Vals-Prokl	S27.48685	E26.81320	11.07	E: Lower Foothills	1400	MRU Vals B	C60J/C60G	C6H003
EWR15	Vet River: Fisantkraal	Vet	C4-Vet-Hoops C4-Vet-Erfen	S27.93482	E26.12569	11.08	E: Lower Foothills	1247	MRU Vet C	C43A	C4H002
Rapid EWR – RE-EWR 3	Klein-Vet, just downstream of Winburg	Klein Vet	C4GVet-V4	S28.564708	E26.943946	11.03	E: Lower Foothills	1367	MRU Vet A	C41A	

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

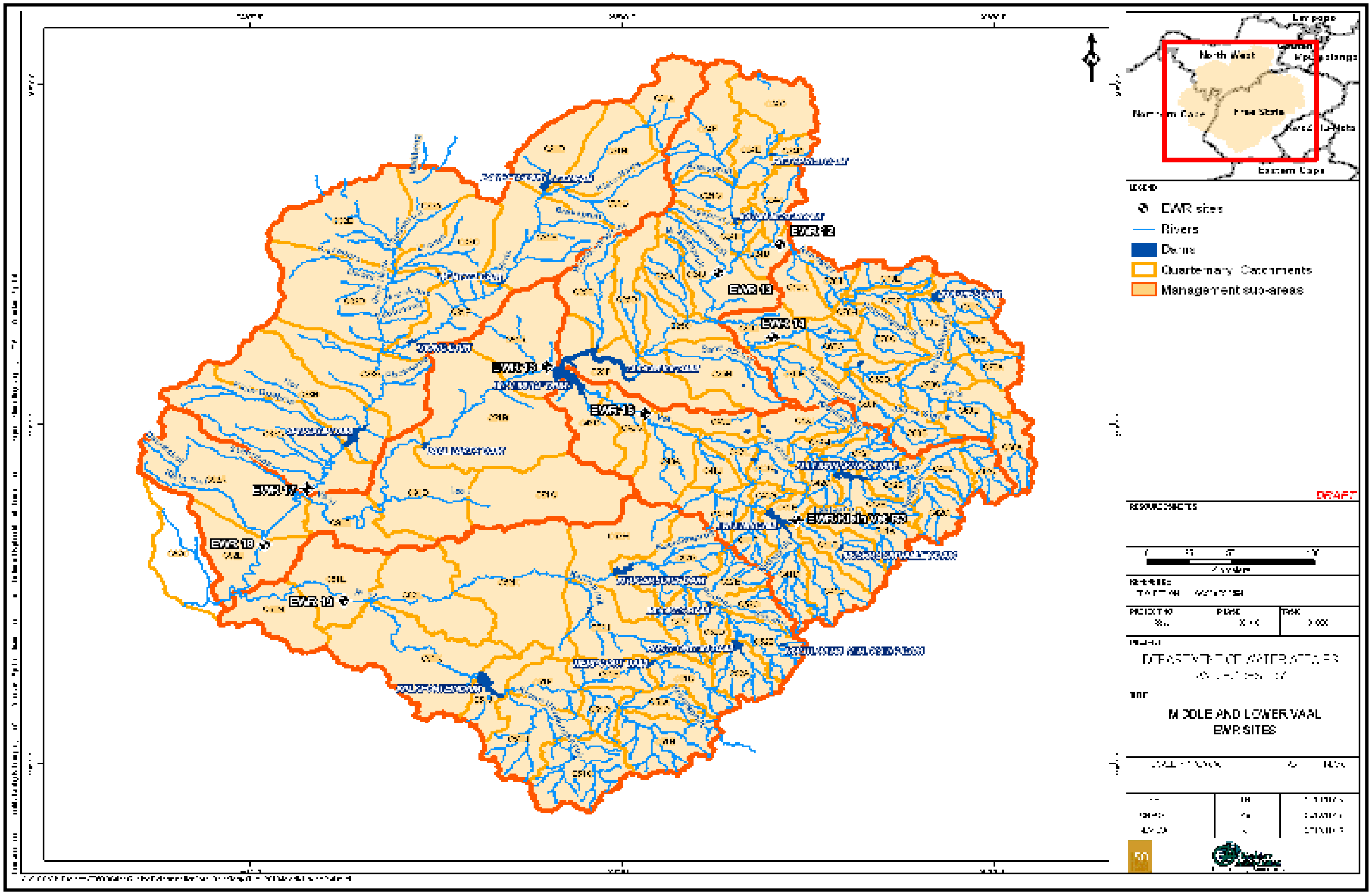


Figure 1.2: Resource Units and selected EWR sites for the Middle and Lower Vaal catchment

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 Middle Vaal, the EWR sites were identified as having more flows than natural with:

- EWR 12 and EWR 13 having higher base flows in winter, with a loss of or masked summer floods due to the Vaal Dam and Vaal Barrage; and
- EWR 14 and EWR 15 having less flow all year round.

The standard Habitat Flow Stressor Response (HFSR) (IWR Source to Sea, 2004) approach was applied to the EWR sites 12-15 to determine low flow requirements for the EWR sites.

1.3.2 Rapid EWR site

The Klein Vet Rapid EWR (RE-EWR 3) site was assessed at Rapid level III for low flows and therefore the HFSR method for setting low flows were not applied to this site. The Reserve was estimated using the Hughes Desktop Reserve Model (DRM) (DWAF, 1999) for the Recommended Ecological Category (REC). Therefore for the low flow requirements, the estimated Reserve was verified and the DRM was adjusted if needed.

1.3.3 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.

1.3.4 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,

  - 0 whether additional instream functions apart from the generic list are required,
  - 0 whether any instream functions are not necessary and can be deleted from the list,
  - 0 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 spaced.

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 Middle Vaal Water Management Area which were finalised at several specialist meetings held during 15 – 19 September 2008 and 17 – 21 November 2008. 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
- Extrapolation (if applicable)
- 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 selected 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: Extrapolation

Summary of potential to use sites for extrapolation.

Section 5: Conclusions and Recommendations

The results are summarised and recommendations are made.

Section 6: References

The detail analysis and models used during the workshops to determine the stresses and ecological water requirements are available on the CD with the electronic information (RDM/ WMA09C000/01/CON/0710.

2 DETERMINATION OF STRESS INDICES

2.1 EWR 12: VERMAASDRIFT (VAAL RIVER)

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)

One indicator species was 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 a 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.

- *Cyperus denudatus:* Obligate riparian sedge that occurs in both the marginal and lower zones. Can form colonies on riverbanks. Rhizomatous, does not self seed. Flowers Dec - Mar.

- *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.

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 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:

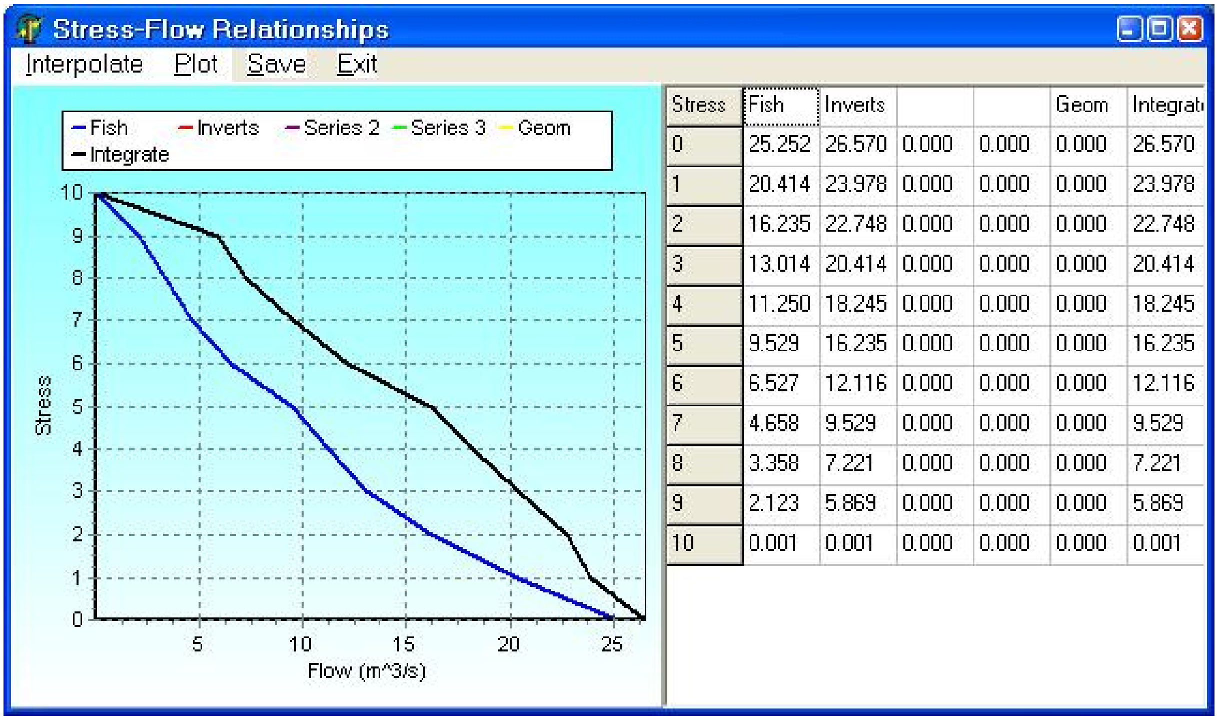
- 0 = Optimum habitat with least amount of stress possible for the indicator groups at the site (fixed at the natural maximum baseflow in the same way as for the habitat response).

- 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) and macroinvertebrates (red underneath the 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.



Stress	Fish	Inverts			Geom	Integrat
0	25.252	26.570	0.000	0.000	0.000	26.570
1	20.414	23.978	0.000	0.000	0.000	23.978
2	16.235	22.748	0.000	0.000	0.000	22.748
3	13.014	20.414	0.000	0.000	0.000	20.414
4	11.250	18.245	0.000	0.000	0.000	18.245
5	9.529	16.235	0.000	0.000	0.000	16.235
6	6.527	12.116	0.000	0.000	0.000	12.116
7	4.658	9.529	0.000	0.000	0.000	9.529
8	3.358	7.221	0.000	0.000	0.000	7.221
9	2.123	5.869	0.000	0.000	0.000	5.869
10	0.001	0.001	0.000	0.000	0.000	0.001

Figure 2.1: Component and integrated stress curves for EWR 12

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)	26.570	Fish guild: All habitats optimal (5[*]).
1 (SSR)	23.978	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)	22.748	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)	20.414	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)	18.245	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)	16.235	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)	12.116	Reduced FDI critical habitat. Most rheophilic species persist, but abundances reduced.
7 (SSR)	9.529	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)	7.221	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)	5.869	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 13: VAAL RIVER AT REGINA BRIDGE

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

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

One indicator species was 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 a 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 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 1metre or so 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.

2.2.2 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 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:

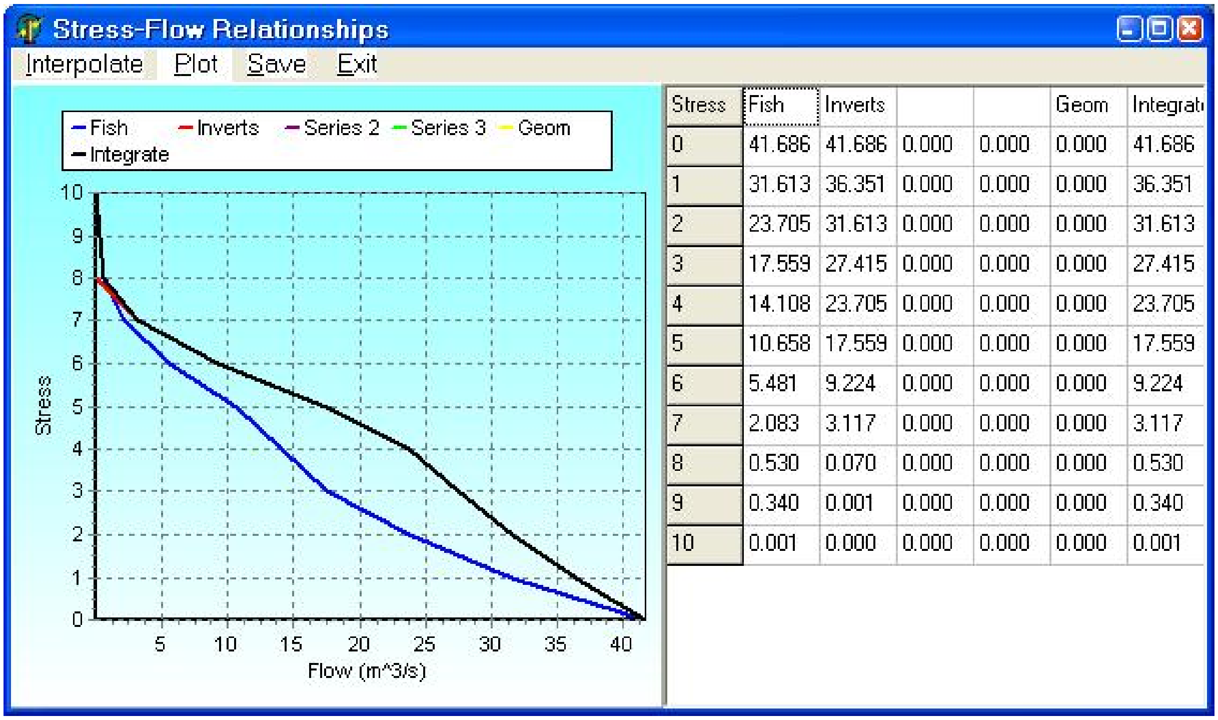
- 0 = Optimum habitat with least amount of stress possible for the indicator groups at the site (fixed at the natural maximum baseflow in the same way as for the habitat response).

- 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 (Appendix B).

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 under black) 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.



Stress	Fish	Inverts			Geom	Integrat
0	41.686	41.686	0.000	0.000	0.000	41.686
1	31.613	36.351	0.000	0.000	0.000	36.351
2	23.705	31.613	0.000	0.000	0.000	31.613
3	17.559	27.415	0.000	0.000	0.000	27.415
4	14.108	23.705	0.000	0.000	0.000	23.705
5	10.658	17.559	0.000	0.000	0.000	17.559
6	5.481	9.224	0.000	0.000	0.000	9.224
7	2.083	3.117	0.000	0.000	0.000	3.117
8	0.530	0.070	0.000	0.000	0.000	0.530
9	0.340	0.001	0.000	0.000	0.000	0.340
10	0.001	0.000	0.000	0.000	0.000	0.001

Figure 2.2: Component and integrated stress curves for EWR 13

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)	41.686	Fish guild: All habitats optimal (5*).
1 (SSR)	36.351	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)	31.613	SSR guild: Habitats as above with nursery and spawning habitats low (2). LSR guild: All habitats are slightly less than optima (4.5).

Integrated stress	Flow m^3/s	Habitat and/or Biotic responses
3 (SSR)	27.415	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)	23.705	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)	17.559	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)	9.224	Reduced FDI critical habitat. Most rheophilic species persist, but abundances reduced.
7 (SSR)	3.117	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)	0.530	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)	0.340	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 14: VALS RIVER PROKLAMEERSDRIFT

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 (BAEN)

One indicator species was 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 a 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.

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.

- *Cyperus denudatus:* Obligate riparian sedge that occurs in both the marginal and lower zones. Can form colonies on riverbanks. Rhizomatous, does not self seed. Flowers Dec - Mar.

- *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.

2.3.2 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 flow of 50% – 60% for the Vals River at the EWR site).
- 10 - No flow (i.e., there can still be surface water in pools).

Biota response

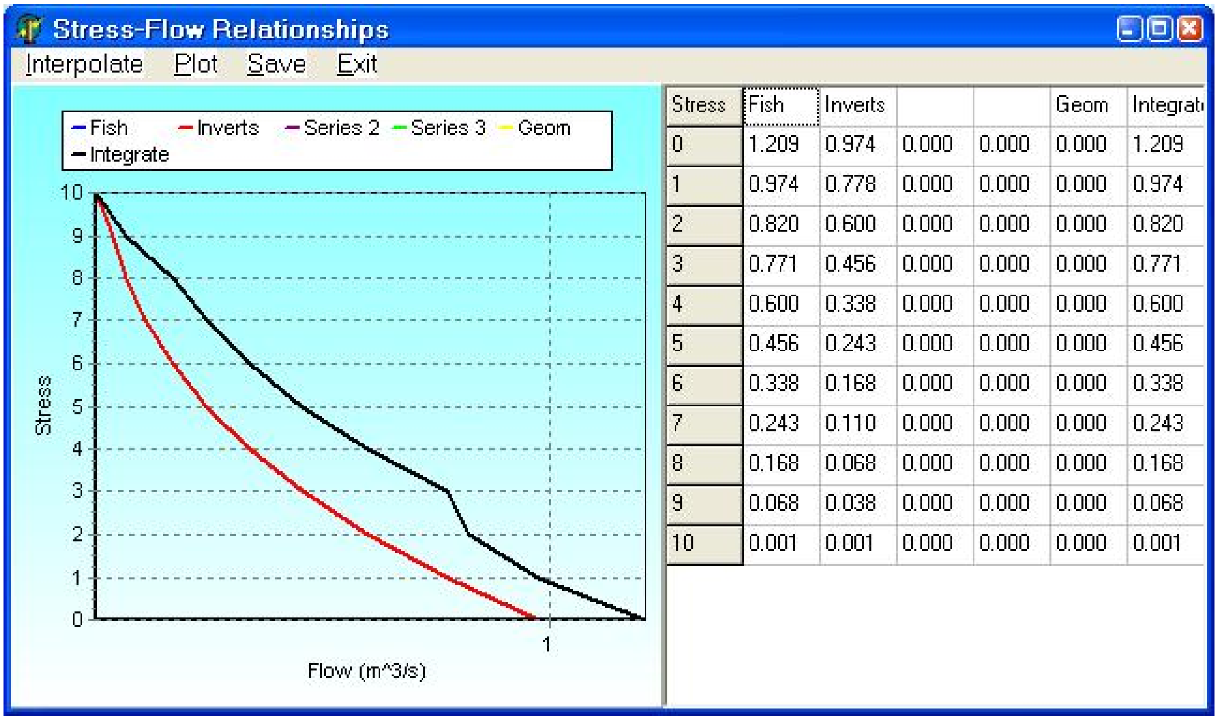
The biota stress index is the instantaneous response of biota to change in habitat (and therefore flow), based on a scale of 0 – 10 where:

- 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 under 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.



Stress	Fish	Inverts			Geom	Integrat
0	1.209	0.974	0.000	0.000	0.000	1.209
1	0.974	0.778	0.000	0.000	0.000	0.974
2	0.820	0.600	0.000	0.000	0.000	0.820
3	0.771	0.456	0.000	0.000	0.000	0.771
4	0.600	0.338	0.000	0.000	0.000	0.600
5	0.456	0.243	0.000	0.000	0.000	0.456
6	0.338	0.168	0.000	0.000	0.000	0.338
7	0.243	0.110	0.000	0.000	0.000	0.243
8	0.168	0.068	0.000	0.000	0.000	0.168
9	0.068	0.038	0.000	0.000	0.000	0.068
10	0.001	0.001	0.000	0.000	0.000	0.001

Figure 2.3: Component and integrated stress curves for EWR 14

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)	1.209	Fish guild: All habitats optimal (5*).
1 (SSR)	0.974	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)	0.820	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)	0.771	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)	0.600	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)	0.456	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)	0.338	Reduced FDI critical habitat. Most rheophilic species persist, but abundances reduced.
7 (SSR)	0.243	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)	0.168	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)	0.068	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 15: VET RIVER AT FISANTKRAAL

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)

One indicator species was 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 a 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.

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.

- *Cyperus denudatus:* Obligate riparian sedge that occurs in both the marginal and lower zones. Can form colonies on riverbanks. Rhizomatous, does not self seed. Flowers Dec **-** Mar.

- *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.

2.4.2 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 Vet 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:

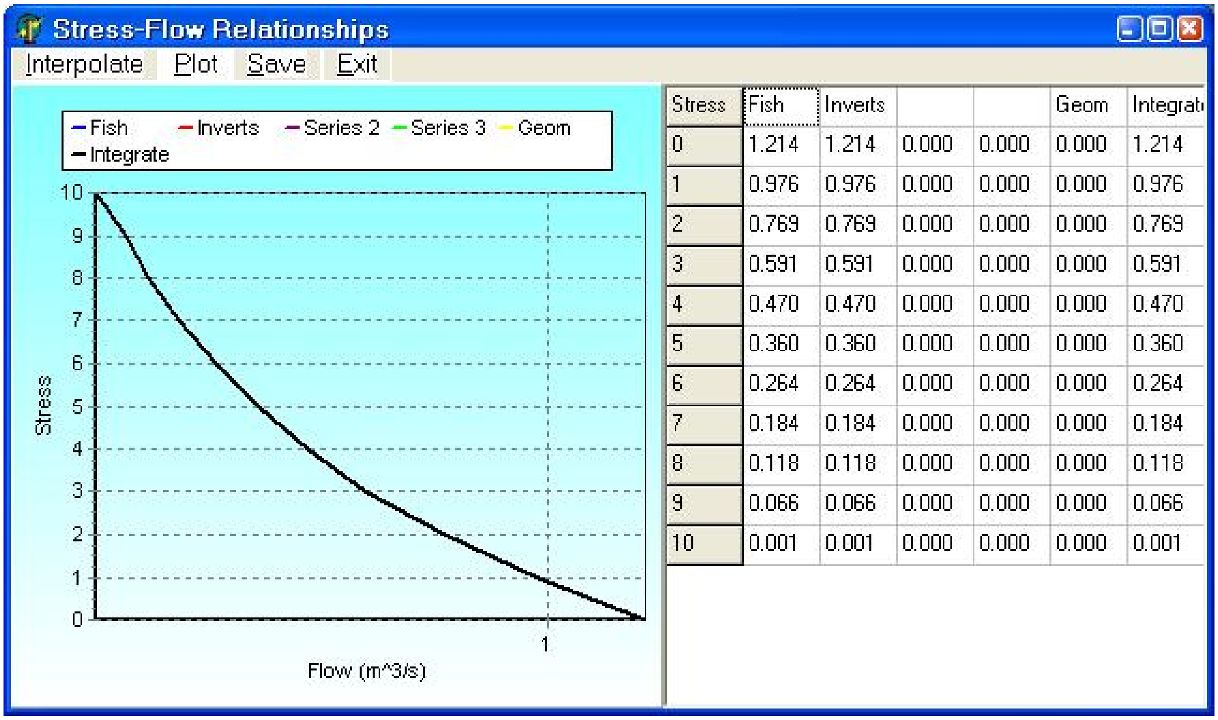
- 0 = Optimum habitat with least amount of stress possible for the indicator groups at the site (fixed at the natural maximum baseflow in the same way as for the habitat response).

- 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 and macroinvertebrates at a specific flow. The highest discharge representing a specific stress is used to define the integrated stress curve. The stress indices for the fish and macroinvertebrates are identical for this EWR site and are shown as the integrated line on the graph below. Figure 2.4 illustrates this graphically.



Stress	Fish	Inverts			Geom	Integrat
0	1.214	1.214	0.000	0.000	0.000	1.214
1	0.976	0.976	0.000	0.000	0.000	0.976
2	0.769	0.769	0.000	0.000	0.000	0.769
3	0.591	0.591	0.000	0.000	0.000	0.591
4	0.470	0.470	0.000	0.000	0.000	0.470
5	0.360	0.360	0.000	0.000	0.000	0.360
6	0.264	0.264	0.000	0.000	0.000	0.264
7	0.184	0.184	0.000	0.000	0.000	0.184
8	0.118	0.118	0.000	0.000	0.000	0.118
9	0.066	0.066	0.000	0.000	0.000	0.066
10	0.001	0.001	0.000	0.000	0.000	0.001

Figure 2.4: Component and integrated stress curves for EWR 14

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)	1.214	Fish guild: All habitats optimal (5[*]).
1 (SSR)	0.976	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)	0.769	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)	0.591	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)	0.470	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)	0.360	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)	0.264	Reduced FDI critical habitat. Most rheophilic species persist, but abundances reduced.

Integrated stress	Flow m^3/s	Habitat and/or Biotic responses
7 (SSR)	0.184	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)	0.118	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)	0.066	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)

2.5 RAPID EWR: KLEIN-VET RIVER DOWNSTREAM OF WINBURG

The rapid undertaken on the Klein Vet was undertaken by the fish, macroinvertebrate and hydraulic specialists. The water quality was assessed using visual observation, physical determinations in the field and available data on the DWA’s Water Management System (WMS). Flows were derived using default values for the catchment in Spatsim. The results of the Rapid 111 Reserve determination is indicated in section 3.

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. EWR sites 12 to 15 were assessed on a comprehensive level and the last site (Rapid EWR) were assessed on a Rapid III level of detail. Detail hydraulic results are provided in Appendix A (Hydraulics).

Table 3.1: Summary of Ecoclassification

EWR site	River	Quaternary catchment	Reference MAR (Mm^3/a)*	PES	EIS	REC
EWR12	Vaal	C24A	2546.4	D	Moderate	D
EWR13	Vaal	C24J	2654.3	C	High	C
EWR14	Vals	C60J/C60G	145.79	C/D	High	C/D
EWR15	Vet	C43A	413.04	D/E	Moderate	D
RE- EWR 3	Klein Vet	C41A	49.56	C	Moderate	C

*The reference flows refers to the natural flow

The following approach was followed for the comprehensive assessments (EWR 12 to 15):

- 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 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.

The approach for the rapid level III assessment (rapid EWR site) is as follows:

- Analyse the natural flows to determine the months with the highest and lowest average low flow;
- Ensure that the seasonal distribution of the desktop adequately represents the seasonal distribution of the natural flow record;
- Run the DRM with the SPATSIM recommended parameters and the REC;
- Introduce changes if necessary to the DRM results for the low and high flow months if requested by fish and macroinvertebrate specialists after inspection of the hydraulic cross-section;
- Check that the requirements do not exceed the natural flow in any month and that the seasonal distribution match that of the natural flow record; and
- Generate the final requirements.

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.

The level of confidence in the hydrology data varied and in many cases the present day data and observed data was used rather than the natural flows.

3.2 HYDRAULIC ASSESSMENT

Five EWR sites were selected during the field surveys of the rivers of the Middle 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	EWR12	Easy access to the site. Single channel. Gauging weir for flow records.	Vegetation on both banks and islands in the river bed influence overall flow resistance at high flows.
Vaal	EWR13	Easy access to the site. Single channel. Gauging weir for flow records.	Vegetation on the right bank influences overall flow resistance at high flows.
Vals	EWR14	Easy access to the site. Gauging weir for flow records.	Hydraulics is complex: 2 channels, islands, standing water pools.
Vet	EWR15	Single low flow channel. Gauging weir for flow records.	Large scale river bad substrates result to non-uniform flow with potential for non-horizontal water profile at low flow conditions.

Klein-Vet	Rapid EWR	Easy access to the site.	Upstream of Erfenis Dam, and could be flooded at Full Supply Level (FSL). Multiple channels at low flow.

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 12	25.09.2007	15.70	0.99	0.0010
		25.06.2008	22.60	1.03	0.0014
		24.08.2008	20.40	1.02	0.0014
Vaal	EWR 13	25.09.2007	11.50	2.20	0.00021
		24.06.2008	24.80	2.36	0.00021
		24.08.2008	23.00	2,34	0.00021
Vals	EWR 14	26.06.2008	0.35	0.51	0.0098
		24.08.2008	0.28	0.49	0.0062
Vet	EWR 15	04.07.2008	0.53	0.43	0.0142
		25.08.2008	0.20	0.26	0.0142
Klein-Vet	Rapid EWR	11.04.2008	0.0018	0.11	0.00837

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 12: VERMAASDRIFT (VAAL RIVER)

3.3.1 Ecoclassification summary of EWR 12 Upstream Vermaasdrift (Vaal River)

EWR 12 UPSTREAM VERMAASDRIFT (VAAL RIVER)

EIS: MODERATE

PES: D

Combination of flow and non-flow related impacts. Impacts mostly related to changes in flow regime due to Vaal Dam and Vaal River Barrage. Water quality impacts from gold mining and nutrient enrichment from urbanisation.

REC: D

Maintain the PES due to the **MODERATE** EIS rating. However note that there is rare and endangered *Austroglanis sclateri* expected which warrants improvement of the fish EC.

AEC up: C/D

Changes in hydrology

- Change seasonality of flows – allow more floods in summer
- Mimic natural flow regime
- Allow freshet cues in summer

Water quality management

- Reduce discharge standards of nutrients for WWTW
- Implement water quality guidelines/objectives
- Use water use licences to management releases
- Mines to use recycle/reuse/treat option

AEC down:

None due to current PES in a D category

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

The REC for EWR site 12 situated on the Vaal River in quaternary catchment C24A is a D category. The reference flow used was the present day simulated flows with the mean annual runoff (MAR) of 1574.6 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 12 in m3/s

High flow month	Maximum base flow	Low flow month	Maximum base flow	Measured		REC
				Jun	Sept	
February	266.756	August	12.781	22.60	15.70	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 Table 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 3.10.

Table 3.5: Fish species and integrated stress requirements for EWR 12

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 there is limited breeding capability and very limited fast deep habitat remaining. (At a stress of 8 semi-rheophilic species will be seriously threatened). **30%** at stress level 7, providing limited fast deep and slow-deep habitats for *B.kimberleyensis.*
MAINTENANCE (D): **50%** at stress level 7 providing limited fast deep habitat and limited habitat for gonadal development. **MAINTENANCE (C/D):** **45%** at stress level 7 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 there is zero breeding capability and very limited fast-deep habitat remaining. (At a stress level of 8 semi-rheophilic species will struggle to survive).
20% at stress level 5, 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):
35% 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 12

INVERTEBRATES:DURATIONS AND MOTIVATIONS TO BE USED FOR DETERMINING STRESS REQUIREMENTS.

Indicator: *Tricorythus*
Invertebrate: The indicator is a rheophilic species dependant on the perennial flow.

INVETERBRATE 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 mayfly *Tricorythus* 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 mayfly, *Tricorythus* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. This should be for a duration of 30%.

MAINTENANCE (C/D):
The river has enough flow to ensure a healthy population of the mayfly, *Tricorythus* 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 mayfly *Tricorythus* 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 *Tricorythus* 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 mayfly, *Tricorythus* 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/D):** The river has enough flow to ensure a healthy population of the mayfly, *Tricorythus* 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 above flows were checked by the riparian vegetation specialist to ensure that these requirements are adequate to achieve the EC in which the marginal vegetation should be, as well as any other flow dependant vegetation that could occur.

The vegetation indicators used were *Imperata cylindrical, 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 C (ECOSTATUS D)
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 both *Cyperus* species. **Dry Season drought** *Imperata cylindrica* and *Cyperus denudatus* rhizome level remains activated for survival. Water level is just below both species rooting level. **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. denudatus* rhizomes on the marginal zone, and facilitate survival of *Cyperus longus*.
AEC up: RIPARIAN VEGETATION EC: C (ECOSTATUS C/D)
Dry Season maintenance Due to the canalisation of the river at this site the maintenance flows will not differ significantly from the present ES. **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 12 and the associated available habitats under various stress levels from 0 (maximum base flow) to 10 (no flow). Figures 3.3 shows the hydraulic profile for EWR12.

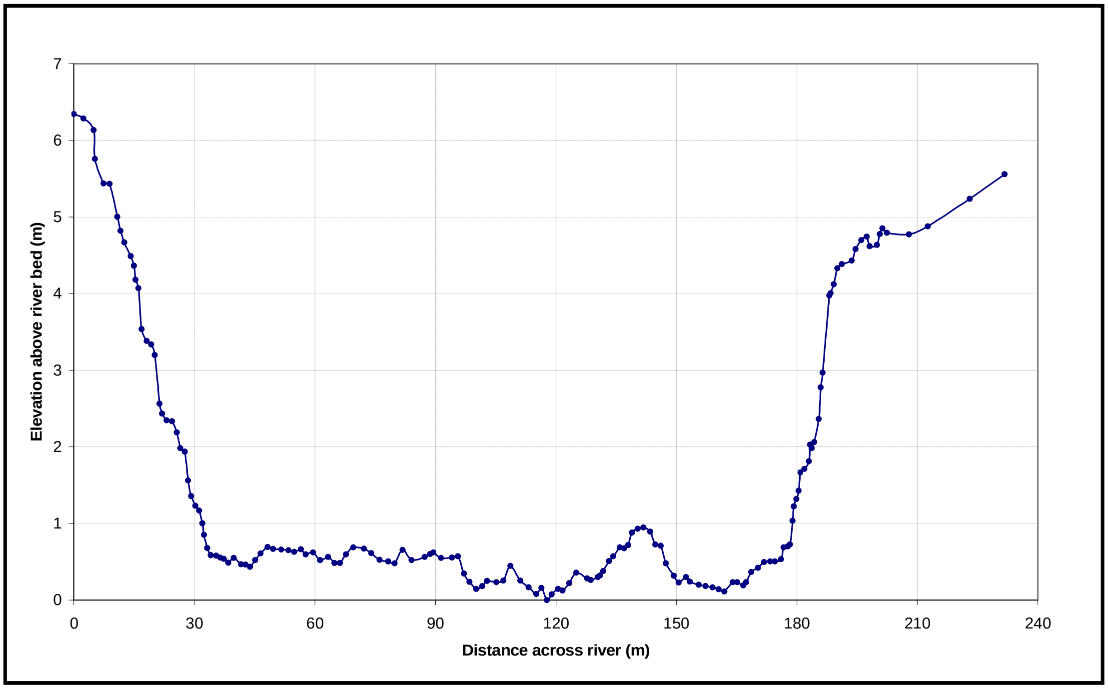


Figure 3.1: Hydraulic profile for EWR 12

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 12 is shown in Figure 3.5 and Figure 3.6.

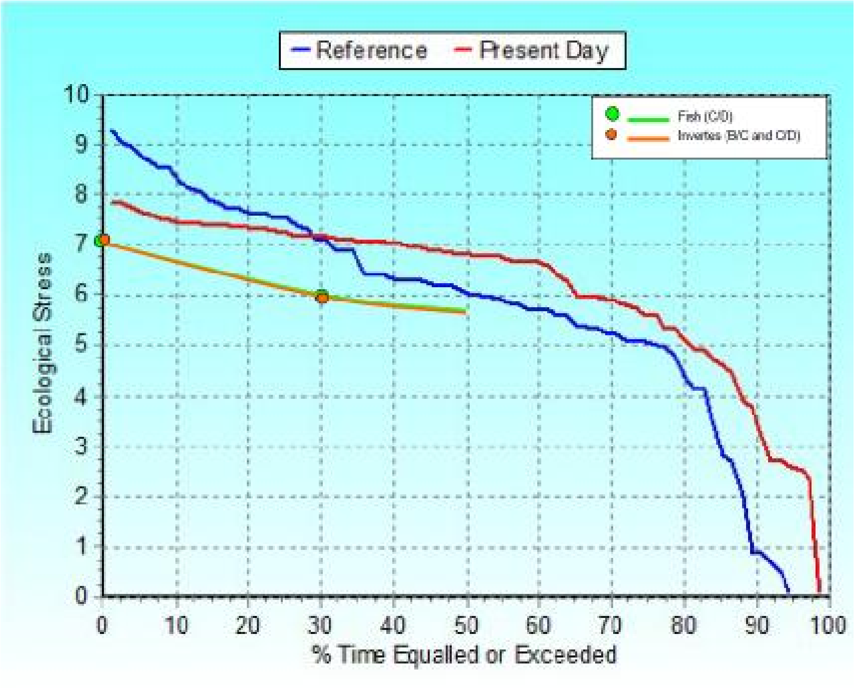


Figure 3.2: Final stress duration curves for EWR 12 (August)

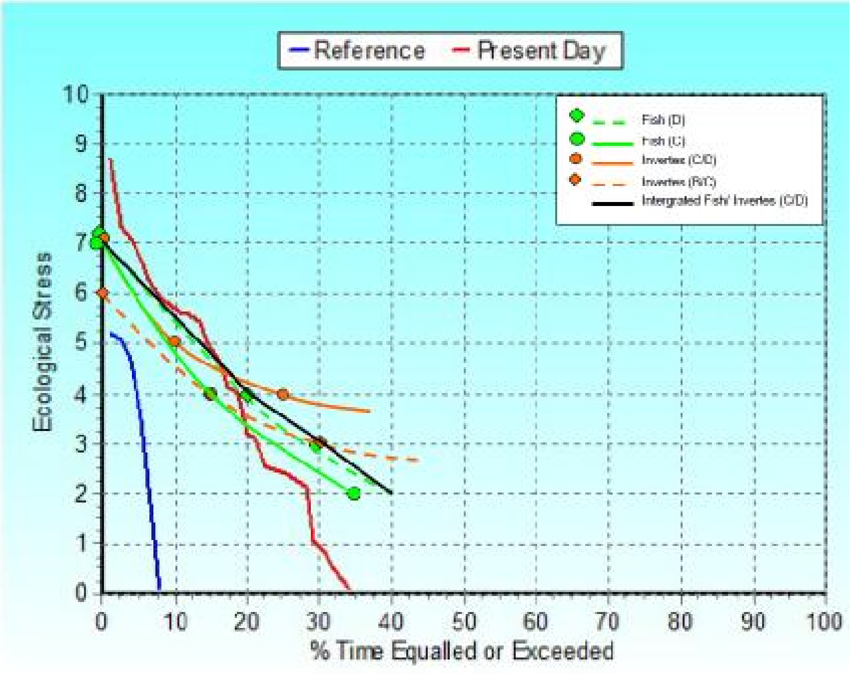


Figure 3.3: Final stress duration curves for EWR 12 (February)

3.3.3 Flood requirements

The flood requirements for EWR 12 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 and detailed motivations are provided in Table 3.8.

Table 3.8: Identification of instream functions addressed by the identified floods for EWR 12

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	20-50 (daily average)	None needed as baseflow already at 30												
II	50 (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:** This flow class is responsible for transporting about 15% of the fine bed material. These flows will clean the gravels and cobbles at the site and inundate the lower bench. **Riparian vegetation:** This flow class will remove some of the aquatic exotics and thereby temporarily reduce the abundance of this species. This flow class may have the effect of forming patches in the marginal zone thereby promoting colonization by other species and increasing patch dynamics along the bank. Unfortunately with the large number of competitive exotics this may allow for further colonization by exotics	x	x	x	x	x	x	x	x	x	x	x	x
III	100 (daily avg)	**Geomorphology:** This flow class is responsible for transporting about 15% of the fine bed material. These flows will scour the gravels and cobbles. **Riparian vegetation:** This flow class will remove quite a substantial amount of the aquatic exotics and thereby temporarily reduce the abundance of this species. This flow class may have the effect of forming patches in the marginal and lower non-marginal zone thereby promoting colonization by other species and increasing patch dynamics along the bank. Unfortunately with the large number of competitive exotics this may just allow for further colonization by exotics	x	x		x	x	x	x				x	x
IV	340 (daily avg)	**Geomorphology:** This flow class represents the effective discharge for the site. It is responsible for the bulk (more than 25%) of the sediment transport. These flows will scour and activate the gravels and cobbles. **Vegetation**: This flow class will remove quite a substantial amount of the aquatic exotics and thereby temporarily reduce the abundance of these species. This flow class may have the effect of forming patches on the marginal and non-marginal zones thereby promoting colonization by other species and increasing patch dynamics along the bank. Unfortunately with the large number of competitive exotics this may just allow for further colonization by exotics.	x	x				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 12: 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	20-50 (daily average)								
II	50 (daily avg)	2 floods	3 floods	3	3	3 floods	Oct, Jan, Feb	50	7 days
III	100 (daily avg)			1	1	1	Feb	100	5
IV	340 (daily avg)				1:2	1:2	Feb	350	10
AEC up: C/D									
I	20-50 (daily average)								
II	50 (daily avg)	2 floods	4 floods	3	4	4	Oct, Jan, Feb, Mar	50	7 days
III	100 (daily avg)			1	2	2	Feb	100	5
IV	340 (daily avg)				1:2	1:2	Feb	350	10

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 12

Desktop version:		2.10	**Reference flows used (Present day) (MCM)**	1574.6
BFI index	0.390	**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	5.421	4.284	50	7
NOVEMBER	6.592	5.210		
DECEMBER	6.783	5.361		
JANUARY	7.588	5.997	50	7
FEBRUARY	9.845	6.486	50 100 350	7 5 10
MARCH	7.720	6.101	50	7
APRIL	6.521	5.154		
MAY	5.619	4.441		
JUNE	5.184	4.097		
JULY	5.035	3.980		
AUGUST	3.954	3.125		
SEPTEMBER	4.321	3.415		
TOTAL MCM	195.257	151.187	250.042	
% OF REFERENCE	12.40	9.60	15.88	

3.4 EWR 13: VAAL RIVER AT REGINA BRIDGE

3.4.1 Ecoclassification summary of EWR 13 Vaal River at Regina Bridge

EWR 13 VAAL RIVER AT REGINA BRIDGE

EIS: HIGH
PES: C
Combination of flow and non-flow related impacts. Impacts mostly related to changes in flow regime due to Vaal Dam and Vaal River Barrage. Water quality impacts due to Upper Vaal (gold mines and nutrients from urbanisation), Mooi River (Gold mines, irrigation and urbanisation), KOSH area (Gold mines, irrigation and urbanisation) and Schoonspruit (irrigation and waste water treatment works).
REC: C
Maintain the PES due to the **HIGH** EIS rating. However note that there is rare and endangered *Labeobarbus kimberleyensis* and *Austroglanis sclateri* expected which warrants improvement of the fish EC.

AEC up: C
Changes in hydrology
- Change seasonality of flows – allow more floods in summer
- Allow freshet cues in summer

Water quality management
- Reduce discharge standards of nutrients for WWTW
- Implement water quality guidelines/objectives
- Use water use licences to management releases
- Mines to use recycle/reuse/treat option
- Manage water hyacinth

AEC down: C
- Less seasonality
- Water quality deterioration
- Change seasonality – less water from tributaries
- Increase irrigation
- Possibility of Klip River IBT to Crocodile West
- Riparian vegetation changes are non flow related
- NB SITE robust and drastic changes required to make changes at this site

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

The REC for EWR site 13 situated on the Vaal River in quaternary catchment C24J is a C category. The reference flow used was the natural simulated flows with the mean annual runoff (MAR) of 2654.289 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 13 in m3/s

High flow month	Maximum base flow	Low flow month	Maximum base flow	Measured		REC
				Jun	Sept	
February	214.942	August	16.175	24.80	11.50	C

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 3.12 and 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 3.17.

Table 3.12: Fish species and integrates stress requirements for EWR 13

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 7 where there is zero breeding capability and no fast deep habitats remaining. (At a stress of 7 semi-rheophilic species will be seriously threatened). **30%** at stress level 6, providing abundant slow deep habitat for over wintering, sufficient water depth for cover but no fast shallow or fast deep habitats for spawning or migration.
MAINTENANCE (D): **30%** at stress level 6, providing abundant slow deep habitat for over wintering and cover but no fast shallow or fast deep habitats for spawning or migration. **MAINTENANCE (C):** **30%** at stress level 6, providing abundant slow deep habitat for over wintering and cover but no fast shallow or fast deep habitats for spawning or migration.
WET SEASON (February)
DROUGHT: **0%** at stress level of 7 where there is zero breeding capability and no fast deep habitats remaining. (At a stress of 7 semi-rheophilic species will be seriously threatened). **10%** at stress level 5, providing limited fast-deep habitats for migration, limited fast flows for spawning and some slow shallow habitats for nursery habitats.
MAINTENANCE (D): **30**% at stress at level 3 providing limited habitat for spawning and nursery areas. Adequate fast deep habitats for increased abundance, migration and water column cover. *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): **20%** at stress level 3 providing limited habitat for spawning and nursery areas. Adequate fast deep habitats for increased abundance, migration and water column cover. **30** % at stress level 2 providing adequate fast deep habitats for abundance, adequate slow deep habitats for water column cover and adequate depths and flows for spawning and nursery areas.

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 3.13: Invertebrate taxa and integrates stress requirements for EWR 13

INVERTEBRATES:DURATIONS AND MOTIVATIONS TO BE USED FOR DETERMINING STRESS REQUIREMENTS.
Indicator: *Tricorythus* **Invertebrate:** The indicator is a rheophilic species dependant on the perennial flow.
INVERTEBRATE 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 mayfly *Tricorythus* 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 mayfly, *Tricorythus* 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 to ensure a healthy population of the mayfly, *Tricorythus* 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 SIC habitat with fast enough velocities (0.3 m/s) and depth (>10 cm) to ensure the survival of the highly flow dependent mayfly *Tricorythus* 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 *Tricorythus* 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 mayfly, *Tricorythus* 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/D):** The river has enough flow to ensure a healthy population of the mayfly, *Tricorythus* 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 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 B/C (ECOSTATUS C)
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*.
AEC up: RIPARIAN VEGETATION EC: B/C (ECOSTATUS C)
Dry Season maintenance Due to the canalisation of the river at this site the maintenance flows will not differ significantly from the present ES. **Wet Season maintenance** Same effect as dry season base flow slight inundation at rhizome level of current sedges.
AEC down: RIPARIAN VEGETATION EC: C (ECOSTATUS C)
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. **Wet Season maintenance** Will inundate marginal zone sufficiently to maintain vigour and density of the expanded 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 13 and the associated available habitats under various stress levels from 0 (maximum base flow) to 10 (no flow, Figure 3.9). Figure 3.9 shows the hydraulic profile for EWR 13.

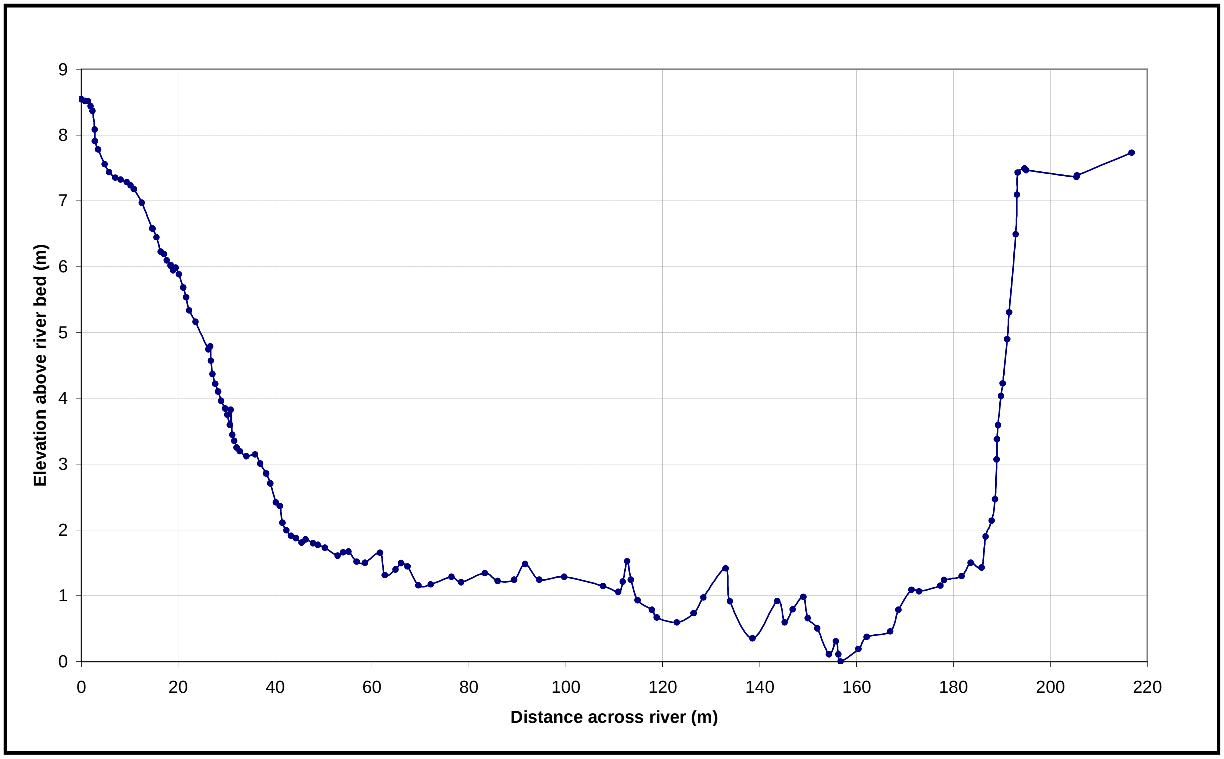


Figure 3.4: Hydraulic profile for EWR 13

To produce the final results (Figure 3.11), the DRM results for the specific category are modified according to specialists' requirements (Figure 3.7 and 3.8). 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 13 is shown in Figure 3.11.

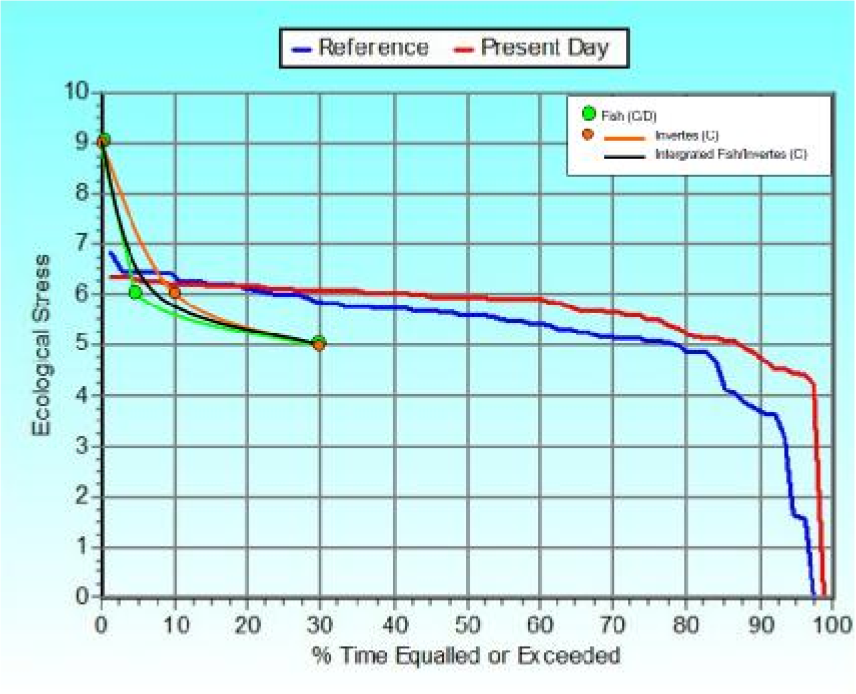


Figure 3.5: Final stress duration curves for EWR 13 (August)

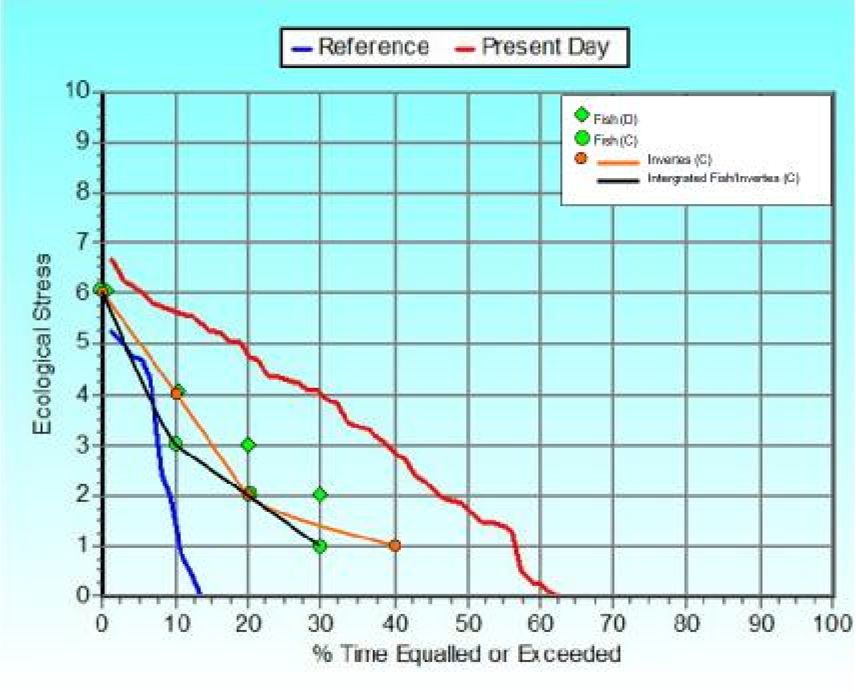


Figure 3.6: Final stress duration curves for EWR 13 (February)

3.4.3 Flood requirements

The flood requirements for EWR 13 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 (indicated by an *X* in Table 3.4.

- 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. Further information is provided in Volume 2.

Table 3.15: Identification of instream functions addressed by the identified floods for geomorphology and riparian vegetation: EWR 13

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	20-50 (daily average)	None needed as baseflow already at 30												
II	50 (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. **Riparian vegetation:** This flow class may move some of the aquatic exotics and thereby temporarily reduce the abundance of this species.	x	x	x	x	x	x	x	x	x	x	x	x
III	100 (daily avg)	**Riparian vegetation:** his flow class will remove a substantial amount of the aquatic exotics and thereby temporarily reduce the abundance of this species. This flow class may have the effect of forming patches in the marginal and lower non-marginal zone thereby promoting colonization by other species and increasing patch dynamics along the bank. Unfortunately with the large number of competitive exotics this may just allow for further colonization by exotics	x	x		x	x	x	x				x	x
IV	520 (daily avg)	**Geomorphology:** This flow class represents the effective discharge for the site. It is responsible for the bulk (about 50%) of the sediment transport. These flows will scour the bed and clean out gravel and cobble areas.	x	x				x						x
V	1500	**Geomorphology:** This flow class is responsible for about 40% of the PBMT. Although extremely infrequent, these very large flood events are important for scouring the reach												

The number of high flow events required for each EC is provided in Table 316. No observed daily data was available to check flood requirements against.

Table 3.16: EWR 13: 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									
I	20-50 (daily average)								
II	50 (daily avg)	2 floods	3 floods	3		3 floods	Oct, Jan, Feb	50	7 days
III	100 (daily avg)			1		1	Feb	100	5
IV	520 (daily avg)				1:3	1:3	Feb	520	10
V	1500				1:10	1:10	Feb		
AEC up: C									
I	20-50 (daily average)								
II	50 (daily avg)	2 floods	4 floods	3	4	4	Oct, Jan, Feb, Mar	50	7 days
III	100 (daily avg)			1	2	2	Feb	100	5
IV	520 (daily avg)				1:3	1:3	Feb	350	10
V	1500								
AEC down: C									
I	20-50 (daily average)								
II	50 (daily avg)	2 floods	4 floods	3	4	4	Oct, Jan, Feb, Mar	50	7 days
III	100 (daily avg)			1	2	2	Feb	100	5

FLOOD CLASS	FLOOD RANGE (m³/s)	INVERTEBRATES	FISH	VEGETATION	GEOMORPHOLOGY	FINAL (Frequency)	MONTHS	DAILY AVERAGE	DURATION
IV	520 (daily avg)				1:3	1:3	Feb	350	10
V	1500								

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 13

Desktop version:		2.10	**Reference flow used Virgin MAR (MCM)**	2654.289
BFI index	0.340	**Distribution type**		Vaal
MONTH	**LOW FLOWS**		**HIGH FLOWS**	
	Maintenance (m^3/s)	**Drought (m^3/s)**	**Daily average (m^3/s) on top of base flow**	**Duration (days)**
OCTOBER	7.254	0.029	50	7
NOVEMBER	10.700	0.043		
DECEMBER	11.931	0.047		
JANUARY	13.892	0.055	50	7
FEBRUARY	18.531	0.073	50 100 350	7 5 10
MARCH	15.172	0.060	50	7
APRIL	11.532	0.046		
MAY	7.732	0.031		
JUNE	5.863	0.024		
JULY	5.278	0.022		
AUGUST	4.780	0.020		
SEPTEMBER	5.177	0.022		
TOTAL MCM	307.950	1.234	134.093	
% OF REFERENCE	11.60	0.05	5.05	

3.5 EWR 14: VALS RIVER PROKLAMEERSDRIFT

3.5.1 Ecoclassification summary of EWR 14 Vals River Proklameersdrift

EWR 3 VALS RIVER PROKLAMEERSDRIFT

EIS: HIGH
PES: C/D
Combination of flow and non-flow related impacts. Impacts mostly related to changes in flow regime due to upstream irrigation and urban water use.
Maintain the PES due to the **HIGH** EIS rating. However note that there is rare and endangered *Labeobarbus kimberleyensis* and *Austroglanis sclateri* expected which warrants improvement of the fish EC.

AEC up: C
The flows are close to natural except what is removed via irrigation and Kroonstad. The river naturally stops flowing and hence water quality deteriorates in winter.
The following aspects can be modified to try and improve the Ecostatus:

- Increase moderate flow events – this can only be done by less water being used for irrigation or storage in farm dams.
- Water quality – manage effluents such as waste water treatment works and abattoirs. Reduce agricultural runoff. This should reduce the nutrients and ammonia in the river.

AEC down: D

- Hydrology – more zero flows, more low flows, less moderate events all due to greater abstractions
- Water quality – greater nutrients and higher ammonia levels.

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

The REC for EWR 14 situated on the Vals River at the border of quaternary catchments C60J and C60G is a C/D category. The reference flow used was the natural simulated flows with the mean annual runoff (MAR) of 145.794 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 14 in m3/s

High flow month	Maximum base flow	Low flow month	Maximum base flow	Measured		REC
				Jun	Aug	
January	10.535	July	0.477	0.35	0.28	C/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 3.19, Table 3.10. 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 3.24.

Table 3.19: Fish species and integrates stress requirements for EWR 14

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 flows during the breeding season and has a high preference for fast shallow habitats, moderate to high preferences for fast deep and slow deep habitats.
FISH STRESS REQUIREMENTS
DRY SEASON (July)
DROUGHT: **5%** at stress level of 9.5 where the habitat consists primarily of slow shallow habitats, no fast flowing habitats available.
MAINTENANCE (D): **30%** at stress level 9.5 where the habitat consists primarily of slow shallow habitats, no fast flowing habitats available. **MAINTENANCE (C):** **30%** at stress level 9 where the habitat consists primarily of slow shallow habitats, no fast flowing habitats available.
WET SEASON (January)
DROUGHT: **5%** at stress level of 9.5 where the habitat consists primarily of slow shallow habitats, no fast flowing habitats available.
MAINTENANCE (D): **30**% at stress at level 9 where the habitat consists primarily of slow shallow habitats, no fast flowing habitats available. *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): **30%** at stress level 2 providing adequate fast shallow, fast deep habitats and slow deep habitats. Adequate fast shallow habitats for spawning and slow shallow habitats for nursery areas. *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%).

Table 3.20: Invertebrate taxa and integrates stress requirements for EWR 14

INVERTEBRATES:DURATIONS AND MOTIVATIONS TO BE USED FOR DETERMINING STRESS REQUIREMENTS.
Indicator: *Tricorythus* **Invertebrate:** The indicator is a rheophilic species dependant on the perennial flow.
INVERTEBRATE STRESS REQUIREMENTS
DRY SEASON (July)
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 mayfly *Tricorythus* 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 mayfly, *Tricorythus* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. This should be for a duration of 30%. **MAINTENANCE (C/D):** The river has enough flow to ensure a healthy population of the mayfly, *Tricorythus* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. This should be for a duration of 30%.
WET SEASON (January)
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 mayfly *Tricorythus* 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 *Tricorythus* 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 mayfly, *Tricorythus* 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/D):** The river has enough flow to ensure a healthy population of the mayfly, *Tricorythus* 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 cylindrical, 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 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 *Imperata cylindrica* on the marginal zone, and facilitate survival of both *Cyperus* species. **Dry Season drought** *Imperata cylindrica* and *Cyperus denudatus* rhizome level remains activated for survival. Water level is just below both species rooting level.

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. denudatus* rhizomes on the marginal zone, and facilitate survival of *Cyperus longus*.

AEC up: RIPARIAN VEGETATION EC: C/D (ECOSTATUS C)

Dry Season maintenance
Due to the slope of the banks of the river at this site, the maintenance flows will not change the ecostatus significantly. The marginal zone may migrate slightly up the bank, but is unlikely to change in size or species composition when compared to the PES.

Wet Season maintenance
Same effect as dry season base flow slight inundation at rhizome level of current sedges.

AEC down: RIPARIAN VEGETATION EC: C/D (ECOSTATUS D)

Dry Season maintenance
Reduced from PES flow requirements. The lower limit of sedges on the marginal zone likely to expand towards the in-stream channel. There may be fatality of the outer zones of the marginal zone due to desiccation of the soil.

Wet Season maintenance
Will inundate marginal zone sufficiently to maintain vigour and density of the expanded 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 14 and the associated available habitats under various stress levels from 0 (maximum base flow) to 10 (no flow). Figure 3.14 shows the hydraulic profile for EWR 14.

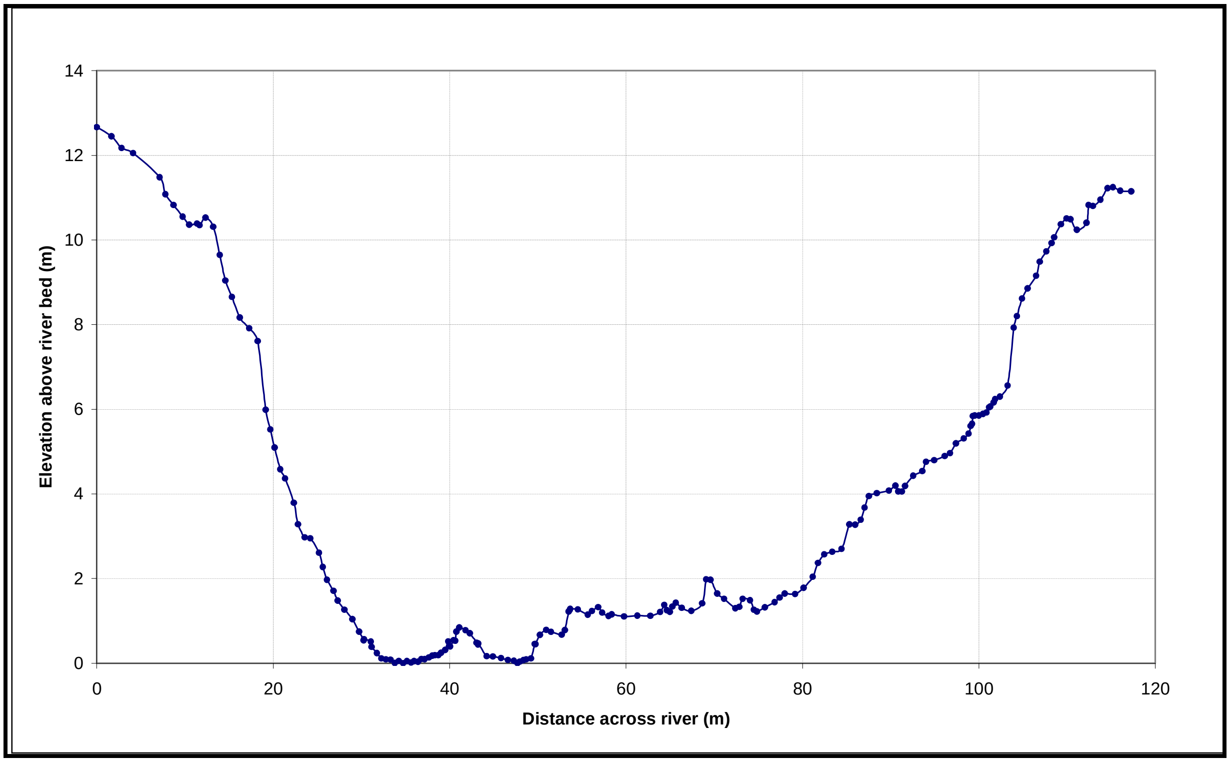


Figure 3.7: Hydraulic profile for EWR 14

To produce the final results (Figure 3.16), the DRM results for the specific category are modified according to specialists' requirements (Figure 3.12 and 3.13). 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 14 is shown in Figure 3.16.

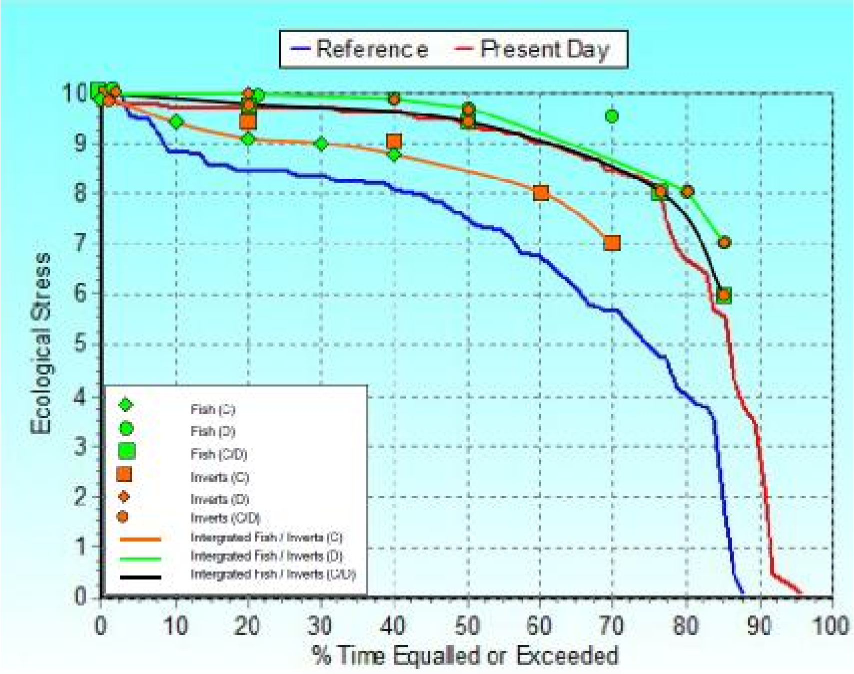


Figure 3.8: Final stress duration curves for EWR 14 (July)

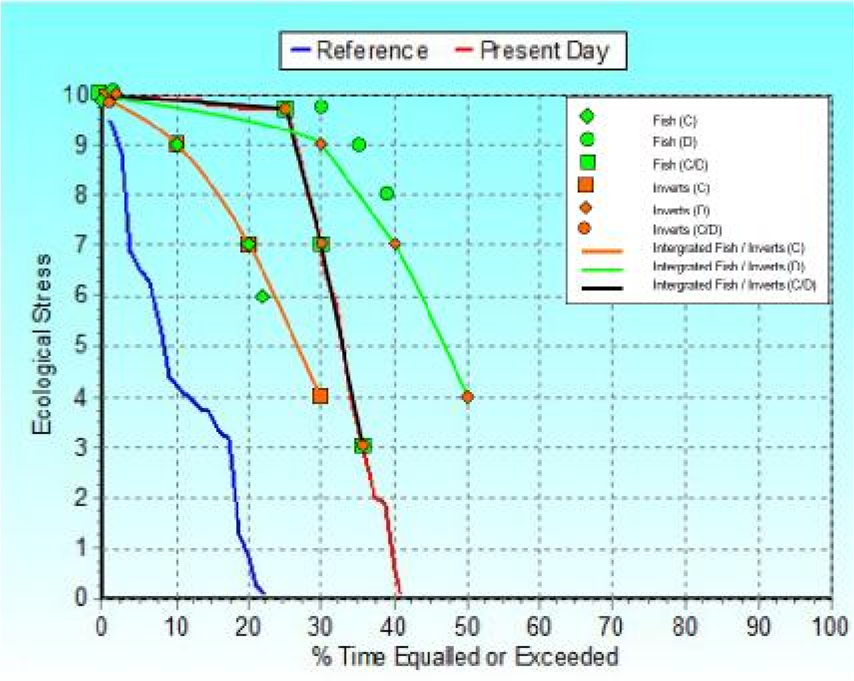


Figure 3.9: Final stress duration curves for EWR 14 (January)

3.5.3 Flood requirements

The flood requirements for EWR 14 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 addressed by the identified floods 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	3 - 5 (daily average)	**Geomorphology:** Accounts for 20% of sediment transport of the fines and this flow will activate the bed. **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.	x	x	x	x	x	x	x	x	x	x	x	x
II	10 (daily avg)	**Riparian vegetation:** Floods the marginal zone and portions of the lower zone. Prevent terrestrialisation of the marginal and lower zones												
III	15 (daily avg)	**Riparian vegetation:** Floods the marginal zone and portions of the lower zone. Prevent terrestrialisation of the marginal and lower zones	x	x	x	x	x	x	x			x	x	x
IV	35(daily avg)	**Geomorphology:** This flow class represents the effective discharge for fines and small gravels at the site. It is responsible for the bulk (more than 40%) of the sediment transport. These flows will scour the bed.	x	x	x	x	x	x	x			x	x	x
V	200	**Geomorphology:** This flow class is responsible for about one quarter of the transport of fines, and is the effective discharge for the coarser gravels.												

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 14: 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	3-5	1	4		4	4	Nov, Jan, Feb, Mar	3	3
II	10			1					
III	15			2	2	2	Nov-Mar	10	2
IV	35				1:1	1	Feb	30	3
V	200				1:10				
AEC up: C									
I	3-5	1	5		5	5	Nov, Jan, Feb, Mar	3	3
II	10								
III	15			3	2	3	Nov-Mar	10	2
IV	35				1:1	1	Feb	30	2
V	200								
AEC down: D									
I	3-5	1	3		3	3	Nov-Mar	3	3
II	10								
III	15								
IV	35				1:2	1:2	Feb	30	2
V	200				1:10				

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 14

Desktop version:		2.10	**Reference flows used Virgin MAR (MCM)**	145.794
BFI index	0.255	**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	0.153	0.003		
NOVEMBER	0.276	0.005	3 10	3 2
DECEMBER	0.333	0.006	10	2
JANUARY	0.447	0.008	3 10	3 2
FEBRUARY	0.484	0.008	3 10 30	3 2 2
MARCH	0.444	0.008	3 10	3 2
APRIL	0.285	0.000		
MAY	0.166	0.003		
JUNE	0.112	0.002		
JULY	0.087	0.002		
AUGUST	0.095	0.002		
SEPTEMBER	0.133	0.000		
TOTAL MCM	7.880	0.123	16.969	
% OF REFERENCE	5.41	0.08	11.64	

3.6 EWR 15: VET RIVER AT FISANTKRAAL

3.6.1 Ecoclassification summary of EWR 15 Vet River at Fisantkraal

EWR 15 VET RIVER AT FISANTKRAAL

EIS: Moderate

PES: D/E

The low PES is due to the issues not being flow related. These issues are mainly due to intense agriculture, loss of riparian vegetation and encroachment of alien vegetation.

Water quality driven by return irrigation.

REC: D

Maintain the instream PES due to the **MODERATE** EIS rating. However note that there is rare and endangered *Austroglanis sclateri* expected which warrants improvement of the fish EC.

AEC up: D

- Moderate flows improved by controlling agricultural abstractions
- Water quality due to improved by controlling agricultural management
- Riparian vegetation cannot be improved by flow alterations

Driver	PES & REC Category	Trend	AEC up	AEC down
Hydrology	C	Stable	C	
Water quality	C	Stable	C	
Geomorphology	C	Stable	C	
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	
Riparian vegetation	E	Stable	D	
Ecostatus	D/E	Stable	D	

The REC for EWR 15 situated on the Vet River in quaternary catchment C43A is a D category. The reference flow used was the present day flows with the mean annual runoff (MAR) of 253.152 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 15 in m3/s

High flow month	Maximum base flow	Low flow month	Maximum base flow	Measured		REC
				Jul	Aug	
March	20.901	July	0.657	0.53	0.20	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 3.26 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 3.31.

Table 3.26: Fish species and integrates stress requirements for EWR 15

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 flows during the breeding season and has a high preference for fast shallow habitats, moderate to high preferences for fast deep and slow deep habitats.
FISH STRESS REQUIREMENTS
DRY SEASON (July)
DROUGHT: **5%** at stress level of 9.5 where the habitat consists primarily of slow shallow habitats, no fast flowing habitats available.
MAINTENANCE (D): **30%** at stress level 9.5 where the habitat consists primarily of slow shallow habitats, no fast flowing habitats available. **MAINTENANCE (C):** **30%** at stress level 9 where the habitat consists primarily of slow shallow habitats, no fast flowing habitats available.
WET SEASON (March)
DROUGHT: **5%** at stress level of 9.5 where the habitat consists primarily of slow shallow habitats, no fast flowing habitats available.
MAINTENANCE (D): **30**% at stress at level 9 where the habitat consists primarily of slow shallow habitats, no fast flowing habitats available. *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): **30%** at stress level 2 providing adequate fast shallow, fast deep habitats and slow deep habitats. Adequate fast shallow habitats for spawning and slow shallow habitats for nursery areas. *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%).

Table 3.27: Invertebrate taxa and integrates stress requirements for EWR 15

INVERTEBRATES:DURATIONS AND MOTIVATIONS TO BE USED FOR DETERMINING STRESS REQUIREMENTS.
Indicator: *Tricorythus* **Invertebrate:** The indicator is a rheophilic species dependant on the perennial flow.
INVETEBRATE STRESS REQUIREMENTS
DRY SEASON (July)
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 mayfly *Tricorythus* 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 mayfly, *Tricorythus* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. This should be for a duration of 30%. **MAINTENANCE (C/D):** The river has enough flow to ensure a healthy population of the mayfly, *Tricorythus* sp., which was selected as an indicator species for the rheophilic macro-invertebrate community. This should be for a duration of 30%.
WET SEASON (March)
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 mayfly *Tricorythus* 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 *Tricorythus* 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 mayfly, *Tricorythus* 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/D):** The river has enough flow to ensure a healthy population of the mayfly, *Tricorythus* 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 3.27).

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

PES and REC: RIPARIAN VEGETATION EC E (ECOSTATUS D/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 both *Cyperus* species. **Dry Season drought** *Imperata cylindrica* and *Cyperus denudatus* rhizome level remains activated for survival. Water level is just below both species rooting level.

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. denudatus* rhizomes on the marginal zone, and facilitate survival of *Cyperus longus*.
AEC up: RIPARIAN VEGETATION EC: D (ECOSTATUS D)
Dry Season maintenance Due to the slope of the banks of the river at this site, the maintenance flows will not change the ecostatus significantly. The marginal zone may migrate slightly up the bank, but is unlikely to change in size or species composition when compared to the PES. **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 15 and the associated available habitats under various stress levels from 0 (maximum base flow) to 10 (no flow). Figure 3.19 shows the hydraulic profile for EWR 15.

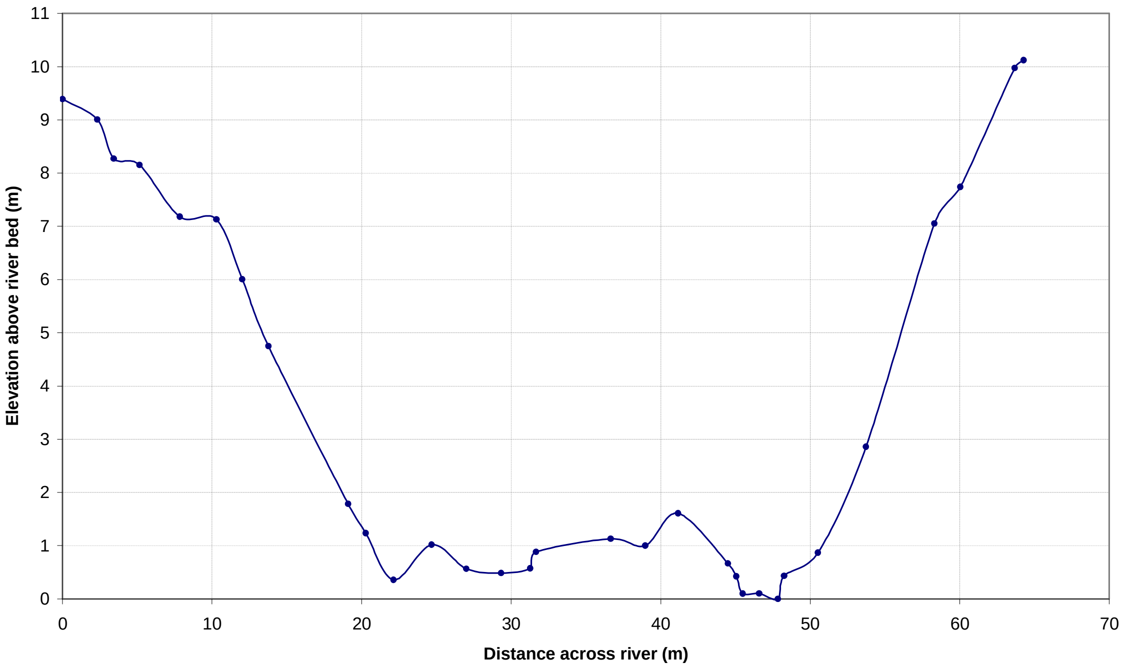


Figure 3.10: Hydraulic profile for EWR 15

To produce the final results (Figure 3.21), the DRM results for the specific category are modified according to specialists' requirements (Figure 3.17 and 3.18). 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 15 is shown in Figure 3.21.

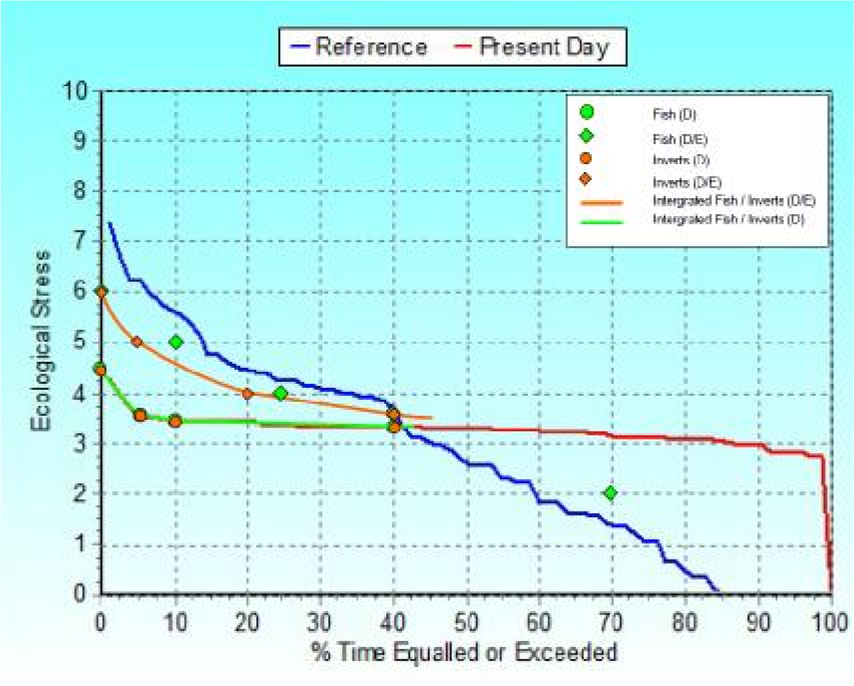


Figure 3.11: Final stress duration curves for EWR 15 (July)

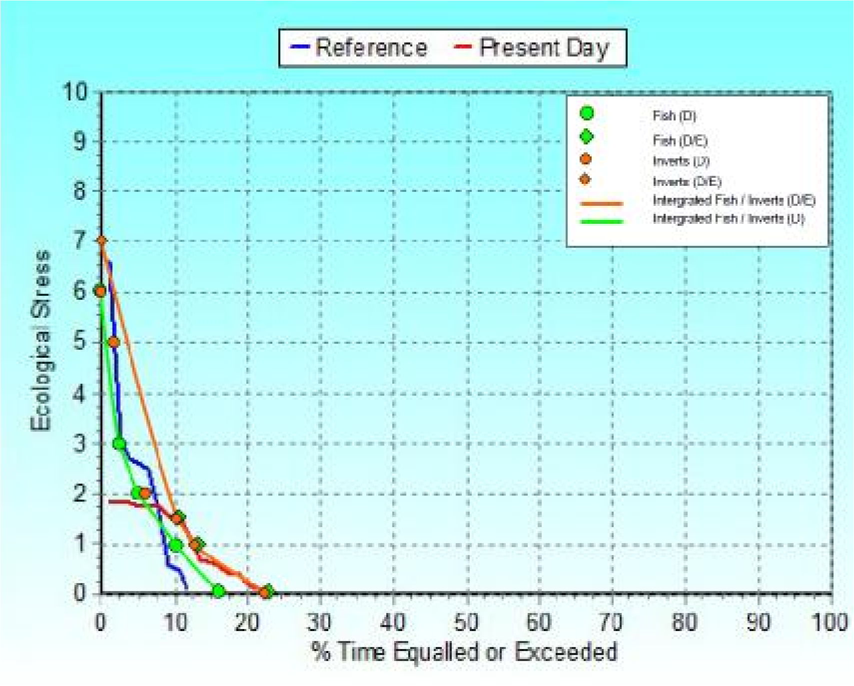


Figure 3.12: Final stress duration curves for EWR 15 (March)

3.6.3 Flood requirements

The flood requirements for EWR 15 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 by the identified floods 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	5 (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 Jan and Feb. **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)													
III	20 - 30 (daily avg)	**Riparian vegetation:** Inundates the marginal zone, and the associated vegetation community	x	x	x			x	x				x	x
IV	70(daily avg)	**Geomorphology:** This flow class is the effective discharge for all sediment sizes (fines, gravels and cobbles). This flood activates the bed. **Riparian vegetation:** Completely inundates marginal zone and some of the lower zone with the associated vegetation communities population, thereby preventing prevent terrestrialization.	x											
V	300	**Geomorphology:** Overtopping in sections to activate floodplain, recharge floodplain lakes and pans, maintain floodplain wetlands (if dams then fl0od are important to overtop an inundate the banks to feed the flood pans and wetlands)	x		x	x	x	x	x	x	x	x	x	x

The number of high flow events required for each EC is provided in Table 3.30. 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
Instream PES and REC: D									
I	5 (daily avg)	3	5			5	Nov- Mar	5	7
II	10 (daily avg)								
III	20-30 (daily avg)			4:1		1	Nov-Jan	20	2
IV	70 (daily avg)			1:1	1:1	1:1	Jan	70	5
V	300 (daily avg)				1:5			300	7
AEC up: C									
I	5 (daily avg)	4	8			8	Nov-Mar	5	7
II	10 (daily avg)								
III	20-30 (daily avg)			4:1		1	Nov-Jan	20	4
IV	70 (daily avg)			1:1	1:1	1:1	Jan	70	5
V	300 (daily avg)				1:5			300	7

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 3.31.

Table 3.31: Final EWRs for EWR 15

Desktop version:		2.10	**Reference flow used Present MAR (MCM)**	253.15
BFI index	0.266	**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	0.250	0.142		
NOVEMBER	0.420	0.135	5 20	7 2
DECEMBER	0.446	0.071	5 20	7 2
JANUARY	0.670	0.340	5 20 70	7 2 5
FEBRUARY	0.857	0.327	5	7
MARCH	0.849	0.213	5	7
APRIL	0.701	0.170		
MAY	0.403	0.269		
JUNE	0.227	0.177		
JULY	0.129	0.129		
AUGUST	0.130	0.130		
SEPTEMBER	0.190	0.190		
TOTAL MCM	13.766	5.999	32.309	
% OF REFERENCE	5.44	2.37	12.76	

3.7 Rapid EWR site: Vet (Re-EWR 3)

Re-EWR 3 was chosen as a potential site for extrapolation. The results of the rapid III that was undertaken for the Klein Vet are discussed below and a summary of the EWR is provided in Table 3.32.

The REC for the Klein Vet River in quaternary catchment C41A is a C category. The natural mean annual runoff (MAR) at the site is 49.56 Mm^3. The reference flow used was the natural simulated flows.

The Desktop Reserve Model (DRM) (SPATSIM, version 2.10) was used to calculate the EWRs for the REC of a C for this site. The EWR flow data were converted to hydraulic conditions at the EWR site (i.e. depths and flow velocities at discharges measured in m^3/s) using a hydraulic model. The maintenance flows were examined for the lowest flow month (July) and the high flow month of February.

The measured flow in the Klein Vet River during the site visit on 11 April 2008 (0.0018 m^3/s) was used as the datum. Together with the site photographs and the rating relationships (flow depth versus discharge) from the hydraulic model, the water levels proposed by the DRM were assessed in terms of the habitat and biotic requirements.

The site-specific flow requirements were based mainly on the velocities and depths required for maintenance of the macroinvertebrate and fish populations. The consensus reached by the ecologists was that the requirements as defined by the DRM for a C category were adequate to maintain the habitat and biota for the Klein Vet River and are summarised in Table 3.32.

Table 3.32: Ecological requirements for the Klein Vet River

Reference MAR	REC	Units	Total EWR	Maintenance Low flow	Maintenance High flow	Drought Low flow
49.56	C	Mm^3/a	9.686	4.139	5.547	0.722
		%	19.54	8.35	11.19	1.46

4 SUMMARY OF FINAL RESULTS

The natural and present day MARs as provided by PDNA are given in Table 3.32. The final flow requirements are expressed as a percentage of either the natural or present day MAR in Table 3.33.

Table 4.1: Natural and PD MARs of the EWR sites

Site	Virgin MAR	Present MAR
EWR 12	2546.392	1574.637
EWR 13	2654.289	1638.37
EWR 14	145.794	118.04
EWR 15	413.036	253.15
Rapid EWR	49.564	-

Table 4.2: Summary of results as a percentage of the reference MAR

EWR Sites	REC	Maintenance Low Flows (% nMAR)	Drought Low Flows (% nMAR)	High Flows (% nMAR)	Long Term Mean (% nMAR)
EWR 12	**D**	**12.4**	**9.6**	**15.88**	**21.09**
EWR 13	**C**	**11.6**	**0.05**	**5.05**	**17.33**
EWR 14	**C/D**	**5.41**	**0.08**	**2.37**	**5.2**
EWR 15	**D**	**5.44**	**2.37**	**12.76**	**12.96**

5 EXTRAPOLATION

No formal extrapolation activities were undertaken during this study but Re-EWR 3 was undertaken as a Rapid Level 111 in order to use the results from this site as potential for future extrapolation.

6 CONCLUSIONS

6.1 Water quality

The water quality of the Vaal River in the Middle Vaal WMA was generally poor due to high dissolved salts and high nutrients, e.g. the Vaal River at Orkney (C2H007) was characterised by unacceptable high EC (90 mS/m; ~630 mg TDS/ℓ), P concentration (0.224 mg/ℓ) and pH (9.11).

The water quality in the Renoster River (C7H006) and Sandspruit (C2H067) was fair in terms of salts (331 & 373 mg/ℓ), but poor in terms of nutrients, 0.080 and 0.118 mg PO4-P/ℓ respectively.

Koekemoerspruit (C2H139) and Schoonspruit (C2H073) are hotspot areas with unacceptable high salts concentrations, 1 760 and 987 mg/ℓ respectively. The salt load evidently originates from the mining activities and the high nutrients draining from the KOSH urban area.

Another problem area is the Sand River at Bloudrift (C4H016) with unacceptable high salts (2 415 mg/ℓ) from the Welkom-Virginia gold mines and very high nutrients (nitrate, 1.05; P, 0.50 mg/ℓ), evidently from poorly treated sewage effluent.

The water quality in the Vals River at Kroonstad (C6H007) was fair with ideal ammonia, sulphate and nitrate concentrations, acceptable pH (8.39), and salts (316 mg/ℓ), but with unacceptable high phosphate concentration (0.080 mg/ℓ). However, the Vals River at Bothaville (C6H002) was in a poor state with high salts concentration (837 mg/ℓ), probably originating mainly from seepage water and return flows from irrigation, unacceptable high pH (8.69) and phosphate concentration (0.90 mg/ℓ).

The water quality in Erfenis Dam (C4R002) was generally good except for the very high phosphate concentrations (0.126 mg/ℓ) that indicate a serious potential for algal productivity. However, the water quality in the lower section of the Vet River (C4H004) was poor with high salts (666 mg/ℓ) and high nutrients concentrations (phosphate, 0.088 mg/ℓ).

All the parameters in Heuningspruit at Dankbaar Mispah (C7H003) were ideal, except for the unacceptable P concentrations (0.194 mg/ℓ) that results in a poor quality.

6.2 Impacts of the mining activities and mine closure

The economy of the Middle Vaal WMA is dominated by the mining sector, with a contribution of 45.6 % to GGP, particularly gold mining. However, discharges from mines impact significantly on both the hydrology and water quality of the Middle Vaal system. The impacts from the gold mining activities on groundwater have been recognised as early as 1960 when localised dewatering became an issue at Stilfontein Gold Mine. Only more recently have the impacts on the quality of the groundwater and the interaction with the Vaal River becomes a concern. The largest volumes are abstracted at Stilfontein Gold Mine’s Margaret Shaft. Although Stilfontein’s underground operations has ceased for more than ten years, pumping at Margaret shaft continues for the safety of the downstream mines. The volume of water abstracted daily is estimated at 32 Mℓ/d. The water is utilized by a number of users and any excess is discharged to the Koekemoer Spruit.

Groundwater is also abstracted from other operating shafts in the KOSH mining area for safety and the water is utilized as process water at the mines. Due to the large quantities of water present in the mined Witwatersrand rocks, a large quantity of water (120 -150 Mℓ/d) is pumped to the surface for accessibility each day. This groundwater however has average conductivities of 500 mS/m (~3 500 mg/ℓ) and cannot be used for drinking or irrigation purposes (DWAF, 2004g).

Water quality in the Vaal River is of serious concern because of high salinity and nutrient content, which mainly results from urban and industrial return flows as well as mining activities in the Upper Vaal WMA. The closure of mines may have further water quality impacts.

6.3 Management of wastewater treatment works discharges

A large proportion of the sewage emanating from SA urban areas is not treated properly prior to discharge, because the sewer systems are incomplete, or sewage treatment plants are overloaded (Oberholster & Ashton, 2008; Green Drop, 2009a).Matjhabeng Local Municipality (Welkom, Odendaalsrus, Virginia, Hennenman, Allanridge and Ventersburg) with 11 sewage purification plants and the Moqhaka municipality (Kroonstad, Maokeng, Steynsrus and Viljoenskroon) have failed to present information to DWA for the Green Drop certification and are classified with zero Green Drop scores. These local municipalities have been implicated for polluting the local rivers and lakes with poorly treated sewage and occasionally raw sewage spills.

Municipal wastewater treatment plants, not complying with effluent standards and informal, unsewered human settlements along the river banks or in close vicinity of the Vaal River, pose a threat to regional water quality, especially eutrophication (nutrient enrichment) and human health. There is a general non-compliance to phosphate Resource Water Quality Objective throughout the WMA.

Sewage wastewater, by its nature, is teeming with microbes. Therefore, from a social perspective, the discharge of sewage effluent into the natural environment can have negative impacts on human health, primarily from bacteriological and other forms of pathogens that survive the biological treatment process and inadequate disinfection of the effluent. Water related diseases kill a child every 8 seconds, and are responsible for 80 % of all illnesses and deaths in the developing world (UNEP/WHO, 2006).

However, Municipal wastewater effluent is also one of the impacts that are most easy to mitigate because they are easily identified, measured, and susceptible to control by policies and regulation.

6.4 Eutrophication

The Vaal River in the Middle Vaal WMA experience regular algal blooms and has been classified as hypertrophic (nutrient over-enriched), that cause several problems to man and the environment. Eutrophication effects and problems are profound in the Vaal River and have become a matter of major concern to all water users. The impacts of eutrophication are ecological, social and economical. Infestations of alien vegetation are also found along the Vaal River (DWAF, 2009d).

Erfenis, Koppies and Allemanskraal Dams are classified as oligotrophic, however, toxic cyanobacterial incidents have been recorded. Bloemhof Dam is eutrophic and experience cyanobacterial blooms usually dominated by Microcystis spp. and Oscillatoria sp. (Van Ginkel, 2004).

Cyanobacterial blooms (frequency and intensity) in the Vaal River are increasing. As cyanobacterial blooms become more common, the likelihood grows that people will be exposed to increased doses of toxins and the risk of animal die-offs grows as well (DWAF, 2009d).

6.5 Urbanisation

Over 75 % of the population in the WMA are classified as living in urban areas, and about 25 % as rural. Most of the population are concentrated in the main urban and mining centres of Klerksdorp, Orkney and Stilfontein in the Middle Vaal sub-area; Welkom and Virginia in the Sand-Vet sub-area, as well as Kroonstad (which is not a mining town) in the Rhenoster-Vals sub-area. The Middle Vaal's freshwater resources are under increasing stress from a growing population and an expanding economy.

6.6 Water Transfers and availability

Substantial transfers take place from the Upper Vaal to the Middle Vaal (790 Mm3/a). However, there are no large control structures with respect to the regulation of flow in the Vaal River within the Middle Vaal WMA, and both the quantity and quality of water in the Vaal River are largely influenced by management practices in the Upper Vaal WMA. There are existing weirs on the Vaal River at Orkney and Balkfontein. Water from tributaries as well as from groundwater in the water management area is fully utilised, mainly for irrigation and for towns remote from the Vaal River (DWAF, 2003b).

6.7 Hydrology

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

- Vaal Dam storage
- Releases from Vaal Dam to dilute salts to 600 mg/L TDS (mainly in winter)
- Releases from Vaal Dam and Vaal River Barrage to supply the Vaal Harts irrigation scheme (completed 1938)

- Interbasin transfers into the Vaal from Lesotho and Grootdraai Dam

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

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

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

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APPENDIX A

HYDRAULIC ASSESSMENT

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REPORT ON

HYDRAULICS FOR COMPREHENSIVE RESERVE DETERMINATION FOR MIDDLE VAAL

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ABBREVIATIONS AND ACRONYMS

Average flow depth	Cross-sectional flow area (m^2) divided by the width of the water surface (m)
BM	Bench mark
Discharge	Volumetric flow rate (m^3/s)
EWR	Environmental Water Requirements
Flow depth	Maximum flow depth, measured from the lowest bed elevation (m)
HABFLO	HABitat-FLOw simulation software

n	Manning's resistance coefficient
Perimeter	Surface of channel in contact with flow, measured along the cross-section (m)
Stage/water level	Elevation of the water surface relative to local datum (m)
Velocity	Average velocity through cross-section (m/s)
a, *b*, *c*	Regression coefficients in the rating relationship

1 INTRODUCTION

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

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

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

This report is presenting the hydraulics assessment of the Comprehensive Reserve determination for the Middle Vaal.

2 SITE SELECTION

During the site selection trip for the Middle Vaal Reserve determination, 4 sites were selected. Coordinates of the selected EWR sites are listed in Table 1. Locations of the selected EWR sites are shown in Figure 1. Photos of the EWR sites are presented in Figure 2 to Figure 5.

Table 1: Coordinates of selected EWR sites

River	Site	South	East
Vaal	EWR12	26.93615	26.85025
Vaal	EWR13	27.09791	26.52434
Vals	EWR14	27.48685	26.8132
Vet	EWR15	27.93482	26.12569

Advantages and disadvantages of the selected EFR sites are given in Table 2.

Table 2: Advantages and disadvantages of selected EWR sites

River	Site	Advantages	Disadvantages
Vaal	EWR12	Easy access to the site. Single channel. Gauging weir for flow records.	Vegetation on both banks and islands in the river bed influence overall flow resistance at high flows.
Vaal	EWR13	Easy access to the site. Single channel. Gauging weir for flow records.	Vegetation on the right bank influences overall flow resistance at high flows.
Vals	EWR14	Easy access to the site. Gauging weir for flow records.	Hydraulics is complex: 2 channels, islands, standing water pools.
Vet	EWR15	Single low flow channel. Gauging weir for flow records.	Large scale river bad substrates result to non-uniform flow with potential for non-horizontal water profile at low flow conditions.

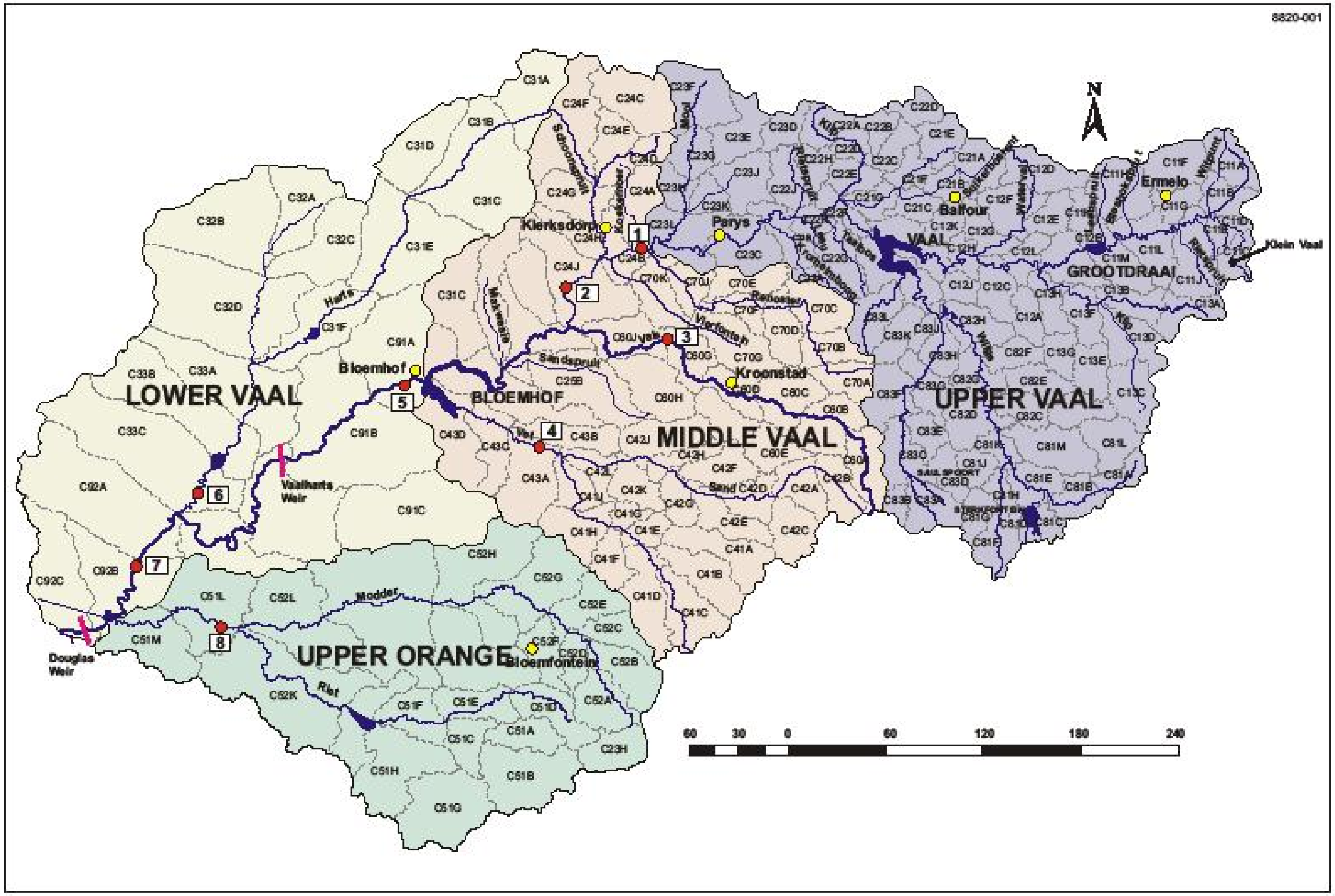

Figure 1: Location of the EWR sites (sites EWR 1 – 8 refer to sites EWR 12 – 19)

Figure 2: Vaal River EWR12 view from the right bank

Figure 3: Vaal River EWR13 view from the left bank

Figure 4: Vals River EWR14 view from the left bank

Figure 5: Vet River EWR15 view from the right bank

3 DATA COLLECTION

3.1 EWR sites survey

Survey of the selected EWR sites was performed by professional surveyors. Permanent bench marks (BM) were installed at each site and information of fixed BMs are listed in Table 3.

Table 3: Coordinates of fixed BMs at the selected EWR sites

River	Site no.	Coordinate system	BM	Remark	Y-Coord (m)	X-Coord (m)	Z-Coord (m)
Vaal	EWR12	LO27 WGS 84	DW1	IPC	14892.38	2980585.63	1286.02
Vaal	EWR13	LO27 WGS 84	DW2	IPC	47514.79	2999286.18	1269.705
Vals	EWR14	LO27 WGS 84	DW3	IPC	18437.11	3041614.37	1285.817
Vet	EWR15	LO27 WGS 84	DW4	IPC	86108.19	3091512.27	1246.877

Surveyed EWR cross-sectional profile for each EWR site is shown in Figure 6 to Figure 9.

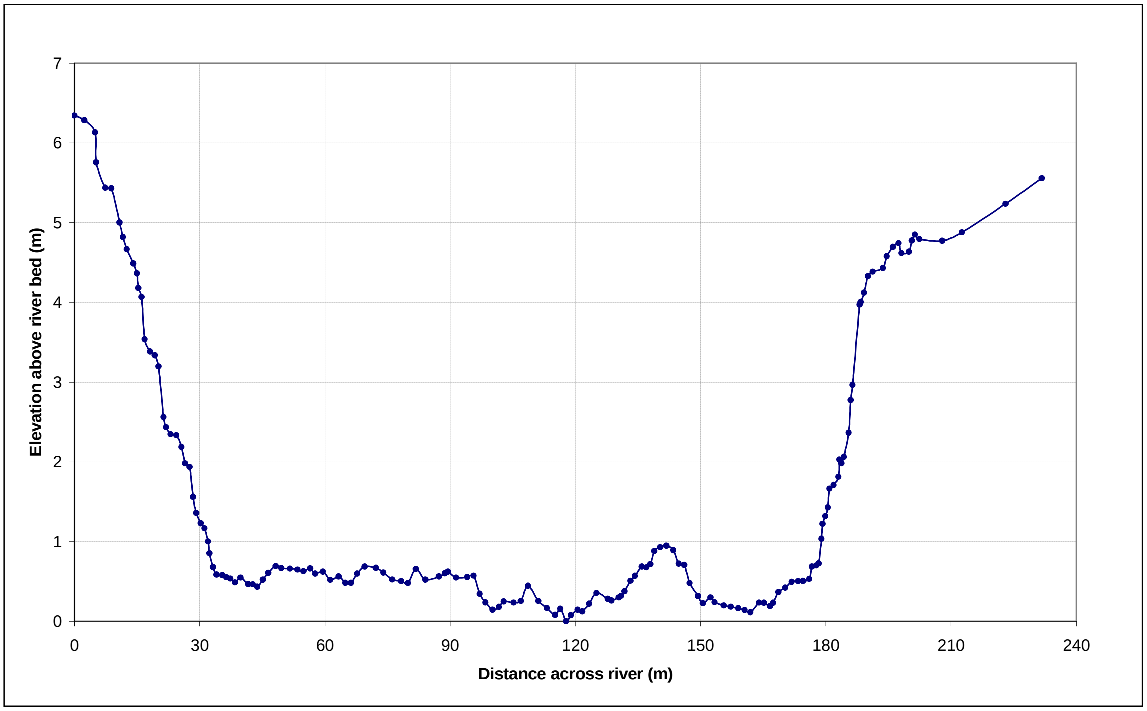

Figure 6: Cross-sectional profile for EWR12 on the Vaal River.

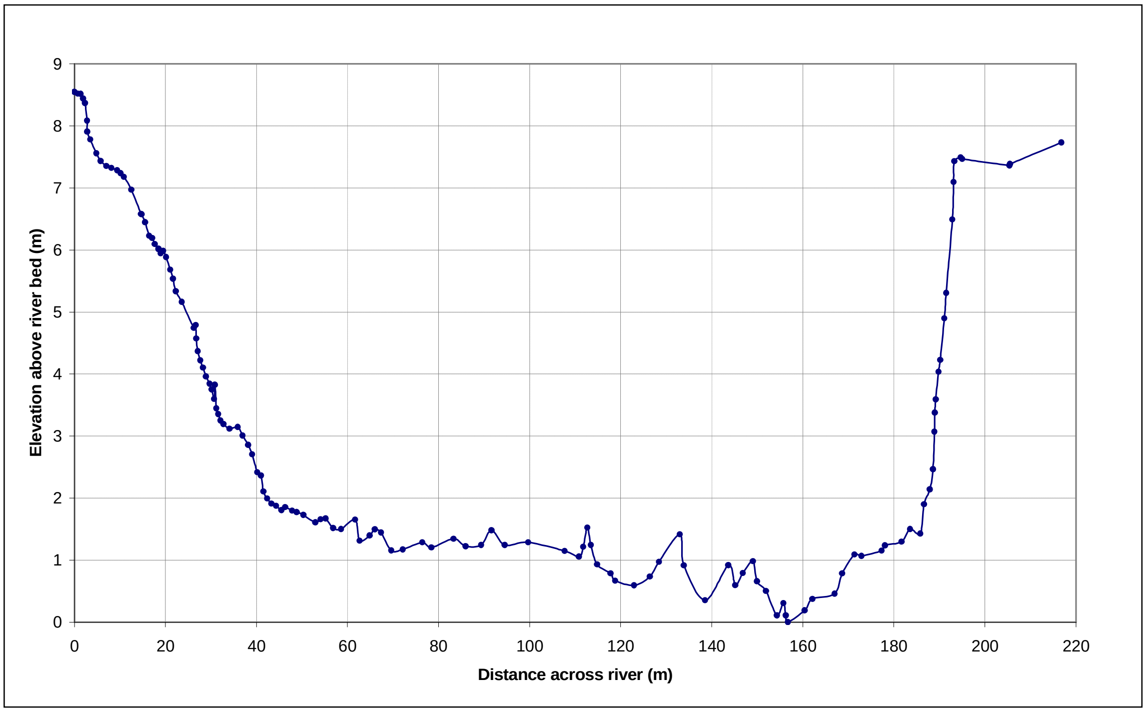

Figure 7: Cross-sectional profile for EWR13 on the Vaal River

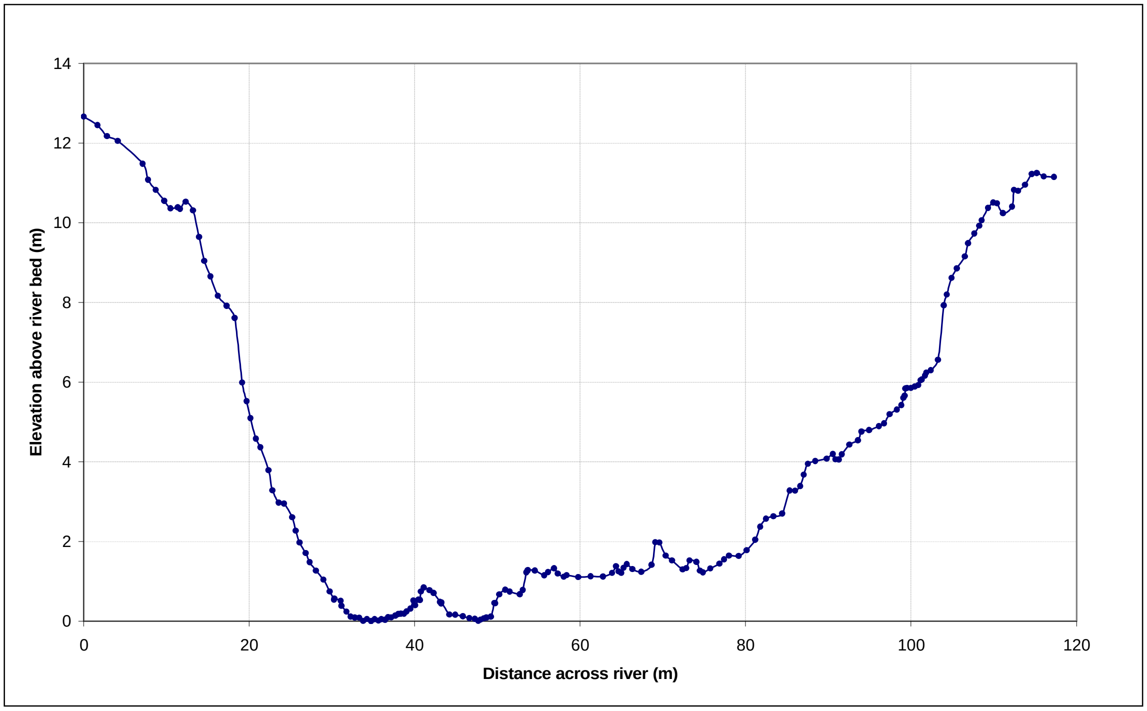

Figure 8: Cross-sectional profile for EWR14 on the Vals River

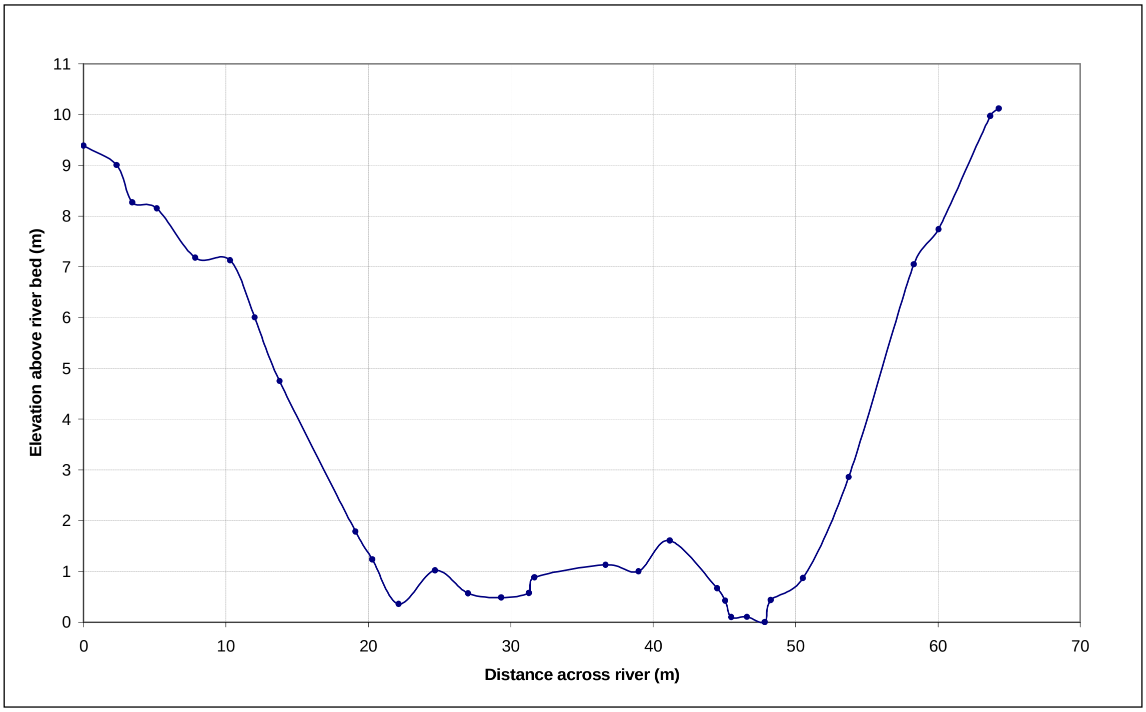

Figure 9: Cross-sectional profile for EWR15 on the Vet River

3.2 Hydraulic data collected

The stage-discharge data collected at the EWR sites together with the dates when the data were collected are provided in Table 4.

Table 4: Hydraulic data collected at EWR sites

River	Site no.	Date	Discharge *Q* (m^3/s)	Max. flow depth, *y* (m)	Slope
Vaal	EWR12	25.09.2007	15.70	0.99	0.0010
		25.06.2008	22.60	1.03	0.0014
		24.08.2008	20.40	1.02	0.0014
Vaal	EWR13	25.09.2007	11.50	2.20	0.00021
		24.06.2008	24.80	2.36	0.00021
		24.08.2008	23.00	2,34	0.00021
Vals	EWR14	26.06.2008	0.35	0.51	0.0098
		24.08.2008	0.28	0.49	0.0062
Vet	EWR15	04.07.2008	0.53	0.43	0.0142
		25.08.2008	0.20	0.26	0.0142

4 MODELLING

Flow resistance in natural channels is generally a function of stage, particularly at low flows where the flow depth is of the same order of magnitude as the size of the roughness elements constituting the bed (Birkhead et al., 1997; Broadhurst et al., 1997). With increased discharge, the local hydraulic controls become inundated, resulting in a tendency towards uniform water surface gradients and asymptotic resistance coefficient values (Birkhead et al., 2002). The observed rating data at the EWR sites were extended using the Manning's *n* resistance relationship and regional bed slopes. The regional bed slopes were obtained from a geomorphologist of the team (Table 5). The values of Manning's *n* resistance coefficients required for extending of the observed rating data were estimated using experience and existing resistance coefficients given in the literature (Barnes, 1967; Hicks and Mason, 1991 and Chow, 1959). The modelled stage-discharge data are given in Table 6.

Table 5: Regional channel slope

River	Site no.	Regional Channel slope
Vaal	EWR12	0.00041
Vaal	EWR13	0.00028
Vals	EWR14	0.000656
Vet	EWR15	0.00028

Table 6: Hydraulic data used to extend the measured rating data

River	Site no.	Discharge (m^3/s)	Manning's resistance, *n*	Max. flow depth, *y* (m)	Energy slope, *S*	Ave. velocity *v* (m/s)
Vaal	EWR12	5.90	0.110	0.75	0.001	0.13
		640.00	0.030	3.50	0.00041	1.34
Vaal	EWR13	0.50	0.280	1.39	0.000021	0.01
		345.00	0.030	3.50	0.00028	0.96
Vals	EWR14	88.00	0.050	3.00	0.000656	0.75
		465.00	0.030	5.00	0.000656	1.84
Vet	EWR15	0.07	0.060	0.15	0.0142	0.35
		4.15	0.085	1.00	0.0070	0.51
		60.00	0.031	3.00	0.00028	0.82

5 RESULTS

5.1 Rating data and functions

A general depth-discharge power relationship for open channel flow (Birkhead and James, 1998) is given by

$$y = aQ^b + c \qquad \text{equation 1}$$

where y is the maximum flow depth (m), Q is the discharge rate (m^3/s), and a, b and c are regression coefficients.

Continuous rating functions of the form given by equation 1 have been fitted to the measured and modelled data, and these are plotted in Figure 10 to Figure 13. The rating relationship coefficients in equation 1 for FWR sites are given in Table 7.

Table 7: Regression coefficients in equation 1

River	Site no.	Discharge Q (m3/s)	Rating coefficients		
			a	b	c
Vaal	EWR12	all	0.392	0.336	0
Vaal	EWR13	all	1.53	0.14	0
Vals	EWR14	all	0.706	0.318	0
Vet	EWR15	Q<0.53	0.58	0.50	0
		Q>0.53	0.55	0.41	0

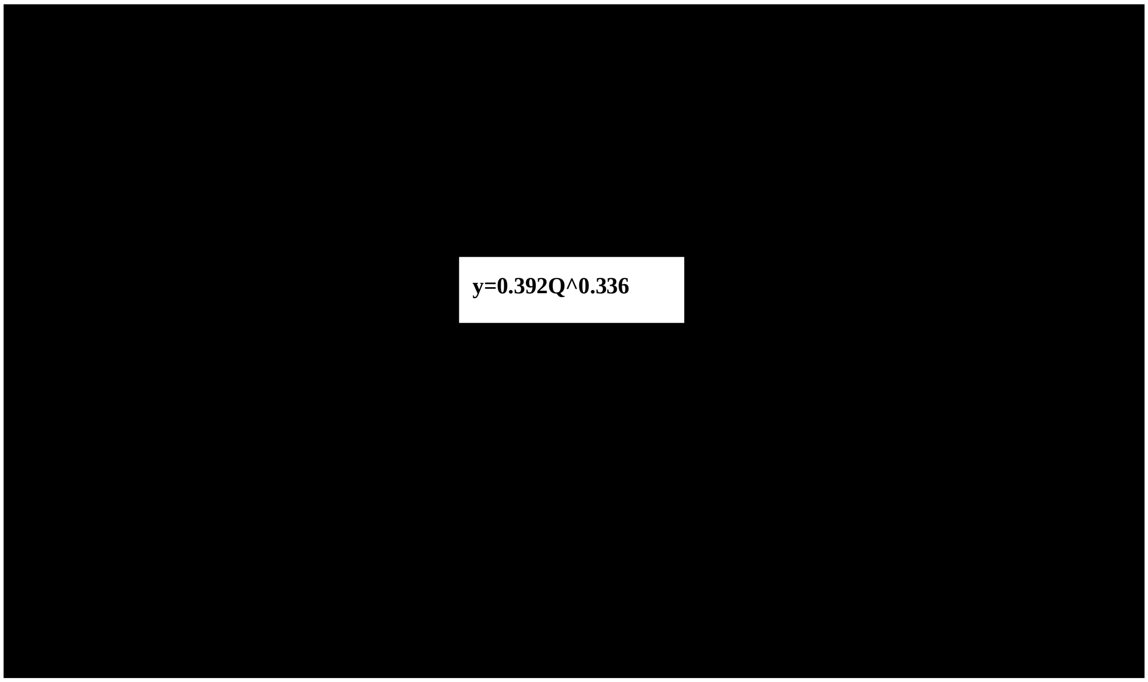

Figure 10: Measured and modelled rating relationship for Vaal River EWR12

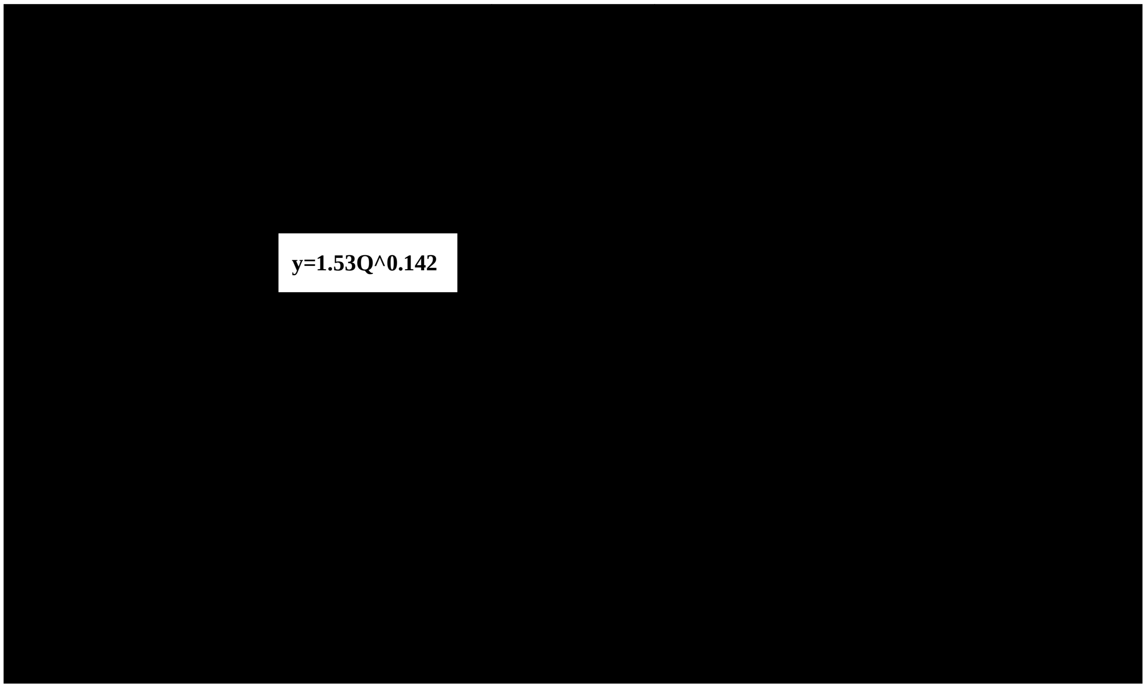

Figure 11: Measured and modelled rating relationship for Vaal River EWR13

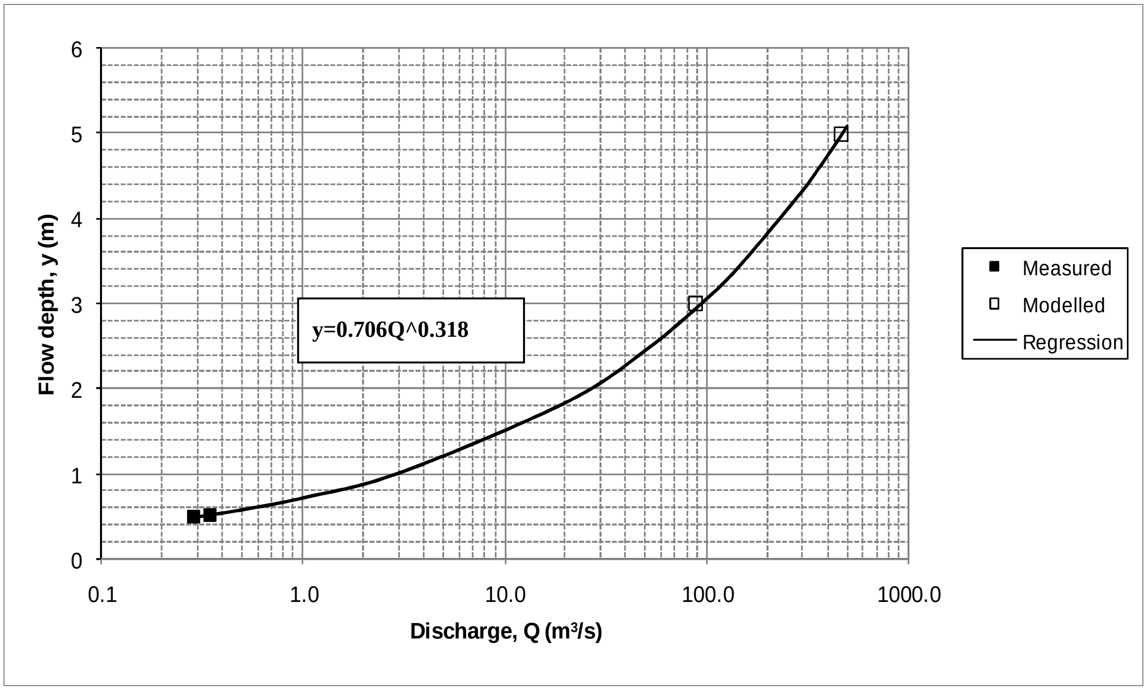

Figure 12: Measured and modelled rating relationship for Vals River EWR14

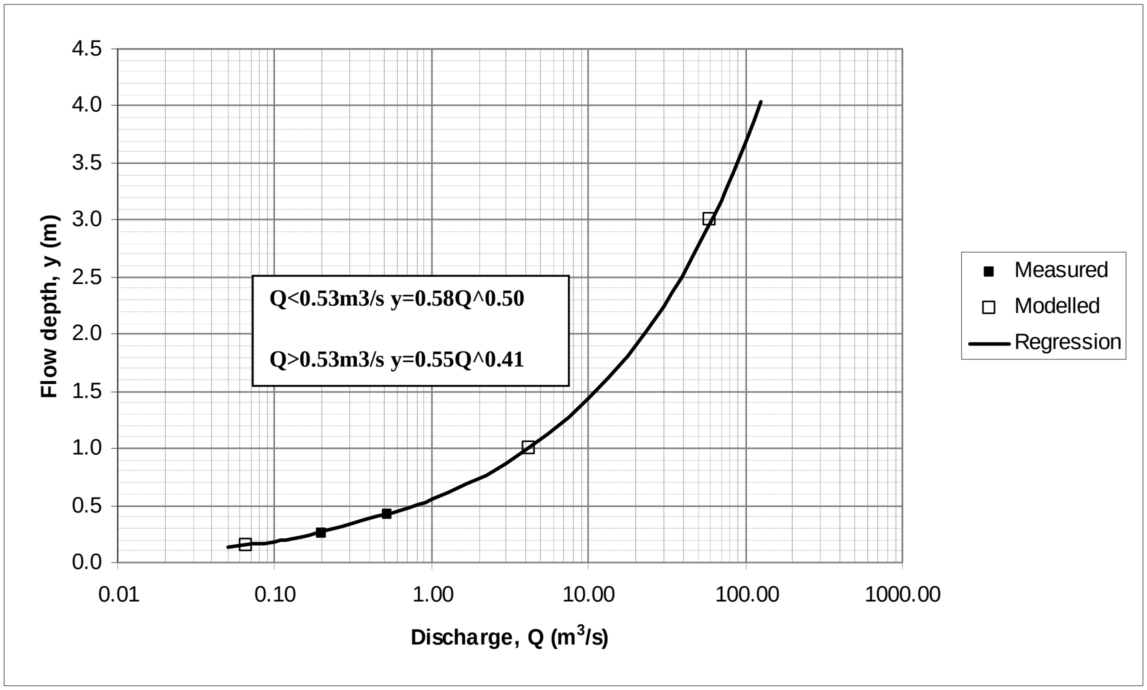

Figure 13: Measured and modelled rating relationship for Vet River EWR15

Modelled hydraulic data for the EWR sites are give in Appendix A.

5.2 Confidence in the hydraulic modelling

Confidence in the hydraulic modelling in a range of confidence of 0 to 5 is given in Table 8. The confidence in the hydraulic modelling for flows that higher and lower then were observed is low. The reason for the low confidence in the hydraulic modelling is related to too narrow range of the observed rating data.

Table 8: Confidence in the hydraulic modelling

EWRs Site	Limits of measured discharge range (m^3/s)		Confidence rating for discharge range (0=none, 1=low, 2=low/medium, 3=medium, 4=medium/high, 5=high)		
	Q_{min}	Q_{max}	$Q<Q_{min}$	$Q_{min}<Q<Q_{max}$	$Q>Q_{max}$
12	15.70	22.60	2	4	2
13	11.50	24.80	2	4	2
14	0.28	0.35	3	4	2
15	0.20	0.53	3	4	2

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APPENDIX A

Table A-1: EWR12 Modelled hydraulics parameters in 0.02 m depth interval

Max depth	Average depth	Discharge	Width	Perimeter	Average Velocity
(m)	(m)	(m3/s)	(m)	(m)	(m/s)
0.50	0.22	1.422	71.3	71.5	0.09
0.52	0.22	1.561	78.8	79.0	0.09
0.54	0.22	1.720	86.6	86.7	0.09
0.56	0.21	1.872	97.2	97.4	0.09
0.58	0.22	2.123	102.4	102.6	0.09
0.60	0.23	2.400	107.5	107.7	0.10
0.62	0.24	2.682	114.0	114.1	0.10
0.64	0.25	3.023	118.3	118.5	0.10
0.66	0.26	3.358	124.7	124.8	0.11
0.68	0.26	3.735	130.5	130.7	0.11
0.70	0.27	4.153	135.9	136.2	0.11
0.72	0.29	4.658	138.5	138.7	0.12
0.74	0.31	5.246	138.9	139.1	0.12
0.76	0.33	5.869	139.3	139.6	0.13
0.78	0.35	6.527	139.7	140.0	0.14
0.80	0.36	7.221	140.2	140.4	0.14
0.82	0.38	7.953	140.6	140.8	0.15
0.84	0.40	8.721	141.0	141.3	0.15
0.86	0.42	9.529	141.4	141.6	0.16
0.88	0.44	10.376	141.7	142.0	0.17
0.90	0.46	11.232	142.7	143.0	0.17
0.92	0.47	12.116	143.9	144.2	0.18
0.94	0.49	13.014	145.6	145.9	0.18
0.96	0.50	13.988	146.7	147.0	0.19
0.98	0.52	15.070	146.8	147.1	0.20
1.00	0.54	16.235	146.9	147.2	0.20
1.02	0.56	17.221	147.0	147.4	0.21
1.04	0.58	18.245	147.2	147.5	0.21
1.06	0.60	19.310	147.3	147.7	0.22
1.08	0.62	20.414	147.4	147.8	0.22
1.10	0.64	21.560	147.5	147.9	0.23
1.12	0.66	22.748	147.7	148.1	0.23
1.14	0.68	23.978	147.8	148.2	0.24
1.16	0.70	25.252	147.9	148.3	0.24
1.18	0.72	26.570	148.2	148.6	0.25
1.20	0.74	27.933	148.5	148.9	0.26
1.22	0.75	29.341	148.8	149.2	0.26
1.24	0.77	30.796	149.2	149.6	0.27
1.26	0.79	32.298	149.5	149.9	0.27
1.28	0.81	33.848	149.8	150.2	0.28
1.30	0.83	35.447	150.0	150.5	0.29
1.32	0.85	37.094	150.3	150.8	0.29
1.34	0.86	38.792	150.6	151.1	0.30
1.36	0.88	40.541	150.9	151.3	0.30
1.38	0.90	42.341	151.1	151.5	0.31
1.40	0.92	44.194	151.3	151.7	0.32
1.42	0.94	46.100	151.4	151.9	0.32
1.44	0.96	48.059	151.6	152.1	0.33
1.46	0.98	50.073	151.7	152.2	0.34

Max depth (m)	Average depth (m)	Discharge (m3/s)	Width (m)	Perimeter (m)	Average Velocity (m/s)
1.48	1.00	52.142	151.8	152.3	0.34
1.50	1.02	54.267	151.9	152.4	0.35
1.52	1.04	56.449	152.0	152.5	0.36
1.54	1.05	58.689	152.2	152.7	0.37
1.56	1.07	60.986	152.3	152.8	0.37
1.58	1.09	63.343	152.4	152.9	0.38
1.60	1.11	65.759	152.4	153.0	0.39
1.62	1.13	68.236	152.5	153.1	0.40
1.64	1.15	70.774	152.6	153.1	0.40
1.66	1.17	73.374	152.7	153.2	0.41
1.68	1.19	76.036	153.1	153.7	0.42
1.70	1.20	78.762	153.5	154.1	0.43
1.72	1.22	81.552	153.9	154.5	0.43
1.74	1.24	84.407	154.2	154.7	0.44
1.76	1.26	87.327	154.4	155.0	0.45
1.78	1.27	90.314	154.7	155.3	0.46
1.80	1.29	93.368	155.0	155.6	0.47
1.82	1.31	96.489	155.2	155.8	0.47
1.84	1.33	99.679	155.2	155.9	0.48
1.86	1.35	102.939	155.3	155.9	0.49
1.88	1.37	106.268	155.4	156.0	0.50
1.90	1.39	109.668	155.5	156.1	0.51
1.92	1.41	113.140	155.5	156.2	0.52
1.94	1.43	116.684	155.8	156.5	0.53
1.96	1.44	120.300	156.2	156.9	0.53
1.98	1.46	123.991	156.7	157.4	0.54
2.00	1.47	127.756	157.1	157.8	0.55
2.02	1.49	131.596	157.5	158.3	0.56
2.04	1.51	135.511	157.9	158.6	0.57
2.06	1.52	139.504	158.1	158.8	0.58
2.08	1.54	143.574	158.3	159.0	0.59
2.10	1.56	147.721	158.4	159.2	0.60
2.12	1.58	151.948	158.6	159.3	0.61
2.14	1.60	156.254	158.7	159.5	0.62
2.16	1.62	160.641	158.9	159.7	0.63
2.18	1.63	165.108	159.1	159.8	0.64
2.20	1.65	169.657	159.3	160.0	0.64
2.22	1.67	174.289	159.5	160.3	0.65
2.24	1.69	179.004	159.7	160.5	0.66
2.26	1.71	183.802	160.0	160.7	0.67
2.28	1.72	188.686	160.2	161.0	0.68
2.30	1.74	193.655	160.4	161.2	0.69
2.32	1.76	198.710	160.7	161.4	0.70
2.34	1.77	203.852	160.9	161.7	0.71
2.36	1.78	209.081	162.5	163.3	0.72
2.38	1.79	214.399	162.8	163.6	0.73
2.40	1.81	219.805	163.1	163.9	0.74
2.42	1.83	225.302	163.4	164.2	0.75
2.44	1.85	230.889	163.6	164.4	0.76
2.46	1.86	236.567	163.7	164.6	0.78

Max depth (m)	Average depth (m)	Discharge (m3/s)	Width (m)	Perimeter (m)	Average Velocity (m/s)
2.48	1.88	242.337	163.8	164.7	0.79
2.50	1.90	248.200	164.0	164.8	0.80
2.52	1.92	254.157	164.1	164.9	0.81
2.54	1.94	260.207	164.2	165.1	0.82
2.56	1.96	266.353	164.3	165.2	0.83
2.58	1.98	272.594	164.4	165.3	0.84
2.60	2.00	278.931	164.4	165.3	0.85
2.62	2.01	285.366	164.5	165.4	0.86
2.64	2.03	291.898	164.6	165.5	0.87
2.66	2.05	298.529	164.6	165.6	0.88
2.68	2.07	305.259	164.7	165.6	0.89
2.70	2.09	312.089	164.8	165.7	0.91
2.72	2.11	319.019	164.8	165.8	0.92
2.74	2.13	326.052	164.9	165.9	0.93
2.76	2.15	333.186	164.9	165.9	0.94
2.78	2.17	340.423	165.0	166.0	0.95
2.80	2.19	347.764	165.1	166.1	0.96
2.82	2.21	355.209	165.2	166.2	0.97
2.84	2.22	362.760	165.3	166.3	0.99
2.86	2.24	370.416	165.4	166.4	1.00
2.88	2.26	378.178	165.4	166.5	1.01
2.90	2.28	386.048	165.5	166.6	1.02
2.92	2.30	394.026	165.6	166.7	1.03
2.94	2.32	402.113	165.7	166.8	1.05
2.96	2.34	410.309	165.8	166.9	1.06
2.98	2.36	418.615	165.9	167.0	1.07
3.00	2.38	427.032	165.9	167.0	1.08
3.02	2.39	435.561	166.0	167.1	1.10
3.04	2.41	444.202	166.1	167.2	1.11
3.06	2.43	452.957	166.1	167.3	1.12
3.08	2.45	461.825	166.2	167.4	1.13
3.10	2.47	470.807	166.3	167.4	1.15
3.12	2.49	479.905	166.4	167.5	1.16
3.14	2.51	489.119	166.4	167.6	1.17
3.16	2.53	498.449	166.5	167.7	1.18
3.18	2.55	507.897	166.6	167.8	1.20
3.20	2.57	517.464	166.6	167.9	1.21
3.22	2.58	527.148	166.8	168.0	1.22
3.24	2.60	536.953	167.0	168.2	1.24
3.26	2.62	546.878	167.1	168.4	1.25
3.28	2.64	556.924	167.3	168.5	1.26
3.30	2.65	567.092	167.4	168.7	1.28
3.32	2.67	577.382	167.6	168.9	1.29
3.34	2.69	587.796	167.8	169.0	1.30
3.36	2.70	598.333	168.4	169.6	1.32
3.38	2.71	608.995	169.0	170.2	1.33
3.40	2.73	619.783	169.2	170.4	1.34
3.42	2.74	630.697	169.3	170.6	1.36
3.44	2.76	641.737	169.5	170.8	1.37
3.46	2.78	652.905	169.7	171.0	1.39

Max depth	Average depth	Discharge	Width	Perimeter	Average Velocity
(m)	(m)	(m3/s)	(m)	(m)	(m/s)
3.48	2.79	664.202	169.9	171.2	1.40
3.50	2.81	675.627	170.1	171.4	1.41

Table A-2: EWR13 Modelled hydraulics parameters in 0.05 m depth interval

Max depth	Average depth	Discharge	Width	Perimeter	Average Velocity
(m)	(m)	(m3/s)	(m)	(m)	(m/s)
0.50	0.21	0.000	17.900	18.000	0.00
0.55	0.24	0.001	19.600	19.800	0.00
0.60	0.26	0.001	22.100	22.300	0.00
0.65	0.24	0.002	28.400	28.500	0.00
0.70	0.26	0.004	32.900	33.100	0.00
0.75	0.28	0.006	36.200	36.400	0.00
0.80	0.31	0.010	39.200	39.400	0.00
0.85	0.33	0.016	42.900	43.200	0.00
0.90	0.35	0.023	46.600	46.900	0.00
0.95	0.38	0.034	49.300	49.700	0.00
1.00	0.42	0.049	51.000	51.400	0.00
1.05	0.46	0.070	52.300	52.700	0.00
1.10	0.46	0.097	58.400	58.800	0.00
1.15	0.46	0.132	64.000	64.500	0.00
1.20	0.46	0.179	72.400	72.900	0.01
1.25	0.42	0.238	87.900	88.400	0.01
1.30	0.40	0.314	104.400	105.000	0.01
1.35	0.43	0.410	110.600	111.300	0.01
1.40	0.46	0.530	114.800	115.500	0.01
1.45	0.50	0.678	118.600	119.300	0.01
1.50	0.52	0.862	123.700	124.500	0.01
1.55	0.56	1.086	127.200	128.000	0.02
1.60	0.60	1.358	129.000	129.800	0.02
1.65	0.63	1.688	132.600	133.400	0.02
1.70	0.67	2.083	135.300	136.200	0.02
1.75	0.71	2.555	136.800	137.700	0.03
1.80	0.75	3.117	138.600	139.600	0.03
1.85	0.79	3.782	141.700	142.700	0.03
1.90	0.83	4.564	143.000	143.900	0.04
1.95	0.87	5.481	144.100	145.000	0.04
2.00	0.92	6.553	144.900	145.800	0.05
2.05	0.96	7.799	145.500	146.500	0.06
2.10	1.01	9.244	146.100	147.100	0.06
2.15	1.06	10.658	146.500	147.500	0.07
2.20	1.11	11.631	146.700	147.700	0.07
2.25	1.15	15.038	146.900	148.000	0.09
2.30	1.20	17.559	147.100	148.200	0.10
2.35	1.25	20.434	147.400	148.400	0.11
2.40	1.29	23.705	148.000	149.100	0.12
2.45	1.34	27.415	148.500	149.600	0.14
2.50	1.39	31.613	148.800	149.900	0.15
2.55	1.44	36.351	149.000	150.200	0.17

Max depth	Average depth	Discharge	Width	Perimeter	Average Velocity
(m)	(m)	(m3/s)	(m)	(m)	(m/s)
2.60	1.48	41.686	149.200	150.400	0.19
2.65	1.53	47.679	149.500	150.700	0.21
2.70	1.58	54.397	149.700	151.000	0.23
2.75	1.63	61.912	150.000	151.300	0.25
2.80	1.67	70.301	150.300	151.600	0.28
2.85	1.72	79.647	150.600	152.000	0.31
2.90	1.76	90.040	151.000	152.400	0.34
2.95	1.81	101.576	151.400	152.900	0.37
3.00	1.85	114.358	151.900	153.400	0.41
3.05	1.90	128.497	152.300	153.800	0.44
3.10	1.94	144.110	152.700	154.200	0.49
3.15	1.96	161.324	155.400	157.000	0.53
3.20	2.00	180.273	156.300	158.000	0.58
3.25	2.04	201.102	156.900	158.600	0.63
3.30	2.09	223.963	157.200	158.900	0.68
3.35	2.13	249.019	157.400	159.200	0.74
3.40	2.18	276.444	157.700	159.500	0.80
3.45	2.23	306.422	157.900	159.700	0.87
3.50	2.27	339.147	158.000	159.900	0.94

Table A-3: EWR14 Modelled hydraulics parameters in 0.05 m depth interval

Max depth	Average depth	Discharge	Width	Perimeter	Average Velocity
(m)	(m)	(m3/s)	(m)	(m)	(m/s)
0.20	0.11	0.019	12.1	12.2	0.01
0.25	0.15	0.038	12.8	13.0	0.02
0.30	0.19	0.068	13.6	13.8	0.03
0.35	0.23	0.110	14.2	14.4	0.03
0.40	0.28	0.168	14.6	14.9	0.04
0.45	0.31	0.243	15.3	15.7	0.05
0.50	0.35	0.338	16.1	16.5	0.06
0.55	0.37	0.456	17.3	17.8	0.07
0.60	0.40	0.600	18.0	18.6	0.08
0.65	0.44	0.771	18.5	19.1	0.09
0.70	0.47	0.974	19.7	20.3	0.11
0.75	0.48	1.209	21.4	22.1	0.12
0.80	0.49	1.482	22.8	23.6	0.13
0.85	0.53	1.793	23.7	24.5	0.14
0.90	0.57	2.146	23.9	24.7	0.16
0.95	0.62	2.543	24.0	24.9	0.17
1.00	0.66	2.989	24.2	25.1	0.19
1.05	0.71	3.484	24.4	25.3	0.20
1.10	0.75	4.033	24.6	25.6	0.22
1.15	0.65	4.638	30.4	31.4	0.23
1.20	0.66	5.302	32.4	33.4	0.25
1.25	0.66	6.028	35.1	36.2	0.26
1.30	0.64	6.820	39.0	40.2	0.27
1.35	0.64	7.679	42.0	43.2	0.28
1.40	0.66	8.610	44.1	45.4	0.30
1.45	0.69	9.614	45.6	47.0	0.31

Max depth (m)	Average depth (m)	Discharge (m3/s)	Width (m)	Perimeter (m)	Average Velocity (m/s)
1.50	0.72	10.696	46.9	48.3	0.32
1.55	0.75	11.857	48.1	49.5	0.33
1.60	0.79	13.102	48.8	50.4	0.34
1.65	0.81	14.433	50.8	52.4	0.35
1.70	0.85	15.854	51.4	53.0	0.36
1.75	0.89	17.367	52.0	53.7	0.38
1.80	0.93	18.976	52.6	54.3	0.39
1.85	0.97	20.683	53.1	54.9	0.40
1.90	1.01	22.493	53.6	55.4	0.42
1.95	1.05	24.407	54.1	56.0	0.43
2.00	1.08	26.430	55.0	56.9	0.44
2.05	1.13	28.564	55.2	57.1	0.46
2.10	1.17	30.812	55.4	57.3	0.47
2.15	1.22	33.179	55.6	57.5	0.49
2.20	1.27	35.666	55.7	57.7	0.51
2.25	1.31	38.278	55.9	57.9	0.52
2.30	1.36	41.017	56.1	58.1	0.54
2.35	1.40	43.887	56.2	58.3	0.56
2.40	1.45	46.891	56.4	58.5	0.57
2.45	1.49	50.032	56.7	58.8	0.59
2.50	1.54	53.314	56.9	59.1	0.61
2.55	1.58	56.739	57.1	59.3	0.63
2.60	1.61	60.312	57.7	59.9	0.65
2.65	1.64	64.035	58.6	60.8	0.67
2.70	1.66	67.912	59.5	61.7	0.69
2.75	1.71	71.946	59.7	62.0	0.71
2.80	1.75	76.140	60.0	62.2	0.73
2.85	1.79	80.498	60.2	62.5	0.75
2.90	1.84	85.023	60.4	62.7	0.77
2.95	1.88	89.719	60.6	63.0	0.79
3.00	1.91	94.588	61.4	63.8	0.81
3.05	1.95	99.635	61.6	64.0	0.83
3.10	1.99	104.862	61.8	64.2	0.85
3.15	2.04	110.273	62.0	64.4	0.87
3.20	2.08	115.872	62.2	64.7	0.90
3.25	2.12	121.661	62.4	64.9	0.92
3.30	2.14	127.645	63.3	65.8	0.94
3.35	2.18	133.826	63.6	66.2	0.96
3.40	2.22	140.208	63.9	66.5	0.99
3.45	2.27	146.795	64.0	66.6	1.01
3.50	2.31	153.590	64.2	66.8	1.03
3.55	2.36	160.596	64.3	67.0	1.06
3.60	2.41	167.817	64.4	67.1	1.08
3.65	2.45	175.256	64.5	67.3	1.11
3.70	2.50	182.917	64.6	67.4	1.13
3.75	2.54	190.803	64.8	67.6	1.16
3.80	2.58	198.918	64.9	67.8	1.19
3.85	2.63	207.266	65.1	68.0	1.21
3.90	2.67	215.849	65.3	68.2	1.24

Max depth (m)	Average depth (m)	Discharge (m3/s)	Width (m)	Perimeter (m)	Average Velocity (m/s)
3.95	2.71	224.671	65.6	68.5	1.26
4.00	2.73	233.737	66.2	69.2	1.29
4.05	2.74	243.048	67.2	70.2	1.32
4.10	2.73	252.609	68.7	71.7	1.35
4.15	2.75	262.424	69.4	72.4	1.37
4.20	2.78	272.496	70.1	73.1	1.40
4.25	2.82	282.828	70.3	73.4	1.43
4.30	2.86	293.424	70.6	73.7	1.46
4.35	2.89	304.288	70.9	74.0	1.48
4.40	2.93	315.423	71.2	74.3	1.51
4.45	2.96	326.832	71.6	74.8	1.54
4.50	2.99	338.520	72.2	75.4	1.57
4.55	3.02	350.490	72.7	75.9	1.60
4.60	3.06	362.745	72.9	76.1	1.63
4.65	3.10	375.289	73.1	76.3	1.65
4.70	3.15	388.126	73.3	76.5	1.68
4.75	3.19	401.259	73.4	76.7	1.71
4.80	3.19	414.692	74.5	77.9	1.74
4.85	3.21	428.428	75.2	78.5	1.77
4.90	3.24	442.471	75.8	79.2	1.80
4.95	3.26	456.826	76.3	79.7	1.83
5.00	3.30	471.494	76.6	80.0	1.86

Table A-4: EWR15 Modelled hydraulics parameters in 0.05 m depth interval

Max depth (m)	Average depth (m)	Discharge (m3/s)	Width (m)	Perimeter (m)	Average Velocity (m/s)
0.10	0.05	0.029	1.3	1.4	0.45
0.15	0.07	0.066	2.5	2.6	0.35
0.20	0.12	0.118	2.7	2.8	0.37
0.25	0.16	0.184	2.8	2.9	0.40
0.30	0.21	0.264	2.9	3.1	0.44
0.35	0.25	0.360	3.0	3.2	0.48
0.40	0.27	0.470	3.4	3.7	0.52
0.45	0.28	0.591	3.9	4.2	0.54
0.50	0.25	0.769	5.1	5.5	0.59
0.55	0.19	0.976	8.5	8.9	0.60
0.60	0.20	1.214	10.4	10.9	0.57
0.65	0.23	1.482	11.4	11.9	0.55
0.70	0.26	1.784	12.5	13.0	0.55
0.75	0.29	2.120	13.5	14.1	0.54
0.80	0.32	2.491	14.5	15.2	0.54
0.85	0.34	2.899	15.6	16.3	0.54
0.90	0.37	3.344	16.9	17.6	0.54
0.95	0.38	3.828	18.7	19.5	0.54
1.00	0.39	4.352	20.5	21.4	0.54
1.05	0.40	4.916	23.1	24.0	0.54
1.10	0.41	5.523	25.5	26.5	0.53
1.15	0.43	6.172	27.2	28.2	0.53

Max depth (m)	Average depth (m)	Discharge (m3/s)	Width (m)	Perimeter (m)	Average Velocity (m/s)
1.20	0.47	6.865	27.7	28.7	0.53
1.25	0.51	7.602	28.3	29.3	0.53
1.30	0.55	8.386	28.8	29.9	0.53
1.35	0.59	9.215	29.4	30.5	0.53
1.40	0.63	10.093	29.9	31.1	0.54
1.45	0.67	11.018	30.5	31.7	0.54
1.50	0.71	11.992	31.0	32.2	0.55
1.55	0.74	13.017	31.6	32.8	0.56
1.60	0.78	14.092	32.1	33.4	0.56
1.65	0.82	15.219	32.4	33.7	0.57
1.70	0.87	16.398	32.6	33.9	0.58
1.75	0.91	17.631	32.7	34.1	0.59
1.80	0.96	18.917	32.9	34.3	0.60
1.85	1.00	20.259	33.1	34.5	0.61
1.90	1.05	21.655	33.3	34.7	0.62
1.95	1.09	23.108	33.4	34.9	0.63
2.00	1.14	24.618	33.6	35.1	0.64
2.05	1.18	26.186	33.8	35.3	0.66
2.10	1.22	27.812	33.9	35.5	0.67
2.15	1.27	29.497	34.1	35.7	0.68
2.20	1.31	31.242	34.3	35.9	0.69
2.25	1.36	33.047	34.5	36.1	0.71
2.30	1.40	34.914	34.6	36.3	0.72
2.35	1.44	36.843	34.8	36.5	0.73
2.40	1.48	38.834	35.0	36.7	0.75
2.45	1.53	40.888	35.1	36.9	0.76
2.50	1.57	43.006	35.3	37.1	0.78
2.55	1.61	45.189	35.5	37.3	0.79
2.60	1.65	47.437	35.6	37.5	0.80
2.65	1.70	49.750	35.8	37.7	0.82
2.70	1.74	52.130	36.0	37.9	0.83
2.75	1.78	54.577	36.2	38.1	0.85
2.80	1.82	57.092	36.3	38.3	0.86
2.85	1.86	59.675	36.5	38.5	0.88
2.90	1.91	62.327	36.6	38.7	0.89
2.95	1.95	65.048	36.8	38.8	0.91
3.00	1.99	67.840	36.9	39.0	0.92

APPENDIX B

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