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SUPPORT TO PHASE 2 OF THE ORASECOM BASIN-WIDE INTEGRATED WATER RESOURCES MANAGEMENT PLAN

Work Package 5:

Assessment of Environmental Flow Requirements

Delineation of Management Resource Units

July 2010

ORASECOM

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Prepared by

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REPORTS, WPS AND OTHER DELIVERABLES SUBMITTED	**TYPE**	**No.**
Overall Study		
Inception Report	Report	004/2010
Overall Project Executive Summary	Report	013/2011
Work Package 1: WATER RESOURCES MODELLING OF THE ORANGE-SENQU BASIN		
Strengths and Weaknesses of Existing Models	WP	005/2010
Setting up and Testing of the Final Extended and Expanded Models; Changes in Catchment Yields and Review of Water Balance	Report & WP	001/2011
Modelling software and datasets	Software	None
Capacity Building and Setting up the Models in each Country; Process of Continuous Review	WP	003/2011
Work Package 2: EXTENSION AND EXPANSION OF HYDROLOGY OF ORANGE-SENQU BASIN		
Improvements to Gauging Network and Review of Existing Data Acquisition Systems	WP	005/2011
Extension of Hydrological Records	Report	006/2011
Hydrological Database	Database	None
Work Package 3: INTEGRATED WATER RESOURCES QUALITY MANAGEMENT PLAN		
Development of Water Quality Monitoring programme and Data Management Framework	*Report*	*007/2011*
Development of Specifications for the Water Quality Model	WP	006/2010
Work Package 4: CLIMATE CHANGE IN THE ORANGE-SENQU RIVER BASIN		
Downscaling Methodology and Ongoing Climate Modelling Initiatives	WP	007/2010
GCC Downscaling for the Orange-Senqu River Basin	Report	008/2011
Projection of impacts and Guidelines on Climate Change Adaptation Strategies	WP	009/2011
Work Package 5: ASSESSMENT OF ENVIORNMENTAL FLOW REQUIREMENTS		
Literature survey and Gap Analysis	WP	008/2010
Delineation of Management Resource Units	***WP***	***009/2010***
Desktop EcoClassification Assessment	Report	016/2010
Goods and Services Report	WP	010/2010
Environmental Flow Requirements	Report	010/2011
Work Package 6: WATER CONSERVATION AND WATER DEMAND IN THE IRRIGATION SECTOR		
The Promotion of Water Conservation and Water Demand Management in the Irrigation Sector	Report	011/2011
Irrigation GIS Database, Interactive Database and Irrigation Scenario Tools	WP	012/2011
Irrigation GIS Database and Interactive Classification Tool	Software	None
Irrigation Scenario Generation Tool	Software	None

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ACRONYMS

AM	Aquatic Macrophytes
BBM	Building Block Methodology
CD: RDM	Chief Directorate: Resource Directed Measures
CMA	Catchment Management Agency
D:RQS	Directorate: Resource Quality Services
DRIFT	Downstream Response to Imposed Flow Transformation
DTM	Digital Terrain Model
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EC	Ecological Category
EcoSpecs	Ecological Specifications
EFR	Environmental Flow Requirements
EIS	Ecological Importance and Sensitivity
EPA	Environmental Protection Agency
EWR	Ecological Water Requirements
FD	Fast Deep
FRAI	Fish Response Assessment Index
FS	Fast shallow
GAI	Geomorphological Driver Assessment Index
GDP	Gross Domestic Product
geozone	Geomorphological zone
GIS	Geographic Information System
GGP	Gross Geographic Product
ha	hectare
HAI	Hydrological Driver Assessment Index
HFSR	Habitat Flow Stressor Response
IFR	Instream Flow Requirements
IHI	Index of Habitat Integrity
LB	Left bank
MAP	Mean Annual Precipitation
MIRAI	Macroinvertebrate Response Assessment Index
MRU	Management Resource Units
NGO	Non Governmental Organization
NRU	Natural Resource Units
NWA	National Water Act
NWRS	National Water Resource Strategy
OV	Overhanging Vegetation
PAI	Physico Chemical Driver Assessment Index
PES	Present Ecological State
PMT	Project Management Team
PSP	Professional Service Provider

quat	Quaternary catchment
RB	Right Bank
RAU	Reserve Assessment Units
REC	Recommended Ecological Category
RQO	Resource Quality Objectives
RQS	Resource Quality Services
RU	Resource Unit
SANBI	South African National Biodiversity Institute
SCI	Socio Cultural Importance
SD	Slow Deep
SPATSIM	Spatial and Time Series Information Modelling
SS	Slow Shallow
SUB	Substrate
ToR	Terms of Reference
TPC	Threshold of Potential Concern
UB	Undercut banks and root wads
VEGRAI	Riparian Vegetation Response Assessment Index
WC	Water Column
WHI	Wetland Health Index
WMA	Water Management Area
WRYM	Water Resource Yield Model

1 RIVER REACH DEMARCATION AND DELINEATION

1.1 Study Area

The study area for the Environmental Flow Requirements work is the Orange-Senqu River Catchment, which traverses four countries, South Africa, Lesotho, Botswana and Namibia. The focus of the Resource Unit delineation is only for the rivers in which Environmental Flow Requirements sites will be selected, which are the Caledon River, Orange River (downstream of Gariep Dam), the Kraai River and the Molopo River (from its source to the Ramabatlama River confluence).

1.2 Approach

If an Environmental Flow Requirement (EFR) determination is required for a whole catchment, it is necessary to delineate the catchment into Resource Units (RU). These are each significantly different and therefore warrant their own specification of the Environmental Flow Requirements. The geographic boundaries of each must also be clearly delineated (DWAF South Africa, 1999, Volume 3).

Resource Units are required, as it would not be appropriate to set the same numerical Environmental Flow Requirements for the headwaters of a river as for the lowland reaches. These sections of a river frequently have different natural flow patterns, react differently to stress (according to their sensitivity) and therefore require individual specifications of the Environmental Flow Requirements appropriate for that reach. The breakdown of a catchment into Resource Units, for the purpose of determining the Environmental Flow Requirements for rivers is done primarily on a biophysical basis within the catchment and called Natural Resource Units (NRU). The more detailed approach is described in Appendix A.

Management requirements (DWAF South Africa, 1999, Volume 3) also play a role in the delineation. An example would be where large dams and/or transfer schemes occur. Furthermore, the type of disturbance/impact on the river under the present circumstances would also play a role in selecting homogenous river reaches (from a biophysical basis). These are called Management Resource Units (MRU) and the more detailed approach is described in Appendix A.

The delineation process considers all of the above aspects. Overlaying all the data does not necessarily result in a logical and clear delineation. Expert judgement, a consultative process and local knowledge are required for the final delineation. The practicalities of dealing with numerous reaches within one study must also be considered in order to determine a logical and practical suite of Management Resource Units.

Management Resource Units can be further delineated in even smaller assessment units and the approach for this is described in Appendix A.

The Environmental Flow Requirementss are determined for each Management Resource Unit by means of either of the following (Louw & Hughes, 2002):

- An Environmental Flow Requirements site is selected within the Management Resource Unit and represents a critical site within the relevant river section. Results generated at the Environmental Flow Requirements site will then be relevant for the Management Resource Unit as a whole.
- No Environmental Flow Requirements site is selected within the Management Resource Unit and extrapolated results from adjacent Management Resource Unit with Environmental Flow Requirements sites are used. The reasons for an Environmental Flow Requirements site not being selected within the Management Resource Unit can be the following:
- The characteristics of the river within the Management Resource Unit do not meet the criteria for Environmental Flow Requirements sites.
- Due to the number of Management Resource Units within the study area, it is not practical and/or cost-effective to address an Environmental Flow Requirements site within each Management Resource Unit.

No estimations will be made for Management Resource Units without Environmental Flow Requirements sites in this study.

1.3 Resource Unit Considerations

1.3.1 EcoRegions (Level II)

The EcoRegion typing approach developed in the USA (Omernik, 1987) was tested and applied at a preliminary level in South Africa. EcoRegional classification, or typing, will allow the grouping of rivers according to similarities based on a top-down approach. The purpose of this approach is to simplify and contextualise assessments and statements on Ecological Water Requirements. One of the advantages of such a system is the extrapolation of information from data rich rivers, to data poor rivers within the same hierarchical typing context.

The first phase (Level I) used available information to delineate EcoRegion boundaries at a very broad scale for South Africa. Attributes such as physiography, climate, rainfall, geology and potential natural vegetation were evaluated in this process and 18 Level I EcoRegions were identified (Kleynhans *et al*., 2005). The next Level II (Kleynhans *et al*., 2007), used the same attributes but in more detail. Physiography can, for example, be explored in more detail by considering terrain morphological classes, slopes, relief, altitude, etc.

1.3.2 Geomorphological Zoning

Rountree and Wadeson (1999) have developed a zonal classification system for Southern African rivers, modified from Noble and Hemens (1978). In their classification, an attempt

was made to give each zone a geomorphological definition in terms of distinctive channel morphological units and reach types. Experience working on a number of different rivers around the country has shown that channel gradient is an accurate indicator of channel characteristics and that probable or expected difference can be identified from an analysis of gradients (see Table 1).

Table 1: Geomorphological Zonation of River Channels[1]

Longitudinal zone	Characteristic channel features	
	Zone Class	Description
Mountain stream	B	Steep gradient stream dominated by bedrock and boulders, locally cobble or coarse gravels in pools. Reach types include cascades, bedrock fall, step-pool. Approximate equal distribution of 'vertical' and 'horizontal' flow components.
Transitional	C	Moderately steep stream dominated by bedrock or boulder. Reach types include plain-bed, pool-rapid or pool riffle. Confined or semi-confined valley floor with limited flood plain development.
Upper Foothills	D	Moderately steep, cobble-bed or mixed bedrock-cobble bed channel, with plain-bed, pool-riffle or pool-rapid reach types. Length of pools and riffles/rapids similar. Narrow flood plain of sand, gravel or cobble often present.
Lower Foothills	E	Lower gradient mixed bed alluvial channel with sand and gravel dominating the bed, locally may be bedrock controlled. Reach types typically include pool- riffle or pool-rapid, sand bars common in pools. Pools of significantly greater extent than rapids or riffles. Flood plain often present.
Lowland river	F	Low gradient alluvial fine bed channel, typically regime reach type. May be confined, but fully developed meandering pattern within a distinct flood plain develops in unconfined reaches where there is an increased silt content in bed or banks.

1.3.3 Land Cover

The land cover for a 500m strip on both sides of the river maps, as well as associated Excel spreadsheets were generated by GIS consultants on the team (**ftp://uranus.esrin.esa.int/pub/globcover_v2**). These spreadsheets provide a total summary of the hectares (ha) per quaternary catchments. This information was used to determine homogeneity of impacts and used in the decision-making regarding the

[1] adapted from Rountree and Wadeson, 1999)

Management Resource Units. The data source (IWQS 500k rivers, Globecover regional land cover map) does not provide the same detail normally provided by DWA and RQS, and therefore emphasis was placed on Google Earth, personal observations and local knowledge.

1.3.4 System Operation

A qualitative systems operation description has been provided, with specific emphasis of the locality and type of infrastructure (formal and informal) that could have an impact on the hydrological characteristics of the river.

1.3.4.1 Orange River: Gariep Dam to Vanderkloof Dam

This section is dominated by hydro-electric releases from Gariep Dam.

1.3.4.2 Orange River: Vanderkloof Dam to Prieska

This section is still dominated by hydro-electric releases, abstractions and return flows.

1.3.4.3 Orange River: Prieska to Boegoeberg Dam

Mostly an inaccessible reach with little irrigation and developments.

1.3.4.4 Orange River: Boegoeberg Dam to Upington

Canal system, extensive irrigation for crops (such as grapes).

1.3.4.5 Orange River: Upington to Vioolsdrift

Extensive irrigation in the reach to the Augrabies National Park. Extensive irrigation at Blouputs, in a riparian section ‘within’ the Augrabies National Park. Downstream of Augrabies National Park, the irrigation areas are fewer, due to the river not being accessible. Irrigation occurs again at Onseepkans. Between Onseepkans and Vioolsdrift, there is almost no irrigation.

1.3.4.6 Orange River: Vioolsdrift to the Orange River Mouth

Canal system and extensive irrigation to ‘Piece of Paradise’. From here, no irrigation on the South African side, to downstream of the Richtersveld National Park. On the Namibian side, outside of the cross-border Park, there are sections of mines and irrigation.

1.3.4.7 Caledon River: Source to Welbedacht Dam

Most of the area has Lesotho on the left bank (LB), with associated sedimentation problems as a result of the extensive land use. On the right bank (RB) in South Africa, formal irrigation and dry land irrigation take place. Many farm dams occur in the tributaries.

1.3.4.8 Caledon River: Welbedacht Dam to Orange River (Gariep Dam)

The only water in this river reach is comprised of spills from the Welbedacht Dam, compensation releases and inflows from tributaries.

1.3.4.9 Molopo River (Upper)

The Molopo River originates at the Molopo Eye and water is abstracted to Mafikeng immediately downstream of the source. The flow that is released into the river is used for agriculture. Further eyes occur lower down the river and this water is diverted into canal systems, supplying PPC Slurry (cement factory), as well as further agriculture. Within Mafikeng, the sewage systems are not functioning properly and the river (which normally has no more flow in this area) now receives sewage discharge, generally of poor quality. Various small dams are present in Mafikeng, as well as the Modimola Dam Dinoseng Dam further downstream. There are very seldom surface flows visible in this area as a result of the extensive flow modification.

2 DELINEATION RESULTS: ORANGE RIVER

2.1 Natural Resource Units

The EcoRegions and geomorphologicalic zones are described in Figure 1. The Natural Resource Units are derived from the EcoRegions and the geozones. The rationale for the delineation is provided in Table 2.

Table 2: Description and rationale for the Orange River Natural Resource Units

NRU	EcoRegion Level 2	Geozone	Rationale	Delineation
NRU Orange A	26.03 (65%) 26.01 (32%) 26.02 (3%)	Lowland (80%) Lower Foothills (20%)	The Vaal River forms a major natural hydrological break. Mostly consists of Lowland and all within one Level 1 EcoRegion, i.e. 26.	Gariep Dam wall to the Vaal confluence. -30.6248; 25.5058 -28.991; 23.8864
NRU Orange B	26.01 (90%) 26.02 (10%)	Lowland (100%)	As it all falls within one geomorphological zone the EcoRegion provides a logical break (26.01).	Vaal confluence to end of 26.01. -28.991; 23.8864 -29.6658; 22.7861
NRU Orange C	26.05 (90%) 26.02 (10%)	Lowland (100%)	As it all falls within one geomorphological zone the EcoRegion provides a logical break (26.05).	End of 26.01 to end of 26.05. -29.6658; 22.7861 -288574; 22.0857
NRU Orange D	26.05 (75%) 26.02 (23%) 29.01 (2%)	Lowland (80%) Lower foothills (17%) Upper foothills (3%)	Mostly falls within Lowland and EcoRegion 26.05. The Augrabies Falls form a natural barrier and therefore a logical break for the NRU.	End of 26.01 to Augrabies Falls. -288574; 22.0857 -28.5974; 20.3369
NRU Orange E	28.01 (99%) 26.02 (1%)	Lowland (75%) Lower foothills (23%) Upper foothills (2%)	The EcoRegion 28.01 provides the logical break for this NRU and coincides with the change from river to estuary.	Augrabies Falls to end of 28.01 (estuary). -28.5974; 20.3369 -28.3904; 16.7772
NRU Orange F	25.03 (100%)	Lowland (100%)	Consists of the estuary.	End of 28.01 (estuary) to sea. -28.3904; 16.7772 -28.6324; 16.4572

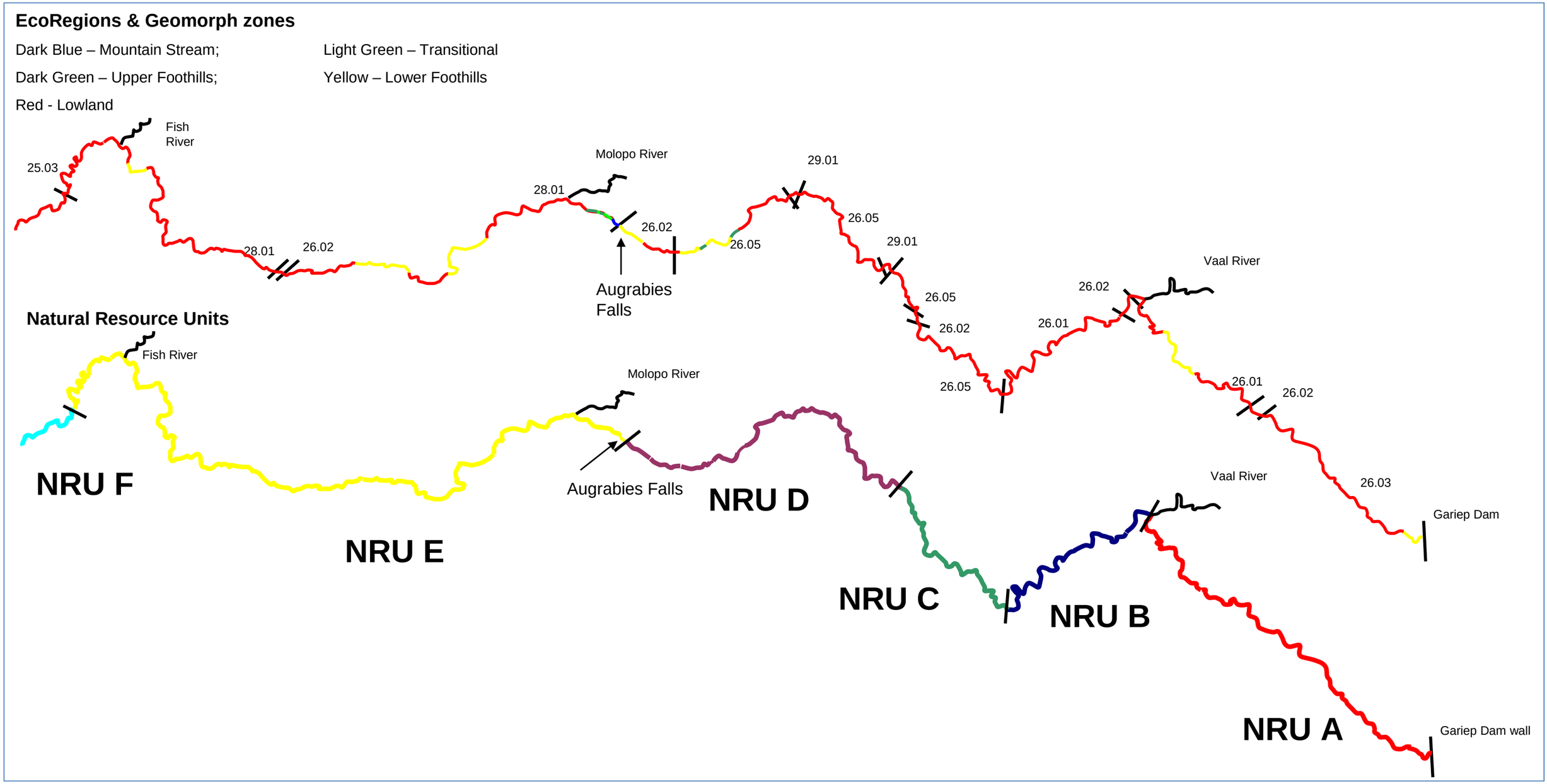

Figure 1: Natural Resource Units: Orange River

2.2 Management Resource Units

The Management Resource Units is illustrated in Figure 2 while a description of the rationale for Management Resource Unit selection provided in Table 3.

Table 3: Description and Rationale of the Orange River Management Resource Units

MRU	EcoRegion Level 2	Geozone	Land cover 500m both banks	Rationale	Delineation	Quat
MRU Orange A	26.03 (100%)	Lowland (90%) Lower Foothills (10%)	Dominated by hydro-electric releases.	The section between the two dams is an isolated section. Vanderkloof Dam is a logical operational endpoint, due to the operation and the barrier effect of the Dam. EFR site will be problematic in this reach due to the constraint of ESCOM operational rules.	Gariep Dam wall to Vanderkloof Dam -30.6248; 25.5058. -30.2898; 25.0075	D34A D34E D34G
MRU Orange B	26.01 (90%) 26.02 (8%) 26.03 (2%)	Lowland (90%) Lower Foothills (10%)	Influenced by the hydro-electric releases from the dam and irrigation.	Prieska town forms a logical endpoint as the water level fluctuation is less significant at this point and irrigation decreases afterwards. As the Vaal River is operated to not contribute significantly to the Orange River, it was not selected as an endpoint as it was for NRU B. EFR site will be problematic in this reach due to the constraint of ESCOM operational rules.	Vanderkloof Dam wall to Prieska (end of 26.01). -29.9983; 24.7917 -29.6658; 22.7861	D33A, D, E, F, G, H, K. D71A, C, D. D72A
MRU Orange C	26.05 (96%) 26.02 (2%) 29.01 (2%)	Lowland (100%)	Mostly an inaccessible gorge with limited farming activities.	Boegoeberg Dam forms a logical endpoint to this reach due to the barrier effect, the similar operation US of Boegoeberg and the increase in irrigation downstream of the dam. As most of this reach is influenced by back-up from Boegoeberg or is inaccessible, an EFR site is not advised.	Prieska (end of 26.01) to Boegoeberg Dam. -29.6658; 22.7861 -29.0426; 22.2008	D72A D72B D72C
MRU Orange D	26.05 (80%) 26.02 (18%) 29.01 (2%)	Lowland (80%) Lower foothills (18%) Upper foothills (2%)	2 reaches differentiated by the nature of the channel (multi-channel versus single) and Upington. Mostly irrigation, levees in the riparian zone and weirs.	Land use is similar to the Augrabies National Park. The actual falls is selected as the end of the MRU due to its role as a natural barrier.	Boegoeberg Dam to Augrabies Falls. -29.6658; 22.7861 -28.5974; 20.3369	D72C D73B, C, D, E, F. D81A

MRU	EcoRegion Level 2	Geozone	Land cover 500m both banks	Rationale	Delineation	Quat
RAU Orange D1	26.05 (100%)	Lowland (100%)	No farming in riparian zone, only canal on LB.	Selected as a RUA as this short reach is less disturbed than rest of section. EFR site should be selected in this reach.	Boegoeberg Dam to start of irrigated lands in riparian zone. -29.6658; 22.7861 -28.9680; 22.1742	D72C D73B
MRU Orange E	28.01 (98%) 26.02 (2%)	Lowland (80%) Lower foothills (17%) Upper foothills (3%)	Mixture of natural areas, National Park and irrigation.	Same delineation as for the NRU. Irrigation limited and constrained by accessibility. EFR site preferably in an undisturbed section, but must be accessible.	Augrabies Falls to Vioolsdrift Weir. -28.3904; 16.7772 -28.7606; 17.7292	D81A, B, D, E, F. D82A, D, E, F.
MRU Orange F	25.03 (100%)	Lowland (97%) Lower foothills (3%)	Extensive canals and irrigation in the floodplain zone on the LB. Section of National Parks (both banks and wilderness areas).	Fish River end of study area for EFR determination, i.e. end point of this MRU.	Vioolsdrif Weir to Fish confluence. -28.3904; 16.7772 -28.71001; 17.1753	D82F D82G D82H D82J
RAU Orange F.1	25.03 (100%)	Lowland (60%) Lower foothills (40%)	National Parks and wilderness area with some limited irrigation on RB.	No access on LB after 'Piece of Paradise', therefore inaccessible and in better condition than the rest of the reach. EFR site should be situated in this section, however due to inaccessibility, this was not an option.	Piece of Paradise (end of irrigation) to Fish confluence. -28.3904; 16.7772 -28.7041; 17.4681	D82J

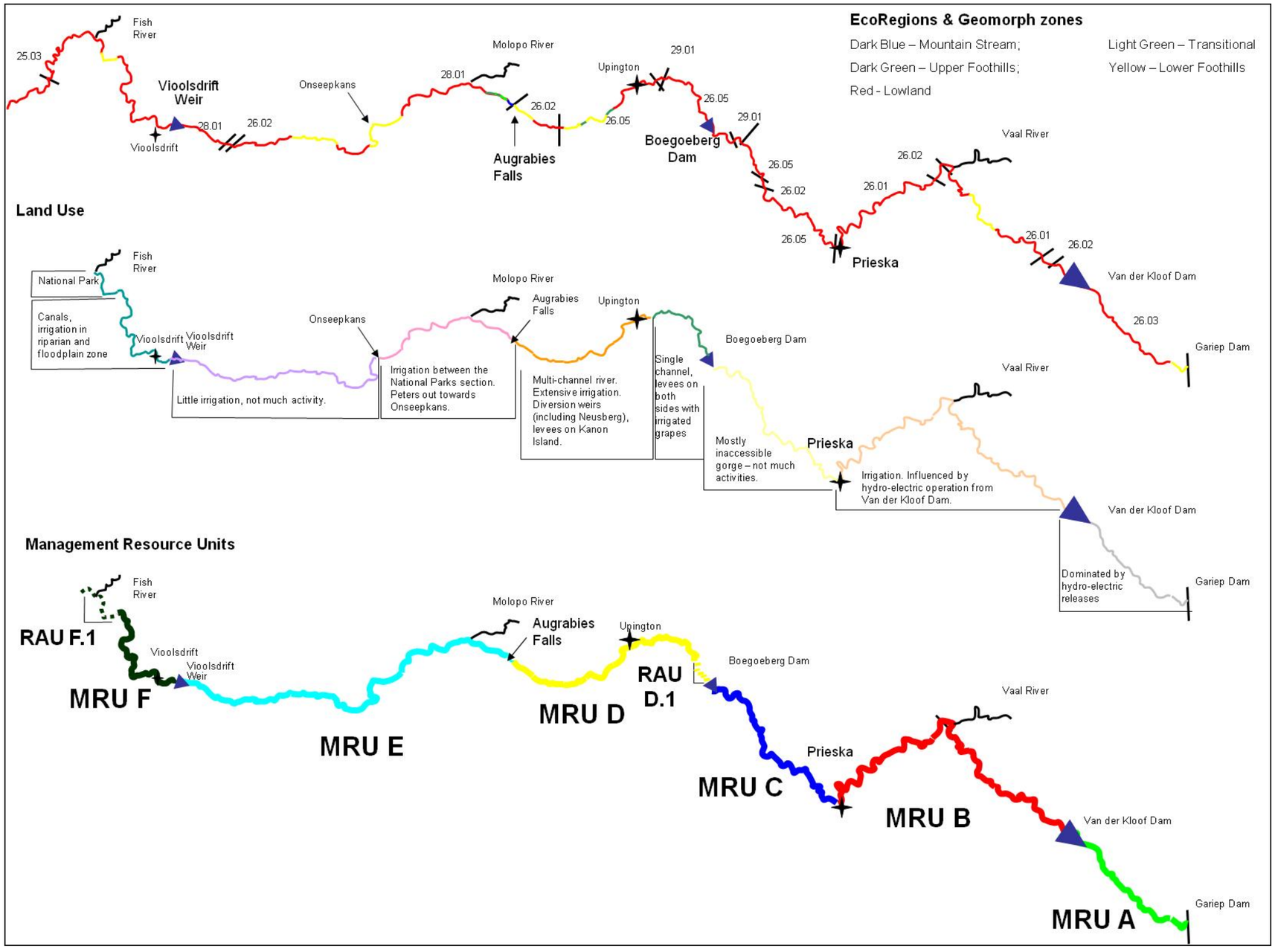

Figure 2: Management Resource Units: Orange River

3 DELINEATION RESULTS: CALEDON RIVER

3.1 Natural Resource Units

The EcoRegions and geozones are described in Figure 3. The Natural Resource Units are derived from these EcoRegions and the geozones. The rationale for the delineation is provided in Table 4

Table 4: Description and rationale for the Caledon River Natural Resource Units

NRU	EcoRegion Level 2	Geozone	Rationale	Delineation
NRU Caledon A	15.03 (100%)	Lowland (7%) Lower Foothills (40%) Upper Foothills (40%) Mountain stream (3%)	The EcoRegion 15.03, as well as the change to Lowland and the inflow of the Little Caledon, makes a logical break at the little Caledon.	Source to Klein Caledon confluence. -28.6172; 28.7047 -28.6946; 28.2340
NRU Caledon B	15.01 (96%) 11.03 (4%)	Lowland (100%)	The next section falls 96% in the 15.01 EcoRegion and 100% in Lowland. The break to the 11.03 EcoRegion where a large stretch falls into that forms the end of NRUB.	Klein Caledon confluence to end of 15.01. -28.6946; 28.2340 -29.5654; 27.2085
NRU Caledon C	11.03 (100%)	Lowland (95%) Lower Foothills (5%)	The 11.03 EcoRegion defines the NRU. Only a very small section of Upper Foothills fall into the NRU.	End of 15.01 to end of 11.03. -29.5654; 27.2085 -29.9637; 26.8758
NRU Caledon D	11.01 (98%) 26.03 (2%)	Lowland (80%) Lower Foothills (20%)	The 11.01 EcoRegion defines the NRU.	End of 11.03 to end 26.03. -29.9637; 26.8758 -30.3754; 26.6552
NRU Caledon E	26.03(98%) 11.01 (2%)	Lowland (100%)	The 26.03 EcoRegion defines the NRU.	End 26.03. -29.9637; 26.8758 -30.5186; 26.0824

3.2 Management Resource Units

The Management Resource Units are illustrated in Figure 4 and Figure 9 while the rationale for selection is provided in Table 5.

Table 5: Description and rationale for the Caledon River Management Resource Units

MRU	EcoRegion Level 2	Geozone	Land cover 500 m both banks	Rationale	Delineation	Quat
MRU Caledon A	15.03 (100%)	Lower Foothills (20%) Upper Foothills (60%) Mountain stream (2%)	RB: Mostly inaccessible which includes the border of Golden Gate. LB: Small inaccessible area and then the typical subsistence farming and erosion associated with Lesotho.	The inaccessible area on the RB defines the MRU. Also falls within one EcoRegion and is therefore ecologically similar.	Source to end of inaccessible area -28.6172; 28.7047. -.28.5519; 28.4050	D21A
MRU Caledon B	15.01 (80%) 11.03 (12%) 15.03 (8%)	Lowland (90%) Lower Foothills (10%)	RB: Upper section indicates more erosion than lower section which consists mostly of dryland farming LB: Subsistence farming, erosion and urban.	The section all falls within one geomorphologicalic zone and with the same land use on the LB. The border of the RU is defined by the change of operation – the pumping of Caledon water into Knelspoort and Welbedacht Dam immediately downstream.	End of inaccessible area to Rietspruit confluence -28.5519; 28.4050 -29.7930; 26.9210	D21A D21C D21H D22C D22D D22F D22H D22L D23A D23E D23F D23J
MRU Caledon C	11.01 (80%) 26.03 (18%) 11.03 (2%)	Lowland (80%) Lower Foothills (20%)	Extensive irrigation on both sides.	The border of the “Tussen-Die-Riviere” forms an operational break between irrigation and natural.	Welbedacht Dam to start of “Tussen-Die-Riviere” Game Reserve -29.9095; 26.8606 -30.4257; 26.3290	D24C D24D D24E D24F D24G D24J
MRU Caledon D	26.03(100%)	Lowland (100%)	Game managed area. Potentially influenced by back-up from Gariep Dam.	Tussen Die Riviere Game Reserve.	Tussen Die Riviere Game Reserve to backup of Gariep Dam -30.4257; 26.3290 -30.5240; 26.065	D24J

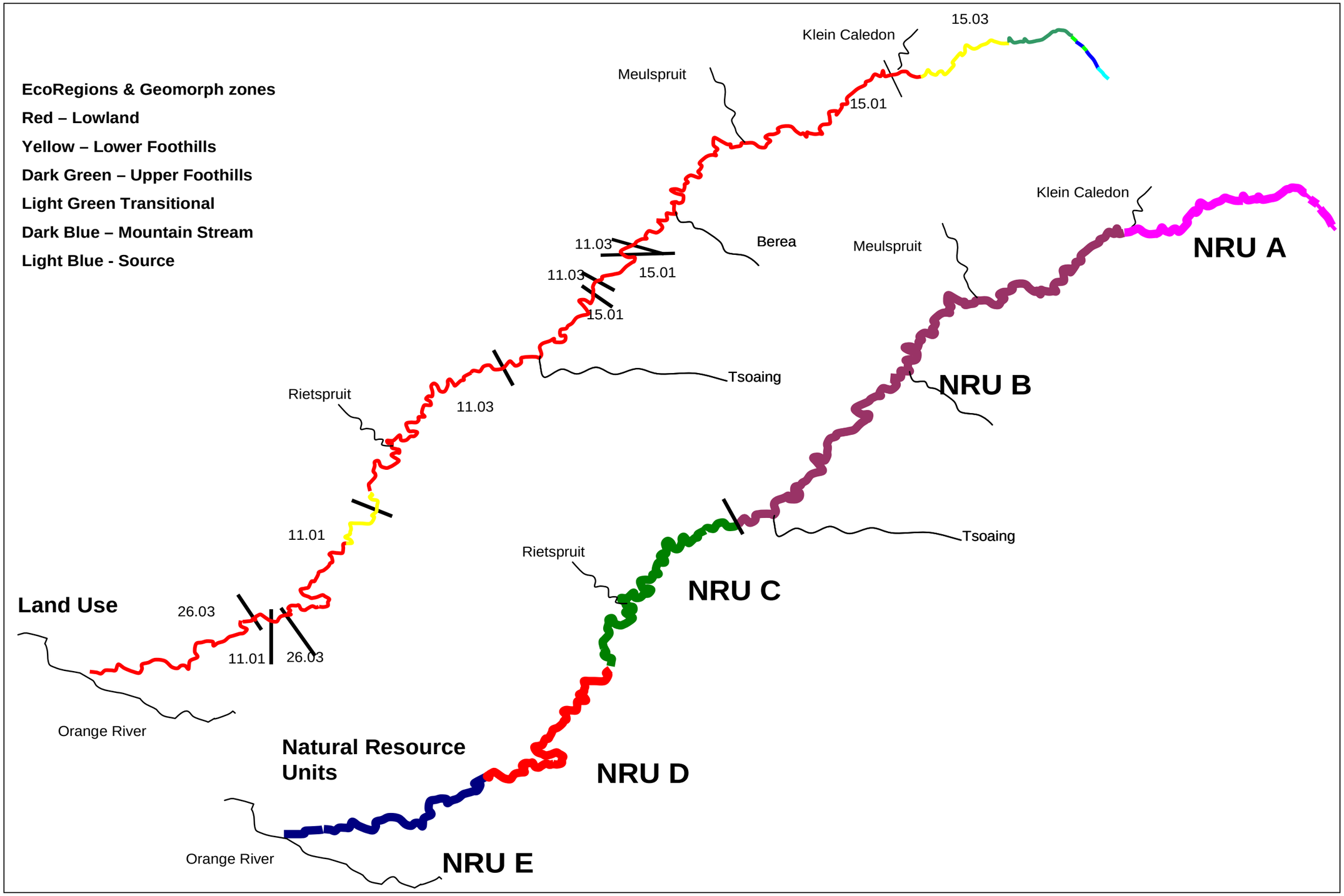

Figure 3: Natural Resource Units: Caledon River

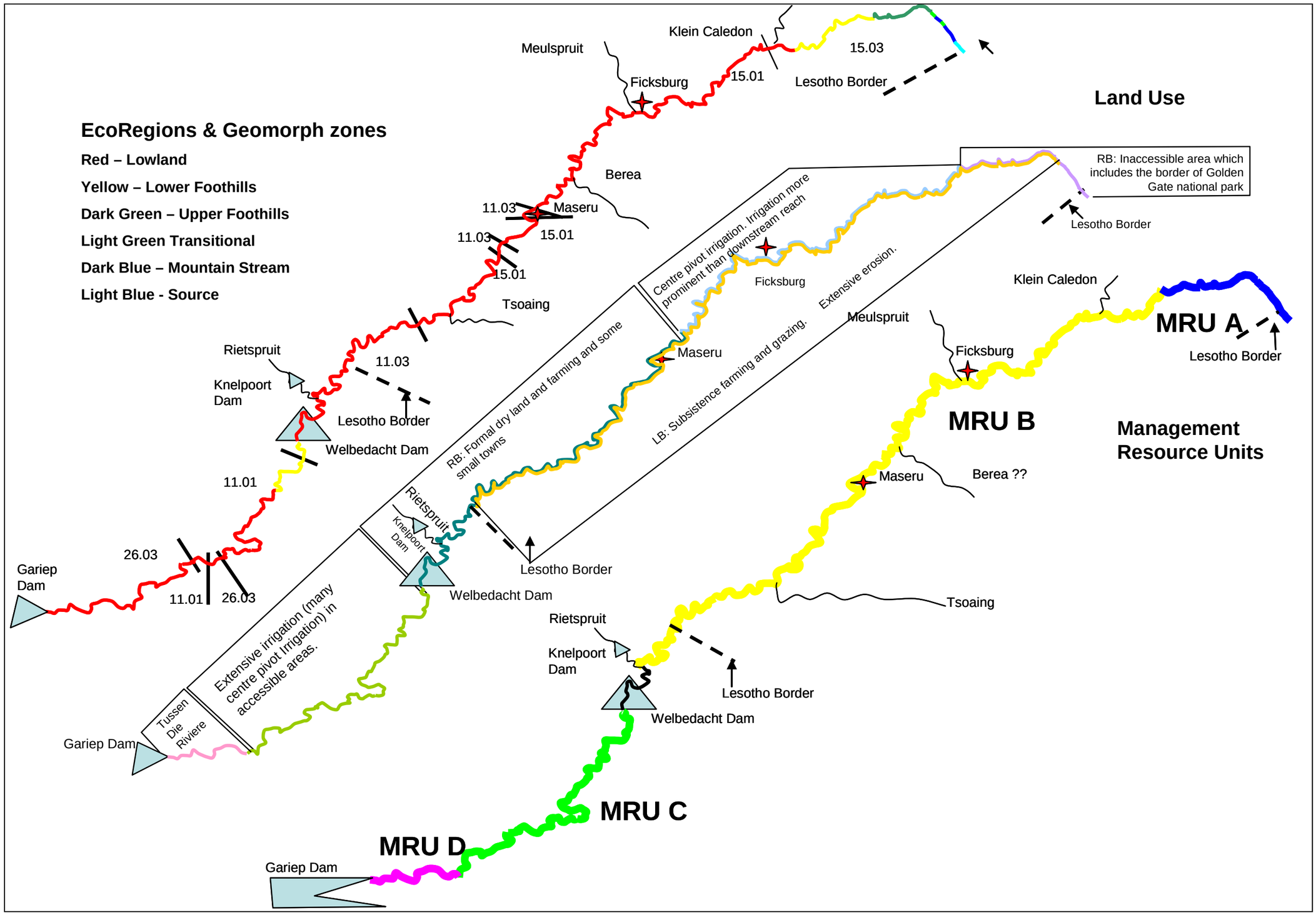

Figure 4: Management Resources Units: Caledon River

4 DELINEATION RESULTS: KRAAI RIVER

4.1 Natural Resource Units

The EcoRegions and geozones are described in the Figure 5. The Natural Resource Units are derived from these EcoRegions and the geozones. The rationale for the delineation is provided in Table 6

Table 6: Description and Rationale for the Natural Resource Units

NRU	EcoRegion Level 2	Geozone	Rationale	Delineation
NRU Kraai A	15.06 (100%)	Lower Foothills (87%) Upper Foothills (8%) Mountain Stream (2%) Lowland (3%)	The EcoRegion 15.06 and the very similar geomorphological zone, describes this long NRU A. The bottom section is defined by the change to Lowland River.	Source to end of Lower Foothills in 15.06 -31.1997; 27.9637 -30.9013; 27.1092
NRU Kraai B	26.03 (60%) 18.04 (35%) 15.06 (5%)	Lowland (100%)	100% Lowland River consisting of two EcoRegions.	End of Lower Foothills in 15.06 to Orange River -30.9013; 27.1092; -30.6648; 26.7503

4.2 Management Resource Units

The Management Resource Units are illustrated in Figure 6 and Figure 9 and the rationale for selection is provided in Table 7.

Table 7: Description and Rationale for Management Resource Units

MRU	EcoRegion Level 2	Geozone	Land cover 500 m both banks	Rationale	Delineation	Quat
MRU Kraai A	15.06 (100%)	Lower Foothills (90%) Upper Foothills (8%) Mountain Stream (2%)	Inaccessible areas mixed with irrigation in floodplain. Small towns and rural areas.	Land use defines the MRU with the Joggemspruit confluence forming a logical end point. One EcoRegion and mostly one geozone.	Source to end of irrigation in floodplain (ds of Joggemspruit)---31.1997; 27.9637 -30.8506; 27.7001	D13C D13E
MRU Kraai B	15.06 (100%)	Lower Foothills (100%)	Mostly inaccessible. Areas where possible, irrigated lands next to the rivers.	Land use defines the MRU and the logical break of a change in land use coincides with the NRU break, i.e, end of 15.06.	End of irrigation in floodplain (ds of Joggemspruit) to end inaccessible area -30.8506; 27.7001 -30.9056; 27.1111	D13E D13F

MRU	EcoRegion Level 2	Geozone	Land cover 500 m both banks	Rationale	Delineation	Quat
MRU Kraai C	26.03 (60%) 18.04 (39%) 15.06 (1%)	Lowland (100%)	Extensive agriculture and irrigation.	The same as the NRU as the same land use, probably due to the change in geozone that will result in the river being more accessible.	End inaccessible area to Orange confluence -30.9056; 27.1111- -30.8506; 27.7001	D13F D13G

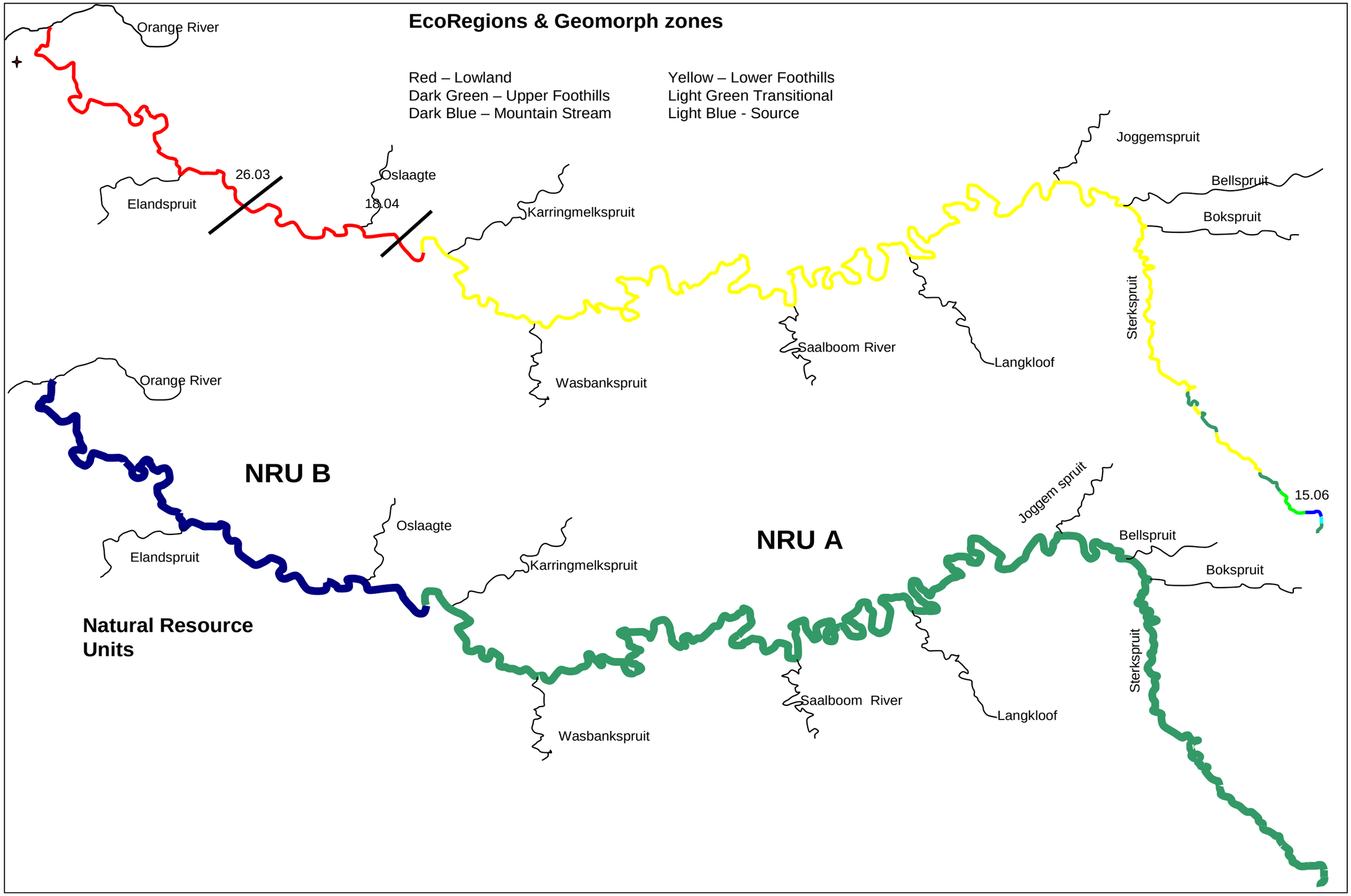

Figure 5: Natural Resource Units: Kraai River

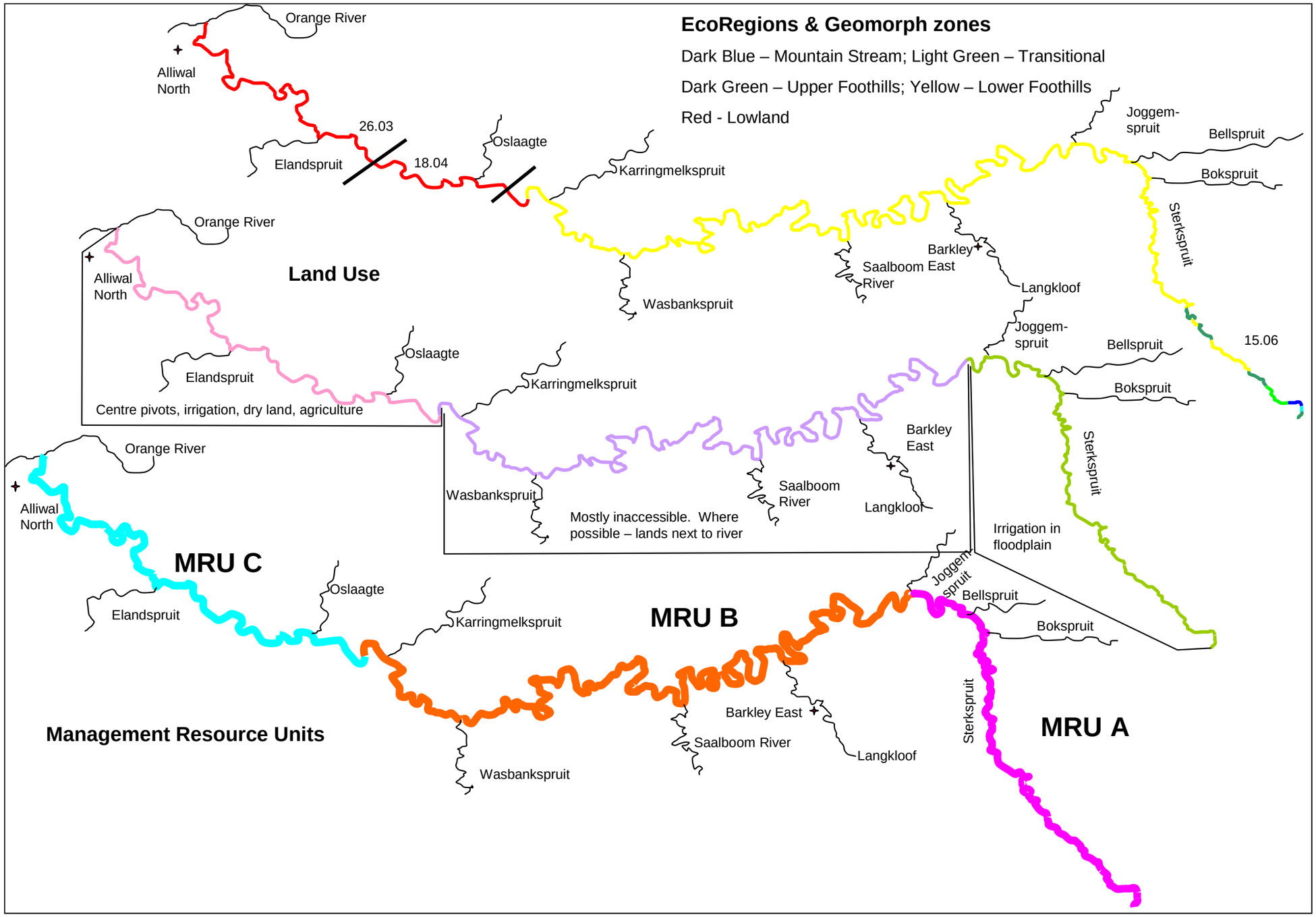

Figure 6: Management Resource Unit: Kraai River

5 DELINEATION RESULTS: UPPER MOLOPO RIVER

5.1 Natural Resource Units

The EcoRegions and geozones are described in Figure 7 and Figure 9. The Natural Resource Units are derived from these EcoRegions and the Geozones and the rationale for the delineation is provided in Table 8.

Table 8: Description and Rationale for Natural Resource Units

NRU	EcoRegion Level 2	Geozone	Rationale	Delineation
NRU UMolopo A	11.01 (100%)	Lower Foothills (100%)	Represents the EcoRegion and includes the Lower Foothill portion.	Source to end of 11.01 -25.8889; 26.0258 -25.8609; 25.9797
NRU UMolopo B	11.01 (90%) 29.01 (10%)	Upper Foothills (70%) Lower Foothills (30%)	Includes all of 11.01 which consists of alternating Upper and Lower Foothills. The logical end was the end of the last section of Upper Foothills which was close to the end of the 11.01 EcoRegion.	End of 11.01 to end of Upper Foothills -25.8609; 25.9797 -25.8737; 25.6139
NRU UMolopo c	29.01 (100%)	Lowland (2%) Lower Foothills (98%)	Rest of the river which consists all of 29.01 and 98% Lowland. End of reach is the confluence with the Ramabatlama River.	End of Upper Foothills to the Ramatlabama River confluence -25.8737; 25.6139 -25.7641; 25.2174

5.2 Management Resource Units

The Management Resource Units are illustrated in Figure 8 and Figure 9 a description of the Management Resource Units and the rationale for selection is provided in

Table 9.

Table 9: Description and Rationale for Management Resource Units

MRU	EcoRegion Level 2	Geozone	Land cover 500m both banks	Rationale	Delineation	Quat
MRU UMolopo A	11.01 (98%) 11.09 (2%)	Lower Foothills (100%)	Mostly wetland, recreation around the eye, farming, old barriers.	Coincides with land use. Represents the wetter portion of the wetland under present conditions.	Source to end wetted wetland section -25.8609; 25.9797 -25.8548; 25.9530	D41A
MRU UMolopo B	11.01 (100%)	Upper Foothills (45%) Lower Foothills (55%)	Intensive farming. Presence of Slurry. Includes gauge where all flows are diverted into two canal systems. Large sections of no flow.	Coincides with land use. Mostly wetland although almost all flow diverted for most of the time.	End wetted wetland section to end of intensive farming US of Mafikeng -25.8548; 25.9530 -25.8558; 25.8638	D41A
MRU UMolopo C	29.01 (100%)	Upper Foothills (100%)	Includes Mafikeng and all its small dams in an area of poor water quality as a result of inadequate sewage works.	Coincides with the land use. Logical endpoint is the Modimola Dam.	End of intensive farming US of Mafikeng to the Modimola Dam -25.8558; 25.8638 -25.8738; 25.5576	D41A
NRU UMolopo D	29.01 (100%)	Lower Foothills (98%)	Large rural areas, overgrazing, trampling, bad water quality and flow mostly consisting of a trickle which is from return flows.	The section between the dams is isolated, has a specific land use and operation, and therefore consists of one MRU.	Modimola Dam wall to the Disaneng Dam -25.8576; 25.5087 -25.8516 ; 25.3785	D41A
NRU UMolopo E	29.01 (100%)	Lower Foothills (90%) Lowland (10%)	Much less activities and settlements. Minimal flow in river.	Land use and all other criteria similar to the Botswana border and the Ramabatlama River confluence.	Disaneng Dam wall to the Ramabatlama River confluence -25.8237; 25.3129 -25.7641; 25.2174	D41A

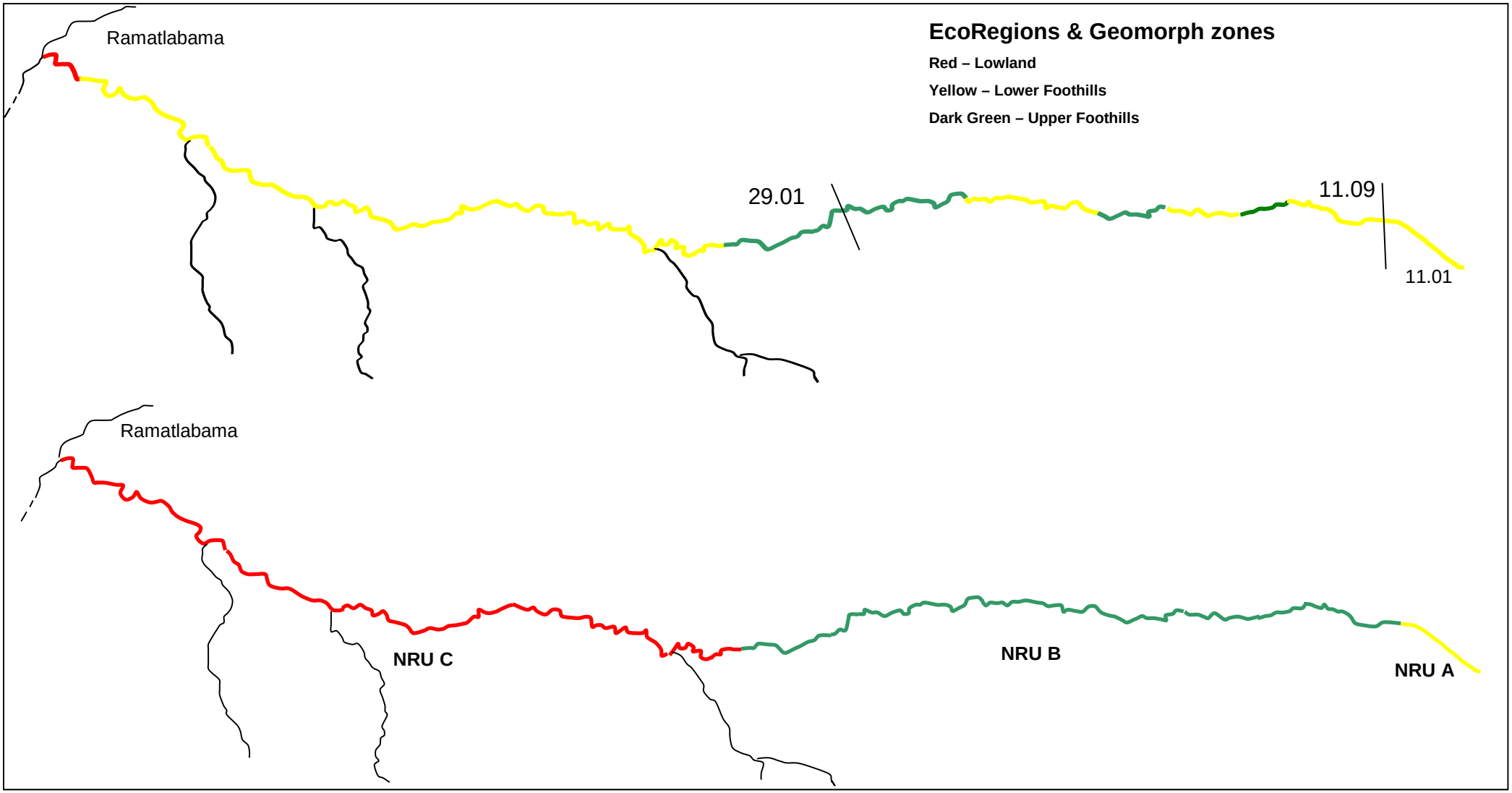

Figure 7: Natural Resource Units: D41A

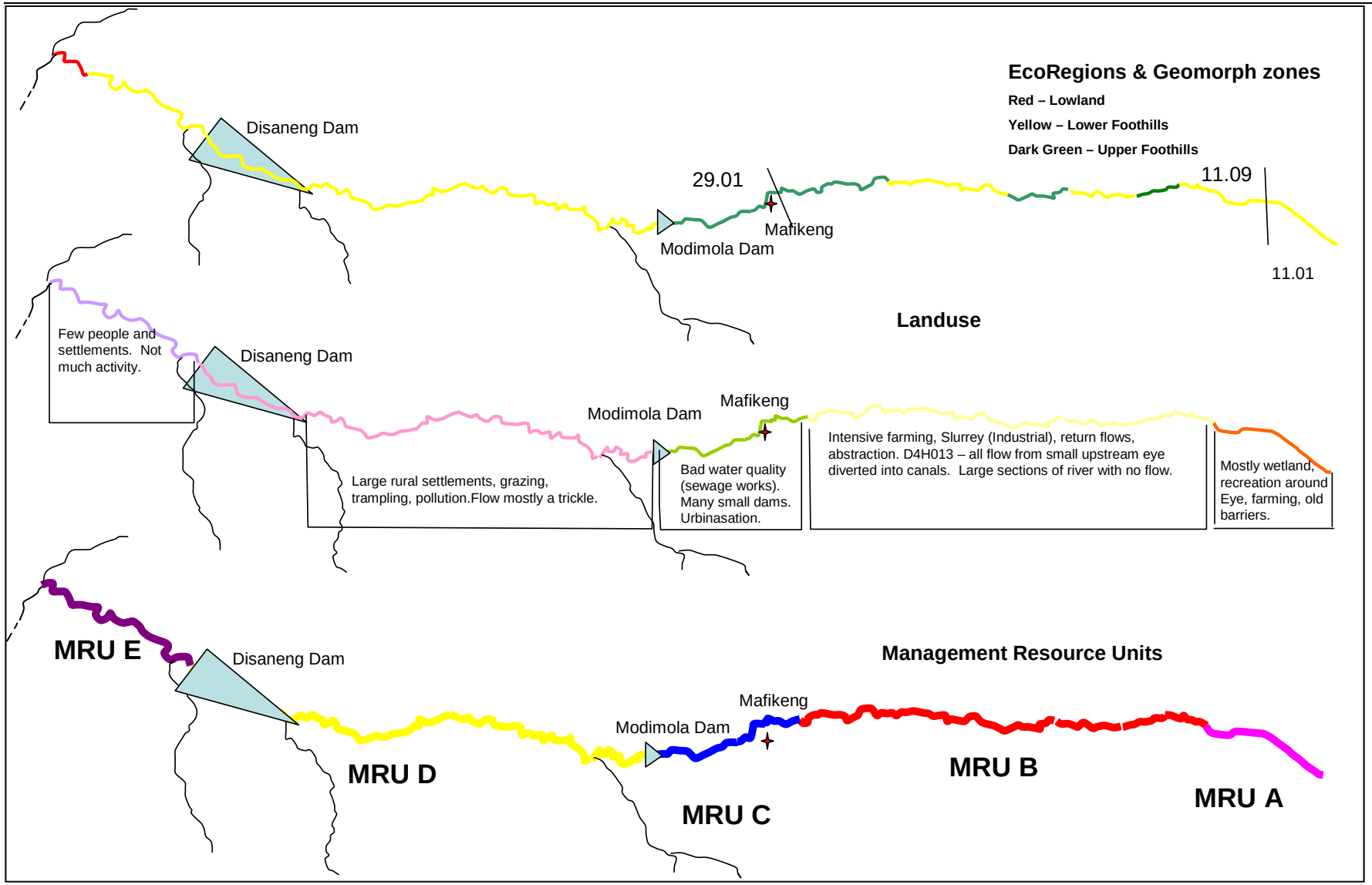

Figure 8: Management Resource Units: D41A

6 ENVIRONMENTAL FLOW REQUIREMENTS SITE SELECTION

6.1 Criteria for Site Selection

Environmental Flow Requirements (EFR) sites (previously called Instream Flow Requirement (IFR) sites but now referred to as Environmental Flow Requirements sites in South Africa) are selected through a multi-disciplinary process. This process consists of evaluating an aerial video (if available) or Google Earth images of the river, to identify a range of possible sites, and then a process of ground truthing (site visits) to make a final selection from the various possibilities. An Environmental Flow Requirements site consists of a length of river, which includes one or more cross-sections for both hydraulic and ecological purposes (modified from Louw *et al*., 1999).

Environmental Flow Requirements sites are then used for determining environmental flow requirements (EFRs) and it is therefore vital that:

- The sites are selected to provide as much information as possible about the variety of conditions in the river reach,
- The specialists that need to use these sites to set flow requirements for their discipline can relate to the habitat represented at the site and
- The persons involved in selecting the sites, understand and have experience in using sites in Environmental Flow Requirements studies.

The selection of Environmental Flow Requirements sites is guided by a number of considerations, including:

- The locality of gauging weirs with good quality hydrological data.
- The locality of the proposed and existing developments.
- The locality and characteristics of tributaries.
- The habitat integrity, or Present Ecological State (PES), of the different river reaches.
- The boundaries of Level II EcoRegions within the study area.
- The reaches where people depend directly on a healthy river ecosystem.
- The suitability of the sites for follow-up monitoring.
- The locality of geomorphologically representative sites.
- The habitat diversity for aquatic organisms, marginal and riparian vegetation.
- The suitability of the sites for accurate hydraulic modelling throughout the range of possible flows, especially low flows.
- Accessibility of the sites.
- An area or site that could be critical for ecosystem functioning. These are often represented by riffle units, where low flow conditions or the cessation of flow constitutes a break in the functioning of the river. Consequently, the biota dependant on this habitat (and/or perennial flow) will be adversely affected by flow modification.

Pools are not considered critical habitats in perennial system, since they are still able to function, or at least maintain life, during periods of no flow.

6.2 Locality and Description of Sites

The locality of the Environmental Flow Requirements sites within the Management Resource Units as identified during this study is provided in Table 10 and Table 11 and in Figure 9.

Table 10: Locality and Characteristics of Environmental Flow Requirements Sites

EFR site number	EFR site name	River	Decimal degrees S	Decimal degrees E	EcoRegion (Level II)	Geozone	Altitude (m)	MRU	Quat	Gauge
EFR O1	Hopetown	Orange	-29.516	24.00927	26.01	Lowland	1060	MRU Orange B	D33G	
EFR O2	Boegoeberg	Orange	-29.0055	22.16225	26.05	Lowland	871	MRU Orange D, RAU D.1	D73C	D7H008
EFR O3	Augrabies	Orange	-28.4287	19.9983	28.01	Lowland		MRU Orange E	D81B	D7H014
EFR O4	Vioolsdrif	Orange	-28.7553	17.71696	28.01	Lowland	167	MRU Orange F	D82F	D8H003 D8H013
EFR C5	Upper Caledon	Caledon	-28.6508	28.3875	15.03	Lower Foothills	1640	MRU Caledon A/B	D21A	
EFR C6	Lower Caledon	Caledon	-30.4523	26.27088	26.03	Lowland	1270	MRU Caledon D	D24J	
EFR K7	Lower Kraai	Kraai	-30.8306	26.92056	26.03	Lowland	1327	MRU Kraai C	D31M	D1H011
EFR M8	Molopo Wetland	Molopo	-25.8812	26.01592	11.01	Lower Foothills	1459	MRU UM C	D41A	D4H030 D4H014

The locality and characteristics of the Environmental Flow Requirements sites are provided in Table 11.

Table 11: Locality, Characteristics and View of Environmental Flow Requirements sites.

Site information	EFR sites	Illustration
EFR nr & name *River* *Previous IFR site* *National RHP site* *Decimal Degrees* *EcoRegion (Level II)* *Geozone* *Altitude (m)* *RU* *Quaternary* *Farm name* *Hydrological gauge*	EFR O1 Hopetown Orange - - -29.51594, 24.00927 26.01 Lowland 1060 MRU Orange B D33G Zuurgat 82 -	
EFR nr & name *River* *Previous IFR site* *National RHP site* *Decimal Degrees* *EcoRegion (Level II)* *Geozone* *Altitude (m)* *RU* *Quaternary* *Farm name* *Hydrological gauge*	EFR O2 Boegoeberg Orange - - -29.0055, 22.16225 26.05 Lowland 871 MRU Orange D, RAU D.1 D73C Blinkfontein 10 D7H008	
EFR nr & name *River* *Previous IFR site* *National RHP site* *Decimal Degrees* *EcoRegion (Level II)* *Geozone* *Altitude (m)* *RU* *Quaternary* *Farm name* *Hydrological gauge*	EFR O3 Augrabies Orange - - -28.42867, 19.9983 28.01 Lowland 434 MRU Orange E D81B Oranjestroom 386 D7H014	

Site information	EFR sites	Illustration
EFR nr & name	EFR O4 Vioolsdrift	
River	Orange	
Previous IFR site	-	
National RHP site	-	
Decimal Degrees	-28.75525, 17.71696	
EcoRegion (Level II)	28.01	
Geozone	Lowland	
Altitude (m)	167	
RU	MRU Orange F	
Quaternary	D82F	
Farm name	-	
Hydrological gauge	D8H013	
EFR nr & name	EFR C5	
River	Caledon	
Previous IFR site	Rapid III	
National RHP site	-	
Decimal Degrees	-28.65078, 28.3875	
EcoRegion (Level II)	15.03	
Geozone	Lower Foothills	
Altitude (m)	1640	
RU	MRU Caledon B	
Quaternary	D21A	
Farm name	Kromdraai 106	
Hydrological gauge	-	
EFR nr & name	EFR C6 Lower Caledon	
River	Caledon	
Previous IFR site	-	
National RHP site	D2Cale_Tusse	
Decimal Degrees	-30.4523, 26.27088	
EcoRegion (Level II)	26.03	
Geozone	Lowland	
Altitude (m)	1270	
RU	MRU CaledonD	
Quaternary	D24J	
Farm name	Inhoek 336	
Hydrological gauge	-	
EFR nr & name	EFR K7 Kraai	
River	Kraai	
Previous IFR site	-	
National RHP site	-	
Decimal Degrees	-30.8306, 26.92056	
EcoRegion (Level II)	26.03	
Geozone	Lowland	
Altitude (m)	1327	
RU	MRU Kraai C	
Quaternary	D31M	
Farm name	Witkoppies 96/2	

Site information	EFR sites	Illustration
Hydrological gauge	D1H011	
EFR nr & name *River* *Previous IFR site* *National RHP site* *Decimal Degrees* *EcoRegion (Level II)* *Geozone* *Altitude (m)* *RU* *Quaternary* *Farm name* *Hydrological gauge*	EFR M8 Molopo Wetland Molopo - - -25.8812, 26.01592 11.01 Lower Foothills 1459 MRU UM C D41A Trekdrift 360.29 D4H030, D4H014	

The location of sites is illustrated in Figure 9.

6.2.1 Site suitability

The site suitability of each site was assessed and is provided in Table 12 and Table 13. The detailed assessment per component is provided in Appendix B to F. The following ratings were used to describe site suitability:

- Very High suitability: 4.1 – 5
- High suitability: 3.1 – 4
- Moderate suitability: 2.1 – 3
- Low suitability: 1.1 – 2
- Very Low suitability: 0 – 1

Table 12: Biophysical Site Suitability for the Orange System

EFR sites	Geomorphological	Riparian veg	Fish	Inverts	Average	Median	Max	Min	Comments
EFR 1	3.7	3.7			3.7	3.7	3.7	3.7	High suitability for EcoClassification from geomorphological and riparian vegetation perspective.
EFR 2	3.0	3.5	3.5	4.2	3.6	3.5	4.2	3	High overall suitability with only geomorphological at top range of moderate.
EFR 3	3.5	3.5	2.8	3.8	3.4	3.5	3.8	2.8	High overall suitability with only fish at top range of moderate. Fish habitat suitability is however very high and that will override the moderate suitability which is due to the (natural) lack of good indicator species.
EFR 4	3.1	3.2	2.8	2.9	3.0	3.0	3.2	2.8	Moderate suitability with geomorphological and riparian vegetation falling just within the high range.
EFR 5	3.0	4.0	2.2	3.0	3.1	3.0	4.0	2.2	High overall suitability. However, only riparian vegetation falls in the top end of high, the other components are in the moderate range.
EFR 6	3.0	3.5	2.5	3.0	3.0	3.0	3.5	2.5	Moderate suitability from all perspectives for setting of EFR requirements.
EFR 7	4.2	2.5	2.8	4.1	3.4	3.5	4.2	2.5	High overall suitability. Geomorphological and invertebrates fall in the very high range.

Table 12 illustrates the site suitability from a biophysical point of view. Any comments regarding outliers are also provided. All sites except EFR4 and EFR 6 were classified as 'highly suitable'. The fish suitability was the lowest for EFR 3, 5 and 6. This is mainly related to the absence of optimal (rheophilic) species for setting flow requirements. The evaluation process will need to be revised in future to address systems where they do not naturally occur.

Hydraulic site suitability is evaluated and this provides a possible indication of the expected confidence in hydraulic modeling. For example, a complex three channel site with a steep rapid will most likely result in low suitability and possibly low confidence in the results of the hydraulic modeling (this is of course ultimately dependent on the range of flow and stage measurements that are obtained to calibrate the hydraulic model with). Furthermore, some sites will have different suitability for low and high flows.

As flow requirements are set separately for low and high flows, the integrated suitability evaluation will be different for low and high flows. Geomorphologicalology and vegetation are usually the most crucial components for setting high flows (floods) while fish and invertebrate generally determine low flows (base flows).

The suitability of the sites is therefore evaluated for both low and high flows and is compared to the corresponding suitability for low and high flow hydraulics. Due to the importance of the hydraulics, the hydraulic site suitability usually overrides the biophysical site suitability.

Table 13: Integrated Site Suitability for the Orange System

	Bio-physical		Hydraulics		Hydraulic comments	Suitability		Comment
EFR SITES	Low flows	High flows	Low flows	High flows		Low flows	High flows	
EFR 2	3.9	3.3	2.0	2.0	**Positive** Reasonably uniform flow conditions => medium flows. Gauging weir for determining discharges at real time. **Negative** Bedrock morphology with rapidly varied flow conditions at low flows. Multiple channels at medium/high-flows. Large and irregular nature of the bed substrate (cobbles, boulders & bedrock). Influence of vegetation on flow resistance at high flows. Non-horizontal water surface across the inundated channel width at low-flows. Possibility of pooled water at the cessation of flow.	**2.0**	**3.3**	Low flow suitability of hydraulics overrides the biophysical high suitability. A long record of daily flows is more important than the hydraulics with the setting of floods. Therefore, in this case, the biophysical rating of moderate represents the overall rating.
EFR 3	3.3	3.5	3.0	4.0	**Positive** Reasonably uniform flow conditions at medium flows and above. Gauge with real time data (Neusberg) although some distance away. **Negative** Large and irregular nature of the bed substrate (cobbles, boulders & bedrock). Possibility of pooled water at the cessation of flow.	**3.0**	**4**	Low flow suitability of hydraulics and biophysical components are similar. A long record of daily flows is more important than the hydraulics with the setting of floods. In this case however, the hydraulics has a high suitability, and a gauge is present. Therefore, the hydraulic rating represents the overall rating.

EFR 4	2.9	3.2	2.0	4.0	**Positive** Reasonably uniform flow conditions at medium flows and above. Location of real time gauging weir for determining discharges. **Negative attributes** Location of site in bedrock morphology with rapidly varied flow conditions at low flows. Large and irregular nature of the bed substrate (cobbles, boulders & bedrock). Non-horizontal water surface across the inundated channel width at low-flows. Possibility of pooled water at the cessation of flow.	**2.0**	**4**	Low flow suitability of hydraulics overrides the biophysical high suitability. A long record of daily flows is more important than the hydraulics with the setting of floods. In this case however, the hydraulics has a high suitability, and a gauge is present. Therefore the hydraulic rating represents the overall rating.
EFR 5	2.6	3.5	2.0	4.0	**Negative** Location of site in bedrock morphology with rapidly varied flow conditions at low and medium flows. Large and irregular nature of the bed substrate (cobbles, boulders & bedrock). Non-horizontal water surface across the inundated channel width at low-flows. Possibility of pooled water at the cessation of flow.	**2.0**	**3.5**	No gauge is present. Therefore the lowest rating between hydraulics and the biophysical components represent the overall rating.
EFR 6	2.8	3.3	2.0	4.0	**Positive** Reasonably uniform flow conditions at medium flows and above. **Negative** Location of site in bedrock morphology with rapidly varied flow conditions at low flows. Large and irregular nature of the bed substrate (cobbles, boulders & bedrock). Non-horizontal water surface across the inundated channel width at low-flows. Possibility of pooled water at the cessation of flow.	**2.0**	**3.3**	No gauge is present. Therefore the lowest rating between hydraulics and the biophysical components represent the overall rating.

EFR 7	3.5	3.4	3.0	4.0	**Positive** Reasonably uniform flow conditions at medium flows and above. Location of real time gauging weir for determining discharges. **Negative** Possibility of divided and two-dimensional flow patterns at low flows. Possibility of non-horizontal water surface across the inundated channel width at low-flows. Possibility of pooled water at the cessation of flow.	**3.0**	**4**	Moderate flow suitability of hydraulics overrides slightly higher biophysical suitability. A long record of daily flows is more important than the hydraulics with the setting of floods. In this case however, the hydraulics has a high suitability and a gauge is present. Therefore the hydraulic rating represents the overall rating.

In conclusion, the overall suitability for low flows ranged from low (2) to moderate (3). This is mainly due to the complexity of the sites in terms of hydraulics. These sites of low suitability (shaded orange in Table 6.4) should however not be problematic, as a logger was installed at these sites to obtain a wide range of calibrations. As no gauge or a logger is present at EFR 5 and 6, it is likely that the hydraulic confidence in the modelling will, ultimately, also be low.

The confidence of high flow Environmental Flow Requirements determination increases proportionately if a gauge, with a long record of daily flows, is relatively close to the site. The presence of a gauge in close proximity to the site outweighs the hydraulic confidence. Apart from the Environmental Flow Requirements sites in the Caledon River (EFR 5 and 6), all the sites are sufficiently close to a gauge and this, combined with the mostly high suitability for the hydraulic suitability, results in a high confidence in the results.

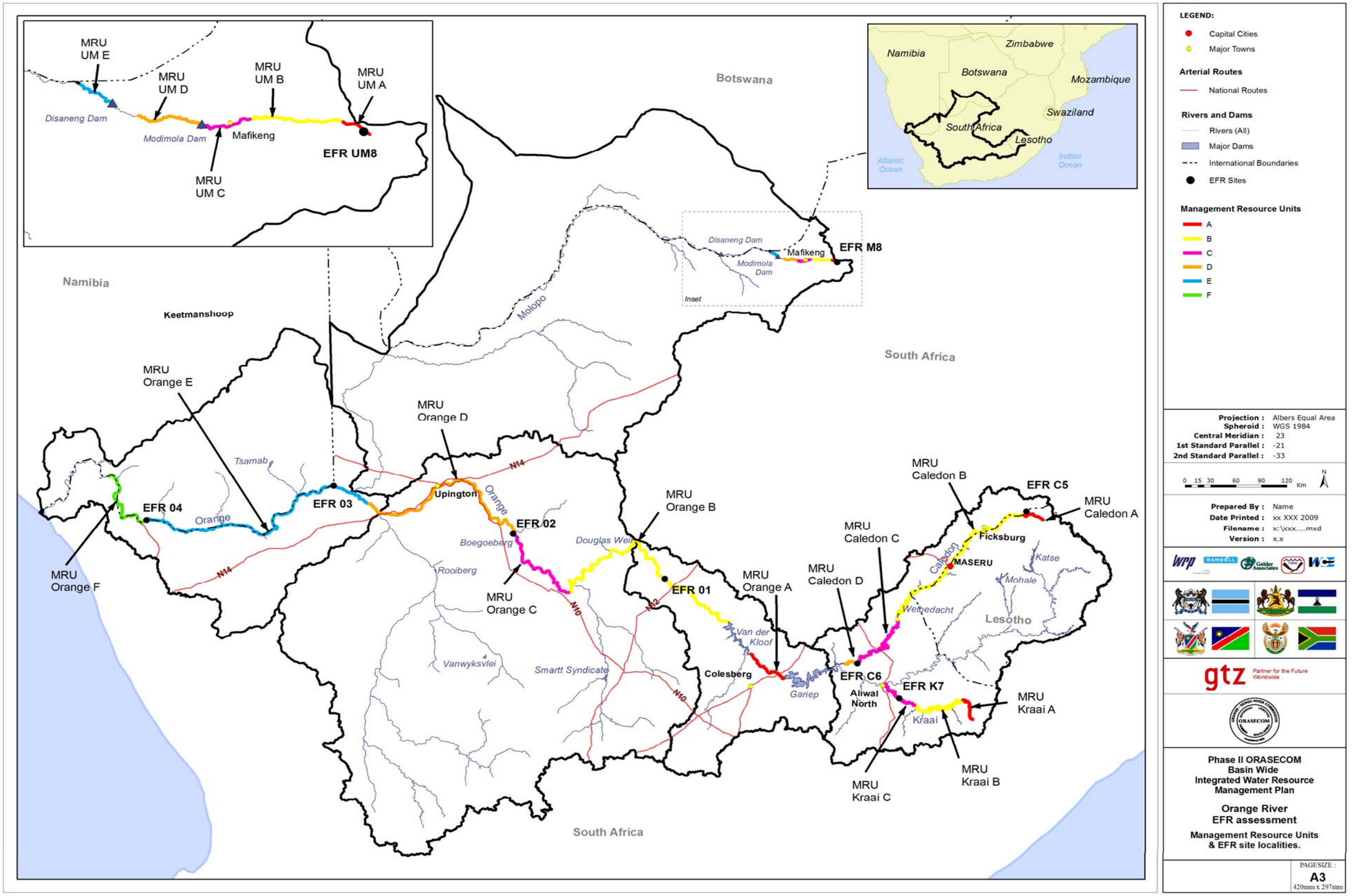

Figure 9: Management Resource Units and Environmental Flow Requirements Sites

7 REFERENCES

AfriDev 2006. Main Report. Komati Catchment Ecological Water Requirements Study.

Department of Water Affairs and Forestry, Pretoria. Report No. RDM X100-00-CONCOMPR2- 1205

Department of Water Affairs and Forestry (1999). *Resource Directed Measures for Protection of Water Resources*. Volume 3: River Ecosystems Version 1.0, Pretoria

Department of Water Affairs and Forestry, South Africa (DWAF). 2004. *Upper Vaal Water Management Area: Internal Strategic Perspective*. Prepared by PDNA, WRP Consulting Engineers (Pty) Ltd, WMB and Kwezi-V3 on behalf of the Directorate: National Water Resource Planning. DWAF Report No P WMA 08/000/00/0304.

Godfrey, L (Ed). 2002. *Ecological Reserve Determination for the Crocodile River Catchment, Inkomati System, Mpumalanga*, Technical Report for the Department of Water Affairs and Forestry, by the Division of Water Environment and Forestry Technology, CSIR, Pretoris. Report No.: ENV-P-C 2001. iii +70pp.

Hay, C.J. (1991) *The distribution of fish in the Fish River, Namibia*: Madoqua 17(2): 211-215.

Hay, C.J. (1993) *The distribution of freshwater fish in Namibia* Unpublished MSc Thesis. Johannesburg: Rand Afrikaans University.

Hill, L. 2004*. Elands Catchment Comprehensive Reserve Determination Study, Mpumalanga Province, Ecological Classification and Ecological Water Requirements (quantity) Workshop Report*, by Contract Report for Sappi-Ngodwana, Submitted to the Department: Water Affairs and Forestry, by the Division of Water Environment and Forestry Technology, CSIR, Pretoria. Report No. ENV-P-C 2004-019.

JLB Smith Institute of Ichthyology (1994) *Conservation of the dolomitic ecosystems in the Western Transvaal, South Africa.* Edited by Skelton E, Ribbink AJ and Twentyman-Jones V. Final Report. Grahamstown, South Africa

Kleynhans, CJ, Thirion, C and Moolman, J. (2005*). A Level I River EcoRegion classification System for South Africa, Lesotho and Swaziland*. Report No. N/0000/00/REQ0104. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria, South Africa.

Kleynhans, CJ, Thirion, C, Moolman, J and Gaulana, L. (2007*). A Level II River Ecoregion classification System for South Africa, Lesotho and Swaziland*. Report No. N/000/00/REQ0XXX. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria, South Africa.

Koekemoer, J.H. (2001) *Fish ecological survey data for the Lower Orange River, 2001*. JH Koekemoer, KAS, PO Box 1100, PARYS, 9585. Surveys conducted for the Ministry of Fisheries and Marine Resources Namibia.

Louw MD, Kemper N and Birkhead AL. (1999). *Procedure for selecting sites in intermediate and comprehensive determination of the ecological reserve (water quantity component).* Appendix 18 in Resource Directed Measures for Protection of Water Resources: River Ecosystems. Published by Department of Water Affairs, South Africa.

Louw, MD and Hughes, DA. (2002). *Resource Directed Measures for Protection of Water Resources: River Ecosystems - Revision of a quantity component* Prepared for the Department of Water Affairs and Forestry, South Africa..

NATIONAL WATER ACT (NWA) (1998). Act No 36 of 1998. Republic of South Africa Government Gazette, Vol 398, No 19182, Government Printer, Pretoria, South Africa. pp. 200.

Noble, RG, Hemens, J. (1978). *Inland water ecosystems in South Africa - a review of research needs*. South African National Scientific Programmes Report No. 34: 150 pp.

Omernik JM (1987) *Ecoregions of the conterminous United States*. Annals of the Association of American Geographers **77** 118-125.

Rountree, KM and Wadeson, RA. (1999). *A hierarchical framework for categorising the geomorphologicalology of river systems*, Water Research Commission Report. Report No. 497/1/99. WRC, Pretoria.

Skelton, P. (1993) *A Complete Guide to the Freshwater Fishes of Southern Africa*. Halfway House, South Africa: Southern Book Publishers.

APPENDIX A. RIVER REACH DEMARCATION, DELINEATION AND SUITABILITY

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September 2007

(THE FOLLOWING IS AN EXACT UNEDITED ABSTRACT FROM KLEYNHANS & LOUW, 2007)

A.1 RATIONALE

This document defines and describes the different units according to which a river should be investigated and studied, for the purpose of ecological reserve determination. The objective is to demarcate and delineate river reaches[1], following a hierarchical approach according to the following considerations:

Broad natural physical reaches that constitute the river from its source downstream. These reaches are the result of the various drivers of the system under reference conditions, *viz*. Hydrology, Geomorphology and Physico-chemical attributes. It follows that the biota responded and adapted to these reference conditions (i.e., the broad and natural habitat template) in a dynamic way, depending on natural climatic variation. The boundaries between different broad natural reaches are not necessarily well defined. However, where marked and rapid changes occur, due to geology (e.g. geomorphology and physico-chemical changes) and hydrology (e.g. large tributaries or a change in climate), these boundaries may be easy to identify.

Smaller natural reaches may be distinguished within these large reaches. Depending on the characteristics of the biological group and taxa considered, the distribution of biota will roughly coincide with the demarcation of the natural reaches. However, depending on the attributes (e.g. preferences and intolerances) of the biota, they may be limited to smaller natural reaches within the broad natural physical reaches. These will result in so-called biological habitat segments (e.g. fish habitat segments, Kleynhans 1999). Depending on the life-history requirements of the biota and the dynamic nature of the ecosystems, the boundaries of the habitat segments can vary temporally and spatially. Some biota may be limited to particular smaller reaches within the broad natural reach. Others may be present throughout the broad natural reach, or across two or more broad natural reaches. This must be considered when defining the reference biological assemblage for a particular river reach.

Changes brought about by anthropogenic activities are superimposed on these natural reaches. These activities may result in a homogenous impact throughout the length of a broad natural reach. Or their impact may be heterogeneous and result in smaller distinguishable sub-reaches. Physical driver changes, as well as biological change agents (e.g. alien biota), may be involved.

[1] For the purpose of this document, “reach” is broadly defined as “a specified segment of a stream’s path” (www.wwnorton.com/college/geo/earth2/glossary/r.htm).

Reference conditions (in terms of natural reaches, drivers and biota) need to be considered when the reserve is determined, as these provide the natural evolutionary setting that indicates the resilience of the system to various forms of modification and stress. However, pragmatic considerations that come into the picture, include anthropogenic changes to the system that are within the medium and long term not likely to change. These changes may include modifications to the system, such as impoundments, agricultural, urbanization and forestry. Such modifications bring about changes in the natural reach characteristics, in terms of the system drivers and biota. They indicate altered reaches that need particular consideration in order to manage them, according to ecological reserve considerations (eco-classification) that encompass, *inter alia,* ecological importance and sensitivity, present ecological state, the recommended category and sustainability. This rationale also enables the setting of resource quality objectives, ecological specifications and monitoring objectives and specifications.

- Following this approach, the subsequent classification of reaches is distinguished in terms of the setting of the ecological reserve, for particular river reaches:
- Natural Resource Units (NRU);
- Management Resource Units (MRU);
- Reserve Assessment Units (RAU); and
- The Ecological Reserve is determined at a specific point in the river, viz. the Ecological Water Requirement Site (EFR Site).

The EFR sites are identified within a system context, where reference conditions are formulated in context of a NRU, according to physical drivers and biota. A hierarchical demarcation process is followed to select and define EFR within this system context. This is described in the following sections and the process is illustrated in Figure A.1 and A.2.

A.2 NATURAL RESOURCE UNIT (NRU)

The guiding principle is, that if the hydrology, geomorphic characteristics (i.e. geozone), physico-chemical attributes and river size remain relatively similar, a NRU can be demarcated.

Two levels can be distinguished:

- Primary NRUs are demarcated according to EcoRegions (including relevant components of an eco-region that may contribute to the demarcation of NRUs) This will determine the broad ecological context (climate, geomorphology, hydrology and the broad physico-chemical profile) within which the river is situated;
- Secondary NRUs can be indicated and, if present, are nested within the Primary NRU and are defined according to a significant change in:
- Geozones (slopes and geological attributes), which will determine the potential presence of certain habitats;
- Hydrology, which may be due to the flow contribution (in volume or seasonality) of tributaries or a change in ground water contribution; and

- Physico-chemical conditions, which may be the result of a change in hydrology or geology. This will result in a specific meso-habitat that is able to influence the presence and abundance of species (e.g. biological habitat segments).

Figure A.1 provides a hypothetical example to illustrate the described delineation. An explanation of the hypothetical delineation in table form (Table A.1) is also provided.

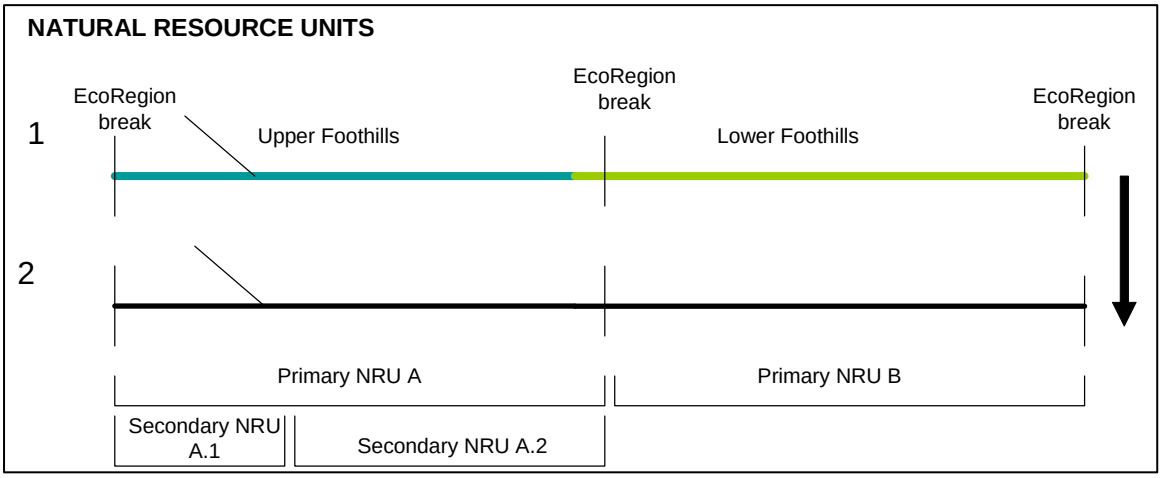

Figure A. 1: **Delineation of National Resource Units**

Table A. 1: Description of the rationale for the delineation of the National Resource Unit for the Figure A.1

UNIT	RATIONALE	DELINEATION
Primary NRU A	EcoRegions main determinant. As most of the EcoRegion also consists of one geozone, this provides additional motivation for the delineation.	Start to end of EcoRegion.
Secondary NRU A.1	The tributary provides sediment (alluvial) and different hydrology. This provides further delineation. The temperature is also different.	Start of EcoRegion to confluence of the tributary.
Secondary NRU A.2	Different hydrology and physico-chemical characteristics from the upstream section.	Confluence of tributary to end of EcoRegion

A.3 MANAGEMENT RESOURCE UNIT (MRU)

The purpose of distinguishing MRUs, is to identify a management unit within which the EFR can be implemented and managed, based on one set of identified flow requirements.

The following provides the concept of Management Resource Units (MRUs):

- MRUs are based on the principle of homogeneity of impacts in the demarcated NRU; This may include the modification of flows in the system due to abstraction, regulation by impoundments and development along the NRU and upstream from the NRU which may influence the geomorphology and physico-chemical conditions.
- This can cause specific changes in the system drivers, which will subdivide the NRU into MRUs.
- Modifications to a river reach, may homogenize adjacent NRUs to the extent that they may constitute a single MRU.

MRUs are homogenous units which are sufficiently different from adjacent areas to warrant a separate EFR assessment being undertaken (Louw & Hughes, 2002). This indicates that an EFR set in the MRU, according to the EFR site selection criteria in context of the MRU, will provide for the whole MRU. Hydrological changes due to incremental runoff must also be taken into account.

The following information is used to demarcate a MRU in relation to the NRU:

- Land cover or land use data;
- Index of Habitat Integrity data (if available); and
- System driver information as obtained from EcoStatus assessments. This may include information on hydrological changes in system operation.

If there are no anthropogenic changes or modifications present along or upstream from a particular NRU, such a NRU will logically constitute a Management Resource Unit (MRU).

A.4 RESERVE ASSESSMENT UNIT (RAU)

The Reserve Assessment Unit (RAU) is situated within an MRU and it is used to demarcate and describe a reach of river within the MRU, with the most critical habitat in the MRU. It has an impact upon the following:

“Critical” refers to habitat being particularly responsive to changes in flow (and the associated physico-chemical and geomorphic conditions) and which can be related to critical phases in the life-cycle of biota.

Additionally, if critical habitats are present in a particular reach, the EFR set to protect such habitat and its associated biota, will also protect less critical habitat (and the associated biota).

If habitat with the same level of "critical" are present over the whole of the MRU (i.e. in all reaches within the MRU), the reach selected as the RAU should, preferably, be the one that is in the best current ecological state.

To provide for an eventual management monitoring context, the RAU can be defined in terms of biological habitat segments, which represent the presence of a homogenous biological assemblage. This is important when reference conditions are formulated.

The demarcation of the RAU is particularly important as it plays a decisive role of where EFR sites should be located.

Figure A.2 provides a hypothetical example to illustrate the described delineation. An explanation of the hypothetical delineation in Table A.2 is also provided. The figure and table show the delineation into MRU, RAUs and also indicate where the EFR site should be situated (the process is described below).

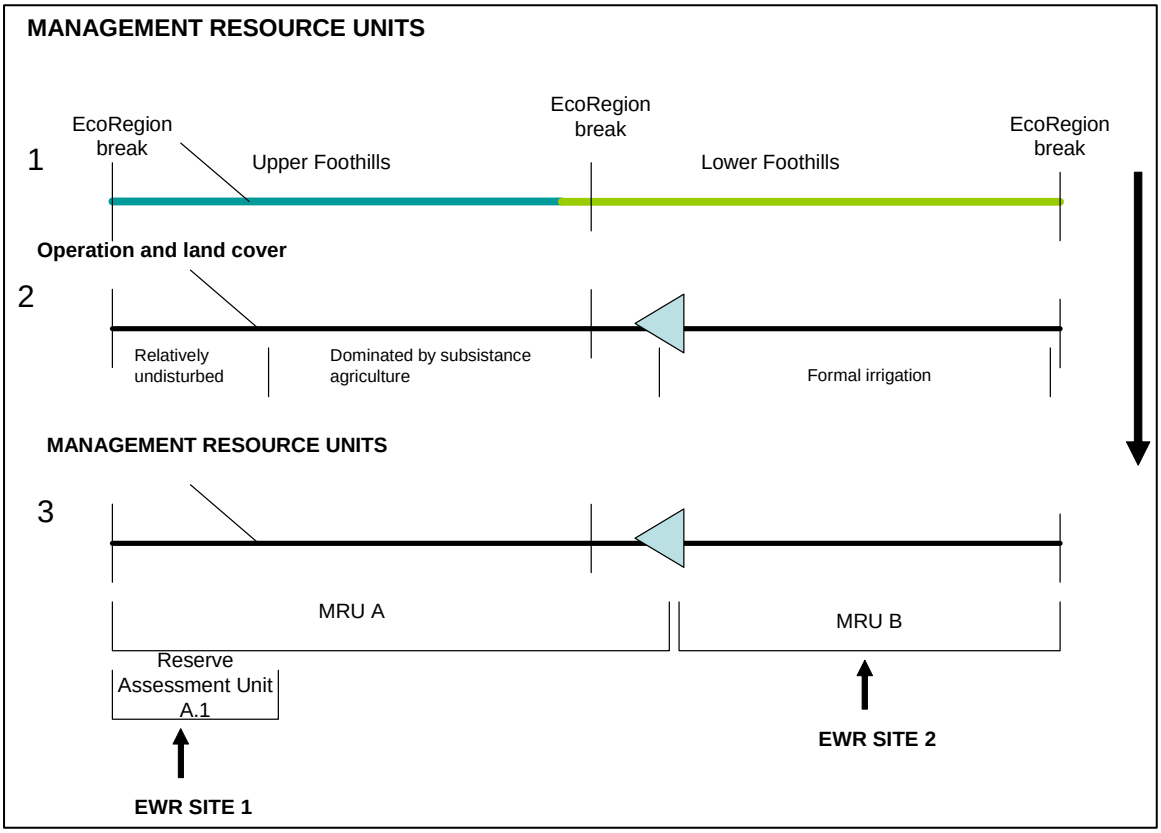

Figure A. 2: Delineation of Management Resource Units

Table A. 2: Description of the rationale for the delineation of the Management Resource Unit for the Figure A.2

UNIT	RATIONALE	DECISION	DELINEATION
MRU A	Consists of mostly one EcoRegion. Consists mostly one Geozone. Land use dominated by subsistence agriculture. Dam provides an operational break.	MRU larger than NRU to include short section to the dam.	Start of EcoRegion to Dam.
RAU A.1	RAU provides critical habitat for species that prefer colder temperatures as the tributary brings in warmer water. As area is isolated, critical vegetation habitat such as marginal and overhanging vegetation present to provide cover. In area downstream from the tributary, this habitat has been removed by grazing and bush clearing.	Assessment of RAU for EcoClassification and EFR assessment important as forms the critical section in the MRU.	Start of EcoRegion to confluence of tributary (coincides with NRU A.1).
Recommendation: RAU A.1: EcoClassification + EFR assessment therefore EFR site if possible to be situated within RAU A.1. MRU A (excluding RAU A.1): EcoClassification			
MRU B	Consists of one EcoRegion. Consists one Geozone. Land use dominated by formal irrigation End of EcoRegion provides logical break.	MRU similar to NRU apart from the short section of NRU B which is above the dam.	Dam wall to end of EcoRegion.
Recommendation: EcoClassification + EFR assessment As no RAU identified within the MRU, the EFR site to be selected anywhere in the MRU. If there are any areas that are potentially in a better state than the rest of the MRU, it is recommended that the EFR be placed within that.			

A.5 ECOLOGICAL WATER REQUIREMENT SITE (EFR SITE)

"Site" refers to "features of a place related to the immediate environment on which the place is located (e.g. terrain, soil, subsurface, geology, groundwater) (www.geographic.org/glossary.html). Linked to this, is the concept of "locality", which refers to the geographic area in which a collecting event occurs (porites.geology.uiowa.edu/entity.htm).

Ecological Water Requirement (EFR) sites are localities in a stream within the descending hierarchy of Primary NRU→Secondary NRU→MRU→RAU→EFR site. An EFR site is therefore a locality, where measurements to determine the ecological water requirements of river, will be undertaken.

The selection of EFR sites should consider the following physical attributes:

- Hydraulic cross section(s) will be established here. The purpose of hydraulic measurements and the consequent modelling, is to provide an interpretive link between flows at different stages and the resulting aquatic habitats at the site. In some cases, a digital terrain model ("habitat model") will be developed to provide a

more accurate and detail perspective of the response of various habitat features, to changes in flow.

- Preferably the EFR site should be representative of the RAU within which it is situated. “Representative” specifically refers to the hydraulics units at the site, which should occur in similar proportions and with similar characteristics, to that which occur at the majority of sites in the RAU. Generally, the more complicated the site is in terms of hydraulic units (e.g. diversity of bed material and multiple channels), the more difficult hydraulic modelling of the site becomes. This can have a detrimental influence on the accuracy of the hydraulic model and thus the prediction of habitat at various discharges. As a result, a compromise is needed between the representativeness of the EFR site and the accuracy of the hydraulics model.
- In addition to an ideal EFR site being representative of the RAU, it should also be sensitive in terms of its response to changes in water level (discharges). This will make the EFR site useful for future monitoring and the confidence in the interpretation of monitoring results.
- The ideal site would therefore be representative, practical and safe to measure and to model reasonably accurately, be accessible and be sensitive to changes in discharge to make it useful for habitat prediction.

Despite the above physical considerations, the following attributes are essential determinants of the suitability of an EFR site for specifying the ecological flow requirements of biota, interpretation and eventually monitoring in terms of fish:

- The presence and abundance of rheophilics. If this group is present and abundant enough to make them useful in terms of monitoring, they would be the ideal subject to use for determining flow requirements as they are sensitive to a cessation of flow (usually fast flow) during all life-stages. If *large*[2] (about >20 cm in length) *rheophilics* are sufficiently present and abundant, they would usually be preferable to *small rheophilics* due to the larger amount of flowing habitat required which would indicate higher discharges. In cases where *small rheophilics* and *large semi-rheophilics* occur, there may be a need for rheophilics during the dry season, but an alternative need for *large semi-rheophilics* during the periods in the wet season when they breed.
- The presence of *semi-rheophilics*. If *rheophilics* are absent, semi-rheophilics should be used as the subjects to determine flow requirements. *Semi-rheophilics* require flowing water (usually fast) during the breeding season. However, flowing water does not necessarily have to be present during the whole duration of the wet season. Duration of flow for *rheophilics* during the wet season will be determined by the length of time required for successful spawning, hatching and growth of larvae to juveniles. The size of the *semi-rheophilics* considered is also important, as it will have an influence on the dimensions of the habitat requirements.

[2] Size of any of the groups do not necessarily refer to a particular species: Different life-stages of the same species may, for example, be classified as large or small. In some case the adults *semi-rheophilics* may vary in size with the smaller adults also occurring in smaller streams.

- The presence of *limnophilics*. If *rheophilics* and *semi-rheophilics* are absent, the requirements of *limnophilics* can be considered. This group does not require flowing water during any stage of their life-cycle. However, they do respond positively to improved habitat conditions (e.g. cover and feeding areas) caused by increased flows. In particular circumstances, the requirements of some *limnophilics* need to be considered, where a drop in the water level in pools may result in a loss for example, of overhanging vegetation which may form an essential cover feature for some species to survive.

The following Tables provide a simple framework to interpret the suitability of a site, in terms of the habitats available, velocity-depth fish guilds present and their size at the site, compared to the RAU[3]:

Table A. 3: **Comparison of velocity-depth ratings for RAU and the EFR site**

	FISH VELOCITY-DEPTH CLASSES (Abundance: 0=absent; 1=rare; 2=sparse; 3=moderate; 4=abundant; 5=very abundant) (SD=slow deep; SS=slow shallow; FD=fast deep; FS=fast shallow)			
	SD	SS	FD	FS
RAU				
SITE				
BRAY -CURTIS SIMILARITY				

Table A. 4: Comparison of cover ratings for RAU and the EFR site

	COVER (Abundance: 0=absent; 1=rare; 2=sparse; 3=moderate; 4=abundant; 5=very abundant)											
	SD			SS			FD			FS		
	SITE	RAU		SITE	RAU		SITE	RAU		SITE	RAU	
UB			UB			UB			UB			
OV			OV			OV			OV			
SUB			SUB			SUB			SUB			
AM			AM			AM			AM			
WC			WC			WC			WC			
BRAY - CURTIS SIMILARITY			BRAY - CURTIS SIMILARITY			BRAY - CURTIS SIMILARITY			BRAY - CURTIS SIMILARITY			

Notes: UB=undercut banks and rootwads; OV=overhanging vegetation; SUB=substrate; AM=aquatic macrophytes; WC=water column)

[3] Where appropriate the similarity between a RAU and the potential site is determined by the Bray-Curtis index, where similarity of 1 indicates complete similarity and 0 no similarity. The categorization of similarities is according to the following: 0=None;0.1-0.20=Very low; 0.20-0.40=Low;0.40-0.60=Moderate;0.60-0.80=High; 0.80-1.0=Very high

Table A. 5: Comparison between sizes of various velocity-depth guilds at an EFR site.

	VELOCITY-DEPTH GUILDS (Indicate number for flow guild per size)							
	SD		SS		FD		FS	
	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL
RHEOPHILICS								
SEMI-RHEOPHILICS								
LIMNOPHILICS								

Notes: Large>20 cm; Small <20 cm

Table A. 6: **Relative abundance of different flow guilds in RAU and at EFR sites**

	RELATIVE ABUNDANCE	
	RAU	SITE
RHEOPHILICS		
SEMI-RHEO		
LIMNOPHILICS		
BRAY -CURTIS SIMILARITY		

Notes: (Abundance: 0=absent; 1=rare; 2=sparse; 3=moderate; 4=abundant; 5=very abundant)

At this stage: the information summarized above should be used to provide a considered and informed decision, as to the suitability of the EFR site for the interpretation of environmental flow requirements of fish, compared to the RAU. This should be ranked according to:

- 0: Not suitable
- 1.0-2.0: very low suitability
- 2.0-3.0: Moderate suitability
- 3.0-4.0: High suitability
- 4.0-5.0: Very high suitability

This suitability rating should be considered in conjunction with suitability ratings for other biota, as well as the hydraulic suitability to provide an overall suitability rating.

APPENDIX B.

GEOMORPHOLOGICAL SITE SUITABILITY

Table B.1: Geomorphological Suitability

EFR site	River	Geomorphological site suitability (/5)
1	Orange	3.7
2	Orange	3.0
3	Orange	3.5
4	Orange	3.1
5	Caledon	3.0
6	Caledon	3.0
7	Kraai	4.2
8	Molopo	4 (below dam) 1 (within the dam).

The Molopo EFR site is a wetland and was not evaluated using the Geomorphological Site Suitability tool, as was done for the other EFR sites. The site which passes through the unchanneled valley bottom wetland (below the dam) is morphologically representative of the reach. It is likely that the vegetation and soil cues located here will provide good estimates of the EFR requirements. The cross-section located within the dam site is unsuitable for wetland EFR determination and is akin to setting flows for a river, based on a cross-section through a dam. The cues from this site would only be able to inform the required level of the dam for the (now artificial) vegetation zonation and fish which have established there.

This table provides an assessment of the suitability of the site for EFR determination studies					Notes
	5	SCORES: 2	1	SCORE	
Representivity of the site for the reach				3.8	
How well does the *morphology* of the site represent that of the reach?	Very well	Don't know	Poorly	4.0	*Morphology of the site is generally consistent with the reach; but the condition (especially of the banks and riparian vegetation) is in far better condition.*
To what extent is the *condition* of the site representative of the general condition of the reach?	Representative	Don't know	Very different	3.5	
Morphological Cues				3.5	*Gross morphology is bedrock controlled, but the bed is primarily composed of mobile cobbles, gravels and sands. The site is within a relatively narrow gorge/valley. There are good cues, although no EFR determination is being undertaken at this site.*
Is the site a bedrock or alluvial dominated section?	Alluvial	Mixed	Bedrock	3.0	
Are there good morphological clues that can be related to flood levels?	Very good	Don't know	Bad	4.0	
If these are present, are the terraces paired?	Yes	Don't know	No	3.5	
Sediment Transport Modelling				4.0	*Site is bedload dominated, and PBMT could be undertaken if an EFR determination was desired.*
Is the river a bedload dominated system (i.e. is potential bed material transport modelling suitable)?	Yes	Don't know	No	4.0	
Is potential bed material transport modelling going to be undertaken at this site?	Yes	Don't know	No	4.0	
OVERALL SCORE:				3.7	

Site Name:	ORANGE RIVER
Site number:	EFR 1
Date of assessment:	2nd June 2010
Name of assessor:	Mark Rountree

This provides an assessment of the suitability of the site for EFR determination studies					Notes
	5	SCORES: 2	1	SCORE	
Representivity of the site for the reach				4.0	
How well does the *morphology* of the site represent that of the reach?	Very well	Don't know	Poorly	4.0	*Morphology and condition of the site is generally consistent with the reach.*
To what extent is the *condition* of the site representative of the general condition of the reach?	Representative	Don't know	Very different	4.0	
Morphological Cues				2.2	
Is the site a bedrock or alluvial dominated section?	Alluvial	Mixed	Bedrock	2.0	*Gross morphology is bedrock controlled, but the bed is mixed with bedrock, mobile cobbles, gravels and sands. Morphological cues are very poor.*
Are there good morphological clues that can be related to flood levels?	Very good	Don't know	Bad	2.0	
If these are present, are the terraces paired?	Yes	Don't know	No	2.5	
Sediment Transport Modelling				3.7	
Is the river a bedload dominated system (i.e. is potential bed material transport modelling suitable)?	Yes	Don't know	No	4.0	*Site is characterised by bedload transport, and PBMT is to be undertaken, if an EFR determination was desired.*
Is potential bed material transport modelling going to be undertaken at this site?	Yes	Don't know	No	3.5	
OVERALL SCORE:				3.0	

Site Name:	ORANGE RIVER
Site number:	EFR 2
Date of assessment:	31st May 2010
Name of assessor:	Mark Rountree

Representivity of the site for the reach				4.0	
How well does the *morphology* of the site represent that of the reach?	Very well	Don't know	Poorly	4.0	*Morphology and condition of the site is generally consistent with the reach.*
To what extent is the *condition* of the site representative of the general condition of the reach?	Representative	Don't know	Very different	4.0	
Morphological Cues				3.0	
Is the site a bedrock or alluvial dominated section?	Alluvial	Mixed	Bedrock	4.0	*Although some bedrock, gross is alluvial with cobbles, gravels and sands. Morphological cues are very poor.*
Are there good morphological clues that can be related to flood levels?	Very good	Don't know	Bad	2.5	
If these are present, are the terraces paired?	Yes	Don't know	No	2.5	
Sediment Transport Modelling				4.0	
Is the river a bedload dominated system (i.e. is potential bed material transport modelling suitable)?	Yes	Don't know	No	4.0	*Site is characterised by bedload transport, and PBMT is to be undertaken if an EFR determination was desired.*
Is potential bed material transport modelling going to be undertaken at this site?	Yes	Don't know	No	4.0	
OVERALL SCORE:				3.5	

Site Name:	ORANGE RIVER
Site number:	EFR 3
Date of assessment:	29th May 2010
Name of assessor:	Mark Rountree

This provides an assessment of the suitability of the site for EFR determination studies					Notes
	5	SCORES: 2	1	SCORE	
Representivity of the site for the reach				3.8	
How well does the *morphology* of the site represent that of the reach?	Very well	Don't know	Poorly	3.5	*Morphology and condition of the site are generally consistent with the reach.*
To what extent is the *condition* of the site representative of the general condition of the reach?	Representative	Don't know	Very different	4.0	
Morphological Cues				2.3	*There is some bedrock exposed at the site, but angular boulders, cobbles and sands are present. Morphological cues are limited and the one bank has been disturbed by engineering (canal construction) and any cues have been lost here.*
Is the site a bedrock or alluvial dominated section?	Alluvial	Mixed	Bedrock	3.0	
Are there good morphological clues that can be related to flood levels?	Very good	Don't know	Bad	2.0	
If these are present, are the terraces paired?	Yes	Don't know	No	2.0	
Sediment Transport Modelling				4.0	*Site is characterised by bedload transport, and PBMT is to be undertaken, if an EFR determination was desired.*
Is the river a bedload dominated system (i.e. is potential bed material transport modelling suitable)?	Yes	Don't know	No	4.0	
Is potential bed material transport modelling going to be undertaken at this site?	Yes	Don't know	No	4.0	
OVERALL SCORE:				3.1	

Site Name:	ORANGE RIVER
Site number:	EFR 4
Date of assessment:	26th May 2010
Name of assessor:	Mark Rountree

This provides an assessment of the suitability of the site for EFR determination studies					Notes
	5	SCORES: 2	1	SCORE	
Representivity of the site for the reach				2.0	
How well does the *morphology* of the site represent that of the reach?	Very well	Don't know	Poorly	4.0	*The morphology and condition of the site generally represent the reach.*
To what extent is the *condition* of the site representative of the general condition of the reach?	Representative	Don't know	Very different		
Morphological Cues				3.2	*The site is alluvial, although some bedrock is exposed on the lower bank. Morphological cues are extremely poor - the morphology of the site is dominated by the deposition of sediment slugs and does not relate to long term flood patterns.*
Is the site a bedrock or alluvial dominated section?	Alluvial	Mixed	Bedrock	4.5	
Are there good morphological clues that can be related to flood levels?	Very good	Don't know	Bad	2.0	
If these are present, are the terraces paired?	Yes	Don't know	No	3.0	
Sediment Transport Modelling				3.8	*The site is largely bedload dominated,, but expect that suspended load is high in the wet season.*
Is the river a bedload dominated system (i.e. is potential bed material transport modelling suitable)?	Yes	Don't know	No	3.5	
Is potential bed material transport modelling going to be undertaken at this site?	Yes	Don't know	No	4.0	
OVERALL SCORE:				3.0	

Site Name:	Caledon River
Site number:	EFR C5
Date of assessment:	22nd June 2010
Name of assessor:	Mark Rountree

This provides an assessment of the suitability of the site for EFR determination studies					Notes
	5	SCORES: 2	1	SCORE	
Representivity of the site for the reach				3.3	*The morphology of the site is generally representative of the reach, although such large bedrock riffles are not common. The condition of the site is probably slightly better than the reach due to location within nature reserve.*
How well does the *morphology* of the site represent that of the reach?	Very well	Don't know	Poorly	3.0	
To what extent is the *condition* of the site representative of the general condition of the reach?	Representative	Don't know	Very different	3.5	
Morphological Cues				2.7	*The site is mix of bedrock and alluvium. Morphological cues are poorly defined - this site is possibly within the backup of the dam and thus cues are masked by extensive silt drapes/deposits. Paired terraces exist high up the banks, but lower "terraces" are related to single flow events and do not reflect long term flooding patterns.*
Is the site a bedrock or alluvial dominated section?	Alluvial	Mixed	Bedrock	3.5	
Are there good morphological clues that can be related to flood levels?	Very good	Don't know	Bad	2.0	
If these are present, are the terraces paired?	Yes	Don't know	No	2.5	
Sediment Transport Modelling				3.5	*Site is dominated by bedload and suspended load. PBMT modelling will be undertaken.*
Is the river a bedload dominated system (i.e. is potential bed material transport modelling suitable)?	Yes	Don't know	No	2.5	
Is potential bed material transport modelling going to be undertaken at this site?	Yes	Don't know	No	4.0	
OVERALL SCORE:				3.0	

Site Name:	Caledon River
Site number:	EFR C6
Date of assessment:	23rd June 2010
Name of assessor:	Mark Rountree

This provides an assessment of the suitability of the site for EFR determination studies					Notes
	5	SCORES: 2	1	SCORE	
Representivity of the site for the reach				4.5	
How well does the *morphology* of the site represent that of the reach?	Very well	Don't know	Poorly	4.5	*Morphology and condition of the site appear to represent the reach very accurately.*
To what extent is the *condition* of the site representative of the general condition of the reach?	Representative	Don't know	Very different	4.5	
Morphological Cues				3.7	
Is the site a bedrock or alluvial dominated section?	Alluvial	Mixed	Bedrock	4.0	*Upper terrace appears to be paired. The site is alluvial, but many of the lower benches and terraces have been scoured away as a result of recent very large floods.*
Are there good morphological clues that can be related to flood levels?	Very good	Don't know	Bad	3.5	
If these are present, are the terraces paired?	Yes	Don't know	No	3.5	
Sediment Transport Modelling				5.0	
Is the river a bedload dominated system (i.e. is potential bed material transport modelling suitable)?	Yes	Don't know	No	5.0	*River is bedload dominated (predominantly cobbles and sands). PBMT will be undertaken for this site.*
Is potential bed material transport modelling going to be undertaken at this site?	Yes	Don't know	No	5.0	
OVERALL SCORE:				4.2	

Site Name:	Kraai River
Site number:	EFR K7
Date of assessment:	24th June 2010
Name of assesor:	Mark Rountree

APPENDIX C. AQUATIC INVERTEBRATES SITE SUITABILITY

Key

Rating (0-5)	Description
>4.0	Very Good
>3.5	Good
>3.0	Moderate
>2.5	Poor
<2.5	Very Poor

Key

Suitability (%)	Description
>80	Very Good
>70	Good
>60	Moderate
>50	Poor
<50	Very Poor

Site: EFR O2 - Boegoeberg			
Site Suitability: Aquatic Invertebrates	Weight	Rating of Site	Weighted Rating
BIOTOPE	(0-10)	(0-5)	
Stones In Current (SIC)	9	4	0.8
Stones Out Of Current (SOOC)	6	4	0.5
Bedrock	1	4	0.1
Aquatic Veg	1	0	-
MargVeg In Current	6	4	0.5
MargVeg Out Of Current	5	5	0.6
Gravel	4	4	0.4
Sand	2	4	0.2
Mud	1	4	0.1
Terraces and bars	10	5	1.1
Overall Suitability (%)	45	85%	
Category		Very Good	

Site: EFR 03 - Blouputs			
Site Suitability: Aquatic Invertebrates	Weight	Rating of Site	Weighted Rating
BIOTOPE	(0-10)	(0-5)	
Stones In Current (SIC)	9	4	0.8
Stones Out Of Current (SOOC)	6	4	0.5
Bedrock	1	0	-
Aquatic Veg	1	4	0.1
MargVeg In Current	6	4	0.5
MargVeg Out Of Current	5	4	0.4
Gravel	4	3	0.3
Sand	2	3	0.1
Mud	1	3	0.1
Terraces and bars	10	4	0.9
Overall Suitability (%)	45	75%	
Category		Good	3.8
Site: EFR O4 - Vioolsdrift			
Site Suitability: Aquatic Invertebrates	Weight	Rating of Site	Weighted Rating
BIOTOPE	(0-10)	(0-5)	
Stones In Current (SIC)	9	3	0.6
Stones Out Of Current (SOOC)	6	2	0.3
Bedrock	1	4	0.1
Aquatic Veg	1	0	-
MargVeg In Current	6	3	0.4
MargVeg Out Of Current	5	3	0.3
Gravel	4	4	0.4
Sand	2	4	0.2
Mud	1	2	0.0
Terraces and bars	10	3	0.7
Overall Suitability (%)	45	59%	
Category		Poor	2.9

Site C5: Caledon Upper			
Site Suitability: Aquatic Invertebrates	Weight	Rating of Site	Weighted Rating
BIOTOPE	(0-10)	(0-5)	
Stones In Current (SIC)	9	4	0.7
Stones Out Of Current (SOOC)	6	2	0.2
Bedrock	3	5	0.3
Aquatic Veg	0	0	-
MargVeg In Current	6	1	0.1
MargVeg Out Of Current	5	3	0.3
Gravel	6	3	0.4
Sand	4	4	0.3
Mud	1	4	0.1
Terraces and bars	10	3	0.6
Overall Suitability (%)	50	61%	
Category		Moderate	3.0

Site C6: Caledon Lower			
Site Suitability: Aquatic Invertebrates	Weight	Rating of Site	Weighted Rating
BIOTOPE	(0-10)	(0-5)	
Stones In Current (SIC)	9	4	0.8
Stones Out Of Current (SOOC)	6	3	0.4
Bedrock	1	4	0.1
Aquatic Veg	0	0	-
MargVeg In Current	6	2	0.3
MargVeg Out Of Current	5	1	0.1
Gravel	4	3	0.3
Sand	2	3	0.1
Mud	1	1	0.0
Terraces and bars	10	4	0.9
Overall Suitability (%)	44	61%	
Category		Moderate	3.0

Site 7: Kraai			
Site Suitability: Aquatic Invertebrates	Weight	Rating of Site	Weighted Rating
BIOTOPE	(0-10)	(0-5)	
Stones In Current (SIC)	9	4	0.8
Stones Out Of Current (SOOC)	6	5	0.7
Bedrock	1	5	0.1
Aquatic Veg	0	0	-
MargVeg In Current	6	3	0.4
MargVeg Out Of Current	5	4	0.5
Gravel	4	5	0.5
Sand	2	4	0.2
Mud	1	2	0.0
Terraces and bars	10	4	0.9
Overall Suitability (%)	44	81%	
Category		Very Good	4.1

APPENDIX D. RIPARIAN VEGETATION SITE SUITABILITY

EFR 1

Site Suitability for the Assessment of Environmental Flows

Habitat availability	**Rate**	**Motivation where applicable**
Presence / absence of the marginal zone.	1	Marginal zone scoured but >80% present for sampling.
Proportion of marginal zone that is able to be sampled.	0	> 80% available for sampling.
Alluvial riparian habitats available for sampling.	0	Alluvial bars abundant as vegetated bars.
Rocky riparian habitats available for sampling.	2	Open bedrock present in lower zone and available for sampling.
	2	
Channel morphology		
Channel bank stabilization.	0	Less than 10% undercutting, and stabilized by vegetation.
Channel manipulation	1	Road along upper zone is incised, site better than reach where agricultural clearing is high.
Profile distance too long to effectively conduct VEGRAI.	1	Profile assessed.
	1	
Vegetation		
Occurrence of obligate, marginal zone, riparian species.	2	Some species reduced or absent due to flow regulation.
Occurrence of obligate, non-marginal zone, riparian species.	0	Woody and non-woody obligates common.
Occurrence of species that are (regional) indicators of the riparian zone, or wetness.		Obligates present, so unrated.
Recent fire/s at site.	0	No recent fires at site.
Exotic species at the site.	1	Less than 10% exotic species at the site.
Left and right-hand banks have riparian vegetation in similar condition.	2	LB with more rocky habitats than RB which is more alluvial
Able to obtain sufficient survey points of indicator species for flow requirements.		Survey not conducted.
Riparian vegetation representative of the reach	0	Site represents reach and is in better condition than majority of reach.
Plant species easily identifiable i.e. leaves or flowers present at time of site visit.	0	All key species identifiable.
	2	
Hydraulic control		
Unnatural up/downstream control affecting site.	0	Not observed in immediate vicinity.
	0	
Overall Site Suitability Rating	**1.3**	**Site suitable**

where:

0 - suite highly suitable
1 - site suitable
2 - site moderately suitable
3 - site unsuitable
4 - site extremely unsuitable
5 - site not to be used

EFR 2

Site Suitability for the Assessment of Environmental Flows

Habitat availability	**Rate**	**Motivation where applicable**
Presence / absence of the marginal zone.	1	Marginal zone scoured but >80% present for sampling.
Proportion of marginal zone that is able to be sampled.	0	Entire marginal zone included in sampling.
Alluvial riparian habitats available for sampling.	2	Alluvial habitats underrepresented at the site due to extensive cobble bars and exposed bedrock in marginal and lower zones.
Rocky riparian habitats available for sampling.	0	Site includes cobble beds and exposed bedrock especially in marginal and lower zones.
	2	
Channel morphology		
Channel bank stabilization.	0	Less than 10% undercutting, and stabilized by vegetation.
Channel manipulation.	1	LB with some clearing, levelling and with a road in upper zone.
Profile distance too long to effectively conduct VEGRAI.	1	Complete profile sampled, with exception of extreme elevation in the upper zone.
	1	
Vegetation		
Occurrence of obligate, marginal zone riparian species.	0	woody and non-woody obligates common
Occurrence of obligate, non-marginal zone riparian species.	0	woody and non-woody obligates common
Occurrence of species that are (regional) indicators of the riparian zone, or wetness.		obligates present, so unrated
Recent fire/s at site.	0	no recent fires at site
Exotic species at the site.	1	less than 10% exotic species at the site
Left and right-hand banks have riparian vegetation in similar condition.	2	banks differ due to bend, differences appear natural
Able to obtain sufficient survey points of indicator species for flow requirements.	0	sufficient both banks
Riparian vegetation representative of the reach.	1	cobble beds additionally present with *Gomphostigma vigatum*
Plant species easily identifiable i.e. leaves or flowers present at time of site visit.	0	all key species identifiable.
	2	
Hydraulic control		
Unnatural up/downstream control affecting site.	1	Boegoeberg dam nearby upstream.
	1	
Overall Site Suitability Rating	**1.5**	**Site suitable**

where:

0 - suite highly suitable
1 - site suitable
2 - site moderately suitable
3 - site unsuitable
4 - site extremely unsuitable
5 - site not to be used

EFR 3

Site Suitability for the Assessment of Environmental Flows

Habitat availability	**Rate**	**Motivation where applicable**
Presence / absence of the marginal zone.	1	Marginal zone scoured but >80% present for sampling.
Proportion of marginal zone that is able to be sampled.	0	> 80% available for sampling.
Alluvial riparian habitats available for sampling.	0	Alluvial bars abundant as open bars and vegetated bars.
Rocky riparian habitats available for sampling.	0	Cobble beds present and available for sampling.
	1	
Channel morphology		
Channel bank stabilization.	0	less than 10% undercutting, and stabilized by vegetation.
Channel manipulation	3	Macro channel manipulated by artificially elevated levees and clearing and levelling for vineyards.
Profile distance too long to effectively conduct VEGRAI.	0	Profile completely sampled.
	3	
Vegetation		
Occurrence of obligate, marginal zone riparian species.	0	Woody and non-woody obligates common.
Occurrence of obligate, non-marginal zone riparian species.	0	Woody and non-woody obligates common.
Occurrence of species that are (regional) indicators of the riparian zone, or wetness.		Obligates present, so unrated.
Recent fire/s at site.	0	No recent fires at site.
Exotic species at the site.	1	Less than 10% exotic species at the site.
Left and right-hand banks have riparian vegetation in similar condition.	2	banks differ due to cobble beds on LB.
Able to obtain sufficient survey points of indicator species for flow requirements.	0	Sufficient both banks.
Riparian vegetation representative of the reach.	1	cobble beds additionally present with *Gomphostigma vigatum*
Plant species easily identifiable i.e. leaves or flowers present at time of site visit.	0	All key species identifiable.
	2	
Hydraulic control		
Unnatural up/downstream control affecting site.	0	Not observed in immediate vicinity.
	0	
Overall Site Suitability Rating	**1.5**	**Site suitable**

where:

0 - suite highly suitable
1 - site suitable
2 - site moderately suitable
3 - site unsuitable
4 - site extremely unsuitable
5 - site not to be used

EFR 4

Site Suitability for the Assessment of Environmental Flows

	Rate	Motivation where applicable
Habitat availability		
Presence / absence of the marginal zone.	1	Marginal zone scoured but >80% present for sampling.
Proportion of marginal zone that is able to be sampled.	0	> 80% available for sampling.
Alluvial riparian habitats available for sampling.	0	Alluvial bars abundant as open bars and vegetated bars.
Rocky riparian habitats available for sampling.	2	Cobble beds present and available for sampling.
	2	
Channel morphology		
Channel bank stabilization.	0	Less than 10% undercutting, and stabilized by vegetation.
Channel manipulation.	3	LB completely artificial to facilitate canal and road.
Profile distance too long to effectively conduct VEGRAI.	1	RB confounded by drainage tributaries.
	3	
Vegetation		
Occurrence of obligate, marginal zone riparian species.	1	Marginal zone riparian obligates present and common at site.
Occurrence of obligate, non-marginal zone riparian species.	1	Sufficient obligate riparian species in non-marginal zone.
Occurrence of species that are (regional) indicators of the riparian zone, or wetness.		Obligates present, so unrated.
Recent fire/s at site.	0	No recent fires at site.
Exotic species at the site.	1	Less than 20% exotic species at the site.
Left and right-hand banks have riparian vegetation in similar condition.	2	Land use differs and so does vegetation types.
Able to obtain sufficient survey points of indicator species for flow requirements.	0	Sufficient both banks.
Riparian vegetation representative of the reach.	0	Represents reach.
Plant species easily identifiable i.e. leaves or flowers present at time of site visit.	0	All key species identifiable.
	2	
Hydraulic control		
Unnatural up/downstream control affecting site	0	Not observed in immediate vicinity.
	0	
Overall Site Suitability Rating	1.8	Site moderately suitable

where:

0 - suite highly suitable
1 - site suitable
2 - site moderately suitable
3 - site unsuitable
4 - site extremely unsuitable
5 - site not to be used

APPENDIX E. FISH SITE SUITABILITY

ABBREVIATIONS

EFR – Ecological Water Requirements

FD – Fast Deep

FS – Fast Shallow

FRAI – Fish Response Assessment Index

NRU – Natural Resource Unit

MRU - Management Resource Unit

RAU – Resource Assessment Unit

SD – Slow Deep

SS – Slow Shallow

Fish Species Abbreviations:

ABBREVIATION	SCIENTIFIC NAMES
ASCL	*AUSTROGLANIS SCLATERI* (BOULENGER, 1901)
BANO	*BARBUS ANOPLUS* (WEBER, 1897)
BAEN	*LABEOBARBUS AENEUS* (BURCHELL, 1822)
BHOS	BARBUS HOSPES (BARNARD, 1938)
BKIM	*LABEOBARBUS KIMBERLEYENSIS* (GILCHRIST & THOMPSON, 1913)
BPAU	BARBUS PALUDINOSUS (PETERS, 1852)
BTRI	*BARBUS TRIMACULATUS* (PETERS, 1852)
CCAR*	*CYPRINUS CARPIO* LINNAEUS, 1758
CGAR	CLARIAS GARIEPINUS (BURCHELL, 1822)
CIDE*	*CTENOPHARYNGODON IDELLA* (VALENCIENNES, 1844)
GAFF*	*GAMBUSIA AFFINIS* (BAIRD & GIRARD, 1853)
LCAP	*LABEO CAPENSIS* (SMITH, 1841)
LUMB	*LABEO UMBRATUS* (SMITH, 1841)
MBRE	*MESOBOLA BREVIANALIS* (BOULENGER, 1908)
OMOS	OREOCHROMIS MOSSAMBICUS
PPHI	PSEUDOCRENILABRUS PHILANDER (WEBER, 1897)
TSPA	TILAPIA SPARRMANII SMITH, 1840
MSAL*	MICROPTERUS SALMOIDES

*Alien fish species

E.1 BACKGROUND

This report provides the results and field notes of a fish survey conducted during May and June 2010, at selected sites in the Orange River Catchment.

E.2 METHODOLOGY

Sites were selected within the Orange River, to be representative of the current habitats available for biota in this river section. The sites were subdivided into sub-sites for the purpose of fish sampling, based on differences in habitats, impacts, etc. At each sub-site, all applicable fishing methods were applied to determine the fish assemblage of the sub-site. The most applicable sampling method was generally found to be electro-fishing (applied using a SAMUS battery operated system) by wading through shallow areas or from a boat in deeper areas. Other methods applied included, seine netting (using small seine net) and gill netting (range of mesh sizes). All fish collected were identified to species level. Those not required for further analyses/identification were returned (unharmed) to the river.

E.3 PRELIMINARY RESULTS

E.3.1 Study Sites

Five sites were selected in the Lower Orange River, two sites were selected in the Caledon River and one in the Kraai River, for the purpose of the baseline fish survey (Table E.1).

Table E. 1: Primary EFR sites of the used for fish assessment (additional sites or stretches of river were sampled up/downstream of EFR sites)

EFR site number	EFR site name	River	Decimal degrees S	Decimal degrees E	EcoRegion (Level II)	Geozone
EFR O1	Hopetown	Orange			26.01	Lowland
EFR O2	Boegoeberg	Orange	-29.0055	22.16225	26.05	Lowland
EFR O3	Augrabies	Orange	-28.4287	19.9983	28.01	Lowland
EFR O4	Vioolsdrif	Orange	-28.7553	17.71696	28.01	Lowland
EFR C5	Upper Caledon	Caledon	-28.6508	28.3875	15.03	Lower Foothills
EFR C6	Lower Caledon	Caledon	-30.4523	26.27088	26.03	Lowland
EFR K7	Lower Kraai	Kraai	-30.8306	26.92056	26.03	Lowland

E.3.2 Site Suitability, fish results and field notes

Site EFR 01: Hopetown

Various sub-sites were sampled at the EFR site, or within the reach, using the most applicable sampling techniques (Table E.2). The habitat of each sub-site is described and the sampling effort provided in Table E.2. Habitat Cover ratings are also provided for each sub-site in Table E.3. The river at this site has a wide flow channel, with rapids and riffles over bedrock and side channels At the time of sampling, vegetated pools were present in some of the non-flowing side channels.

Table E. 2: **Description of fish sub-sites sampled in reach EFR 01: Hopetown**

SUB-SITE	DESCRIPTION	SAMPLING EFFORT
Sub-site 1	FS & FD over bedrock (covered by algae) and reeds as overhanging and instream vegetation along sides. Limited SS & SD along edge.	40min EW
Sub-site 2	FS & FD over bedrock (covered by algae) and reeds as overhanging and instream vegetation along sides.	30 min EW
Sub-site 3	*Potamogeton* spp. stand on sand in mainstream along reeds.	8 min EW
Sub-site 4	Side/secondary channel with trickle at time of sampling (will be connected with more flow during peak of release). SS & SD with bedrock (often covered with silt), abundant aquatic vegetation and overhanging vegetation. Filamentous algae abundant.	12 min EW

EW: Electro-fishing through wading.

Table E. 3: Fish Habitat Assessment (sampled) at each sub-site

Velocity-Depth Category:	SLOW-DEEP			SLOW-SHALLOW			FAST-DEEP			FAST-SHALLOW		
SUB-SITE:	1&2	3	4	1&2	3	4	1&2	3	4	1&2	3	4
ABUNDANCE:	1	0	3	1	0	3	4	0	0	2	0	0
Overhanging vegetation:	3	0	3	2	0	3	1	0	0	0	0	0
Undercut banks & root wads:	1	0	0	1	0	0	0	0	0	0	0	0
Substrate:	4	0	2	4	0	2	5	0	0	5	0	0
Instream vegetation:	2	0	3	2	0	3	0	0	0	0	0	0
Water Column:	3	0	3	1	0	1	3	0	0	1	0	0

0 – absent; 1 – rare; 2 – sparse; 3 – common; 4 - abundant; 5 – very abundant

Six indigenous fish species were sampled at the different sub-sites (Table E.4). A habitat profile of the area in which each species was sampled or observed for this reach, is provided in Table E.5, (which indicates the general habitat preferences of fish species at the site/in reach).

Table E. 4: Presence, in number of individuals (and size range in mm) of different fish species sampled at the different sub sites (May/June 2010) and their relative size-flow guild

Species	Size Flow-guild classification	Sub-site 1	Sub-site 2	Sub-site 3	Sub-site 4
ASCL	Large semi-rheophilic	5 (50-250)			
BAEN	Large semi-rheophilic	8 (100-600)	1 (100)		
BTRI	Small semi-rheophilic			2 (50,80)	
LCAP	Large semi-rheophilic	6 (150-450) (2 with anomalies)	3 (70-100)		
PPHI	Small limnophilic	12 (40-80)		4 (30-50)	2 (30, 70) (1 with anomaly)
TSPA	Intermediate limnophilic				1 (40)

Table E. 5: Fish habitat profile based on habitats where different fish species were observed or sampled at the site EFR O1

	SLOW-DEEP	SLOW-SHALLOW	FAST-DEEP	FAST-SHALLOW
Overhanging vegetation:	PPHI, TSPA	PPHI, TSPA		
Undercut banks & root wads:				
Substrate:			BAEN (A), LCAP (A), ASC (A&J) (more in FI)	LCAP (A), ASCL (A&J)
Instream vegetation:	PPHI (A&J), TSPA	TSPA, BTRI		BTRI
Water Column:				

*Alien species; J- juvenile; A - adult

Suitability of the site to be utilised in ecological water requirement study, in terms of fish, is provided in Table E.6.

Table E. 6: **Suitability scores of site in terms of EFR application**

SUITABILITY SCORES		Comments
EFR SUITABILITY	n/a	Only eco-classification site
0: Not suitable, 1 - 1.9: very low suitability, 2 - 2.9: Moderate suitability,		
3 - 3.9: High suitability, 4 - 5: Very high suitability.		

General comments:

- FRAI application: Site atypical of the reach, especially due to the presence of rapids (FS & FD) over bedrock and secondary channels (therefore most probably higher habitat variability than most of reach). Reach most probably dominated by FD habitats. Site, however, provided best diversity of habitats (i.e. rapids, riffles, side channels, and pools in side channels) and therefore the highest possibility of sampling fish species is present in this reach.
- Daily water level fluctuations at site/reach will have negative impact on fish (in terms of habitat suitability and availability, water quality - especially temperature regime, etc.). Daily water fluctuations will also have a negative impact on nesting fish species (Cichlidae).
- Extensive substrate algae on rocks (possible indication of nutrient enrichment).
- Water had a relatively high turbidity, with an almost milky colour. Could especially have negative influence on predatory species (adult BKIM).
- Adequate spawning habitats occur in the area, if inundated during higher flows (i.e. sand, gravel and cobble beds (Yellowfish) and grassy vegetated areas (catfish) for semi-rheophilics).

Site EFR 02: Boegoeberg

Various sub-sites were sampled at the EFR site, or within the reach, using the most applicable sampling techniques (Table E.7). The habitat of each sub-site is described and the sampling effort provided in Table E.7. Habitat Cover ratings are also provided for each sub-site in Table E.8.

Table E. 7: Description of Fish sub-sites sampled in reach EFR 02: Boegoeberg

SUB-SITE	DESCRIPTION	SAMPLING EFFORT
Sub-site 1a	FD & FS with overhanging vegetation, instream vegetation and substrate (bedrock & boulders), reeds and grass.	60min EW (total for 2 samplers)
Sub-site 1b	FD & FS over bedrock & boulders (white water)	
Sub-site 1c	SS (below FS) with rocks and vegetation	
Sub-site 1d	SS over bedrock	
Sub-site 1e	FD & SD with overhanging vegetation (reeds), logs over bedrock and boulders.	
Sub-site 2a	SS & SVS over rocks (silted) and with instream vegetation as cover	75min EW (total for 2 samplers)
Sub-site 2b	FS & FD over rocks (bedrock & boulders)	
Sub-site 2c	SS, SD & FD with instream and overhanging vegetation over rocks (bedrock)	
Sub-site 3	FD & FS over rocks	15 min EW
Sub-site 4	SD, SS in and upstream of weir, with abundant reeds as cover, sand banks and rocky habitats (bedrock, cobble and boulders)	40min EB
Sub-site 5	FS & FD (rapid) over rocks (boulder, cobble and bedrock)	12min EB Angling

EW: Electro-fishing through wading.

Table E. 8: Fish Habitat Assessment (sampled) at each sub-site

Velocity-Depth Category:	SLOW-DEEP					SLOW-SHALLOW				
SUB-SITE:	1	2	3	4	5	1	2	3	4	5
ABUNDANCE:	1	3	0	4	0	2	3	0	1	1
Overhanging vegetation:	3	3	0	3	0	3	2	0	1	1
Undercut banks & root wads:	2	1	0	2	0	2	1	0	0	0
Substrate:	3	3	0	2	0	3	3	0	1	3
Instream vegetation:	2	3	0	2	0	2	2	0	1	0
Water Column:	3	3	0	5	0	1	1	0	1	1
Velocity-Depth Category:	**FAST-DEEP**					**FAST-SHALLOW**				
SUB-SITE:	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
ABUNDANCE:	3	2	4	2	4	2	2	2	0	2
Overhanging vegetation:	3	2	1	2	1	3	3	1	0	0
Undercut banks & root wads:	1	2	1	0	0	1	1	1	0	0
Substrate:	3	4	5	2	4	3	4	5	0	4
Instream vegetation:	1	2	2	2	0	1	2	2	0	0
Water Column:	3	3	3	3	3	1	1	1	0	1

0 – absent; 1 – rare; 2 – sparse; 3 – common; 4 - abundant; 5 – very abundant

Eight indigenous and three alien fish species were sampled at the different sub-sites (Table E.9). A habitat profile of where each species was sampled or observed for this reach, is provided in Table E.10 (which indicates the general habitat preferences of fish species at the site/in reach).

Table E. 9: Presence in number of individuals (and size range in mm) of different fish species sampled at the different sub sites (May/June 2010) and their relative size-flow guild

Species	Size Flow – Guild classification	Sub-site 1a	Sub-site 1b	Sub-site 1c	Sub-site 1d	Sub-site 1e	Sub-site 2a	Sub-site 2b	Sub-site 2c	Sub-site 3	Sub-site 4	Sub-site 5
ASCL	*Large semi-rheophilic*		1 (100)				No fish					
BAEN	*Large semi-rheophilic*		2 (150)					n.c.			n.c.	n.c.
BPAU	*Small semi-rheophilic*								n.c.			
BTRI	*Small semi-rheophilic*	40 (40 – 90)	20 (40 – 90)	4		15		n.c.	n.c.	n.c.		
CCAR*	n/a			1 (50)								
CGAR	*Large semi-rheophilic*				1 (150)	1 (anomaly)			n.c.			
CIDE*	n/a								n.c.			
GAFF*	n/a								n.c.			

Species	Size Flow – Guild classification	Sub-site 1a	Sub-site 1b	Sub-site 1c	Sub-site 1d	Sub-site 1e	Sub-site 2a	Sub-site 2b	Sub-site 2c	Sub-site 3	Sub-site 4	Sub-site 5
LCAP	*Large semi-rheophilic*	20 (40 – 150)	15 (40 – 150)	5	3	5		n.c.	n.c.	n.c.	n.c.	n.c.
PPHI	*Small limnophilic*	2 (40)							n.c.			
TSPA	*Intermediate limnophilic*	5 (40 – 50)							n.c.			

n/a – not applicable (alien species) n.c. – Not counted

Table E. 10: Fish habitat profile based on habitats where different fish species were observed or sampled at the site EFR O2: Boegoeberg

	SLOW-DEEP	SLOW-SHALLOW	FAST-DEEP	FAST-SHALLOW
Overhanging vegetation (reeds & trees):	BTRI, LCAP			
Undercut banks & root wads:		Roots: TSPA, PPHI, BTRI		
Substrate:	LCAP (J&A), BTRI (J&A), CGAR (J), CIDE* (J)	CCAR* (J), PPHI, TSPA (with veg. & rocks), BPAU (veg. & sand)	BAEN (J&A), LCAP (J&A), BTRI (A), ASCL (A)	BTRI (A&J), LCAP (J)
Instream vegetation:	PPHI (J&A), TSPA (J&A), BPAU (A), GAFF*	Sand & veg.: GAFF*, TSPA, BPAU		Sand & veg.: TSPA, BTRI
Water Column:	BAEN, CGAR, BTRI, LCAP			

*Alien species; J- juvenile; A - adult

Suitability of the site to be utilised in setting flows (ecological water requirement) in terms of fish is provided in Table E.11.

Table E. 11: **Suitability scores of site in terms of EFR and FRAI application**

SUITABILITY SCORES		Comments
EFR SITE SUITABILITY	3.5	Flow sensitive habitats for fish (FS & FD) very well represented at site. High habitat diversity with various secondary canals at site. In the absence of rheophilic species in the Orange River system, next best guild expected to be large semi-rheophilic. Various *large semi-rheophilic* species expected and sampled at site and will be important indicator group for fast-flowing habitats. Representatives of *small-rheophilic* and limnophilic guild also present at site.
0: Not suitable, 1 - 1.9: very low suitability, 2 - 2.9: Moderate suitability,		
3 - 3.9: High suitability, 4 - 5: Very high suitability.		

General comments:

- FRAI APPLICATION: Most of the available habitats (velocity-depth and cover classes) were sampled adequately at the site, as well as additional sites upstream of EFR site (FD sampling generally difficult, but adequately sampled using electro-fishing from boat). Although habitats at the site may be atypical of reach (higher habitat diversity related to secondary channel), they should provide an indication of the fish diversity of the reach.
- NB: Overall fish abundance very low (much lower than observed at downstream sites EFR3 & 4), especially for BAEN & LCAP. Most abundant species BTRI.
- As observed at other sites, very few fish utilize SD with reeds (instream and overhang) along edge of channel (marginal zone).
- Right bank of EFR site had abundant gravel-cobble beds that would be suitable Yellowfish spawning site.
- Good spawning habitat for most of fish species in side channel.
- Sediment regime altered (upstream weir and dam).
- Temperature regime altered by inundation of dam and weir.
- Dam and even weir a definite migration barrier to fish during low flows (and possibly high flows as well).

Site EFR 03: Augrabies

Various sub-sites were sampled at the EFR site, or within the reach, using the most applicable sampling techniques (Table E.12). The habitat of each sub-site is described and the sampling effort provided in Table E.12. Habitat Cover ratings are also provided for each sub-site in Table E.13.

Table E. 12: **Description of fish sub-sites sampled in reach EFR 03: Augrabies**

SUB-SITE	DESCRIPTION	SAMPLING EFFORT
Sub-site 1	FD, FS, SD & SS. Abundant bedrock and boulder (esp. in FD & FS), reeds as overhang and instream veg. along edge, inundated grass on sand banks (grazed).	EB 65min.
Sub-site 2	SS with inundated grass, FS & FD over rocks (boulders & cobbles), SD with sand, grass and silt.	EW 55 min (2 samplers). 2 x small (30m) anchovy seine net.
Sub-site 3	SD along reeds.	3 hours
Sub-site 4a	FS & FD over rocks.	EB: 13 km of reach covered in boat. Approximately 60min in total.
Sub-site 4b	SS with inundated vegetation and stones (out of current).	
Sub-site 4c	SD (along edge) with reeds as instream and overhanging vegetation.	

EW: Electro-fishing through wading. EB: Electro-fishing from boat.

Table E. 13: Fish Habitat Assessment (sampled) at each sub-site

Velocity-Depth Category:	SLOW-DEEP				SLOW-SHALLOW			
SUB-SITE:	1	2	3	4	1	2	3	4
ABUNDANCE:	3	1	5	3	2	3	0	1
Overhanging vegetation:	3	0	2	3	1	0	0	2
Undercut banks & root wads:	1	0	1	2	0	0	0	0
Substrate:	3	1	0	3	2	1	0	2
Instream vegetation:	2	2	3	2	3	2	0	2
Water Column:	5	5	5	5	1	1	0	1
Velocity-Depth Category:	**FAST-DEEP**				**FAST-SHALLOW**			
SUB-SITE:	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
ABUNDANCE:	3	2	1	2	2	2	0	1
Overhanging vegetation:	3	0	1	3	1	0	0	1
Undercut banks & root wads:	1	0	0	1	0	0	0	0
Substrate:	4	3	0	3	4	4	0	4
Instream vegetation:	0	0	3	2	1	0	0	0
Water Column:	5	5	5	5	1	1	0	1

0 – absent; 1 – rare; 2 – sparse; 3 – common; 4 - abundant; 5 – very abundant

Ten indigenous and two alien fish species were sampled at the different sub-sites (Table E.14). A habitat profile of where each species was sampled or observed for this reach, is provided in Table E.15 (indicates general habitat preferences of fish species at site/in reach).

Table E. 14: Presence in number of individuals (and size range in mm) of fish species sampled at the different sub sites (May/June 2010) and their relative size-flow guild

Species	Size Flow-Guild Classify-cation	Sub-site 1	Sub-site 2	Sub-site 3	Sub-site 4a	Sub-site 4b	Sub-site 4c
BAEN	*Large semi-rheophilic*	8 (100-350)	3 (50-150)		n.c. (50-500)		
BKIM	*Large semi-rheophilic*	1 (450)					
BPAU	*Small semi-rheophilic*		1 (60)				
BTRI	*Small semi-rheophilic*	2 (40-60)	29 (40-80)				
CCAR*	n/a						1 (400)
CGAR	*Large semi-rheophilic*	1 (800)		1 (700)			
GAFF*	n/a		2				
LCAP	*Large semi-rheophilic*	20 (250-400)	6 (60-100)		n.c.		
MBRE	*Small semi-rheophilic*	10 (20-45)	13 (30-60)				50 (30-50)
OMOS	*Large limnophilic*	3 (140-150)	9 (30-40)			12 (30-80)	
PPHI	*Small limnophilic*		3 (25-40)				
TSPA	*Intermediate limnophilic*					2 (40-70)	

n/a – not applicable (*alien species) n.c. – Not counted

Table E. 15: Fish Habitat Profile based on habitats where different fish species were observed or sampled at the site EFR O3: Augrabies

	SLOW-DEEP	SLOW-SHALLOW	FAST-DEEP	FAST-SHALLOW
Overhanging vegetation (mostly reeds)	No fish	No fish	No fish	No fish
Undercut banks & root wads:	Not sampled/available	Not sampled/available	Not sampled/available	Not sampled/available
Substrate:	LCAP, BAEN, BKIM, BTRI, MBRE	MBRE	LCAP, BAEN, BKIM, BTRI	LCAP (J), BTRI (A&J)
Instream vegetation:	CGAR (A), MBRE, BPAU, PPHI	OMOS (A&J), MBRE, BPAU, PPHI		
Water Column:	CGAR (A), BAEN, BKIM, LCAP		CGAR (A), BAEN, BKIM, LCAP	

*Alien species; J- juvenile; A - adult

Suitability of the site to be utilised in setting flows (ecological water requirement) in terms of fish is provided in Table E.16.

Table E. 16: **Suitability Score of site in terms of EFR**

SUITABILITY SCORES		Comments
EFR SITE SUITABILITY	2.8	Flow sensitive habitats for fish (FS & FD) well represented at site. Moderate habitat diversity at site. In the absence of rheophilic species in the Orange River system, next best indicator guild (in terms of setting flows) expected to be *large semi-rheophilic*. Various large *semi-rheophilic* species expected and sampled at site and will be important indicator group for fast-flowing habitats. Representatives of *small-rheophilic* and *limnophilic* guild also present at site.
0: Not suitable, 1 - 1.9: very low suitability, 2 - 2.9: Moderate suitability,		
3 - 3.9: High suitability, 4 - 5: Very high suitability.		

General comments:

- *FRAI APPLICATION***:** Most of the available habitats (velocity-depth and cover classes) were sampled adequately at the site, as well as an additional 13km river section sampled upstream of EFR site.
- LCAP seems to be less abundant than at site EFR04: Vioolsdrift.
- Mostly deep wide channels/long pools with intermittent rapids/runs. Wide. deep channel, with dense reeds, as marginal vegetation.
- Gravel and cobble beds on bends for spawning habitat.

- Sandy gravel beds are also present on bends with vegetation for fish species with preference for this habitat type as cover.
- Consider the maintenance of sand/gravel and even mud banks/bars required for establishment of vegetation.
- Riparian zone seems close to natural and very dense.
- Reeds along edges (mostly SD) again observed to be a "dead zone" at time of sampling, with very limited fish sampled/observed in these areas.
- Side channels occur at the site (dry during sampling), with vegetation (grasses), rocks and gravel beds, which would provide good spawning and nursery habitat at higher flows when inundated.
- At the time of sampling, a good riffle area existed at the cross section (good for *large semi-rheophilics* in terms of. habitat and feeding).
- Density or abundance of fish seemed to be low at the time of sampling, with most fish sampled in FD.
- In the reach - FS vegetated habitats with sandy and/or gravel substrate (on bends or at in-stream islands) also seemed to be more productive in terms of fish sampling.

Site EFR 04: Vioolsdrift

Various sub-sites were sampled at the EFR site, or within the reach, using the most applicable sampling techniques (Table E.17). The habitat of each sub-site is described and the sampling effort provided in Table E.17. Habitat Cover ratings are also provided for each sub-site in Table E.18.

Table E. 17: **Description of fish sub-sites sampled in reach EFR 04: Vioolsdrift**

SUB-SITE	DESCRIPTION	SAMPLING EFFORT
Sub-site 1	FS, FD, SS & SD. Rocks, reeds along edges as overhanging and instream vegetation.	EB: 45 min
Sub-site 2	SS & SD with reeds, logs & rootwads[4],	EB: 30 min
Sub-site 3	Below weir: FS, SS & FD over rocks, reeds provide instream vegetation and overhang.	EW: 28 min
Sub-site 4	13km stretch of river: mostly SD & FD with limited FS & SS. Reeds along edges and rocky areas and substrates provide cover. Also overhang from trees.	EB: 13 km stretch covered. In total approximately 80 min electro-fishing.

EW: Electro-fishing through wading. EB: Electro-fishing from boat.

[4]Rootwads: A mass of roots from a tree, shrub, reeds, sedges or grasses that provide shelter and nutrients for a fish.

Table E. 18: Fish habitat assessment (sampled) at each sub-site

Velocity-Depth Category:	SLOW-DEEP				SLOW-SHALLOW			
SUB-SITE:	1	2	3	4	1	2	3	4
ABUNDANCE:	2	5	0	4	2	1	2	1
Overhanging vegetation:	0	2	0	2	0	0	1	1
Undercut banks & root wads:	0	1	0	1	0	2	0	0
Substrate:	4	2	0	3	4	3	4	2
Instream vegetation:	1	4	0	3	1	2	2	1
Water Column:	5	5	0	5	1	0	1	1
Velocity-Depth Category:	**FAST-DEEP**				**FAST-SHALLOW**			
SUB-SITE:	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
ABUNDANCE:	4	1	2	2	2	0	4	1
Overhanging vegetation:	0	1	1	1	0	0	1	1
Undercut banks & root wads:	0	2	0	2	0	0	0	0
Substrate:	5	4	4	4	5	0	4	4
Instream vegetation:	1	2	1	2	1	0	1	1
Water Column:	5	5	3	5	1	0	1	1

0 – absent; 1 – rare; 2 – sparse; 3 – common; 4 - abundant; 5 – very abundant

Eleven indigenous and one alien fish species were sampled at the different sub-sites (Table E.19). A habitat profile of where each species was sampled or observed for this reach, is provided in Table E.20 (which indicates the general habitat preferences of fish species at the site/in reach).

Table E. 19: Presence in number of individuals (and size range in mm) of different fish species sampled at the different sub sites (May/June 2010) and their relative size-flow guild

Species	Size Flow-guild classification	Sub-site 1	Sub-site 2	Sub-site 3	Sub-site 4
BAEN	*Large semi-rheophilic*	7 (50-450) 2 anomalies		13 (20-450)	n.c.
BHOS	*Small semi-rheophilic*			47 (70-90)	n.c.
BKIM	*Large semi-rheophilic*	1 (400)			
BPAU	*Small semi-rheophilic*	1 (50)		1 (70)	n.c.
BTRI	*Small semi-rheophilic*	7 (35-75)		38	
CCAR*	*n/a*		2 (400-600)		
CGAR	*Large semi-rheophilic*		1 (1200)	1 (300) anomaly	
LCAP	*Large semi-rheophilic*	48 (35-400)	15 (50-400)	37 (100-200)	n.c.
MBRE	*Small semi-rheophilic*	60 (35-80)	8 (35-80)	38	n.c.
OMOS	*Large limnophilic*	9 (50-140)		14 (50-100)	
PPHI	*Small limnophilic*	1 (45)	1 (50)		
TSPA	*Intermediate limnophilic*	1 (50)		24 (40-45)	n.c.

n/a – not applicable (alien species) n.c. – Not counted

Table E. 20: Fish habitat profile based on habitats where different fish species were observed or sampled at the site EFR O4: Vioolsdrift

	SLOW-DEEP	SLOW-SHALLOW	FAST-DEEP	FAST-SHALLOW
Overhanging vegetation	**CGAR (A)**			
Undercut banks & root wads:				
Substrate:	LCAP (A&J), MBRE (A&J), BTRI, BKIM (A)	LCAP (J), MBRE (A&J), BAEN (J)	LCAP (A), MBRE (A&J), BKIM (A), BAEN (A&J). BHOS	LCAP (J&A), MBRE (A&J), BAEN (J), BTRI, BHOS
Instream vegetation:	CGAR (A)	OMOS (J), TSPA (A), PPHI, BPAU	MBRE	MBRE
Water Column:	LCAP (A&J), MBRE (A), CCAR*	TSPA (A), OMOS (J), PPHI	LCAP (A)	

*Alien species; J- juvenile; A – adult

Suitability of the site to be utilised in setting flows (ecological water requirement) in terms of fish is provided in Table E.21.

Table E. 21: **Suitability score of site in terms of EFR**

SUITABILITY SCORES		Comments
EFR SITE SUITABILITY	2.8	Flow sensitive habitats for fish (FS & FD) well represented at site. Moderate habitat diversity at site. In the absence of *rheophilic* species in the Orange River system, next best indicator guild (in terms of setting flows) expected to be *large semi-rheophilic*. Various *large semi-rheophilic* species (including BKIM) expected and sampled at site and will be important indicator group for fast-flowing habitats. Representatives of *small-rheophilic* and *limnophilic* guild also present at site.

0: Not suitable, 1 - 1.9: very low suitability, 2 - 2.9: Moderate suitability,
3 - 3.9: High suitability, 4 - 5: Very high suitability.

General comments:

- FRAI APPLICATION: Most of the available habitats (velocity-depth and cover classes) were sampled adequately at the site, as well as an additional 13km river section sampled downstream of EFR site. Site also sampled directly below weir upstream of EFR site.
- Reeds along edges (mostly SD) observed to be a "dead zone" at time of sampling, with very limited fish sampled/observed in this habitat.
- Most potadromous fish species should be able to successfully negotiate upstream weir (limited migration barrier to small species or juveniles).
- LCAP very abundant at site, with Yellowfish also being abundant (especially in rapid-run habitats).
- BHOS sampled in relatively fast flowing water (below weir).
- Good rapid and riffle habitat at site. FD dominant. Instream aquatic vegetation not abundant (little or few vegetated areas) at site.
- OMOS, PPHI, and CGAR sampled in *Phragmites*.
- In-stream aquatic vegetation species identified, of importance for fish, at site and reach are *Cyperus marginatus* (water reed)*, Persicaria serrulata* (snake roots and knot weeds)*, and Cynodon dactylon* (water grass). These plants provide cover and habitat for fish and need sediment (including pebbles, gravel, sand, and mud) to establish.
- The *Phragmites* do not seem to provide adequate or preferred habitat for fish (cover, feeding etc.). The other plant species (as mentioned above) seem to be the preferred by fish.

Site EFR C5: Upper Caledon

Representative sections of the entire available habitat were sampled at the EFR site, or within the reach, using most applicable sampling techniques (Table E.22). The habitat sampled is described and the sampling effort provided in Table E.23. Habitat Cover ratings are also provided for each sub-site in Table E.23.

Table E. 22: **Description of fish sub-sites sampled in reach EFR 01: Hopetown**

SUB-SITE	DESCRIPTION	SAMPLING EFFORT
Sub-site 1	FS, SS & SD over bedrock, boulders, cobbles. Substrate covered with algae and sediment. Very limited sedges (inundated), some overhanging vegetation provided by grass, shrubs and poplars. Limited undercut banks.	45min EW

EW: Electro-fishing through wading.

Table E. 23: **Fish Habitat Assessment (sampled) at the site (June 2010)**

Velocity-Depth Category:	SLOW-DEEP	SLOW-SHALLOW	FAST-DEEP	FAST-SHALLOW
ABUNDANCE:	1	3	0	3
Overhanging vegetation:	2	2	0	1
Undercut banks & root wads:	2	1	0	1
Substrate:	2	3	0	3
Instream vegetation:	1	2	0	1
Water Column:	3	1	0	1

0 – absent; 1 – rare; 2 – sparse; 3 – common; 4 - abundant; 5 – very abundant

Only one indigenous fish species, namely the Small-mouth Yellowfish (*Labeobarbus aeneus*) was sampled at the site during June 2010 (Table E.24). A habitat profile of where the species was sampled or observed for this reach, is provided in Table E.25 (which indicates the general habitat preferences of fish species).

Table E. 24: Presence in number of individuals (and size range in mm) of different fish species sampled at the different sub sites (June 2010) and their relative size-flow guild

Species	Size Flow-guild classification	Sub-site 1
BAEN	*Large semi-rheophilic*	1 (85)

Table E. 25: Fish habitat profile based on habitats where different fish species were observed or sampled at the site EFR C5

	SLOW-DEEP	SLOW-SHALLOW	FAST-DEEP	FAST-SHALLOW
Overhanging vegetation:				
Undercut banks & root wads:				
Substrate:		BAEN (J) over sand/silt.		
Instream vegetation:				
Water Column:				

*Alien species; J- juvenile; A - adult

Suitability of the site to be utilised in ecological water requirement study in terms of fish, is provided in Table E.26.

Table E. 26: **Suitability scores of site in terms of EFR application**

SUITABILITY SCORES		Comments
EFR SITE SUITABILITY	2.2	Flow sensitive habitats for fish (FS & FD) very well represented at site. Habitat diversity at site representative of those expected under natural conditions (potentially some loss of deep areas due to sedimentation). In the absence of *rheophilic* species in the area (none expected under natural conditions), next best guild for determining flow requirements should be the *large semi-rheophilic* guild. One *large semi-rheophilic* species sampled at site during survey, which may be an important indicator group for fast-flowing habitats. The low fish species diversity (natural and present) however reduced the applicability of fish in setting flows for the site, resulting in overall moderate site suitability.
0: Not suitable, 1 - 1.9: very low suitability, 2 - 2.9: Moderate suitability,		
3 - 3.9: High suitability, 4 - 5: Very high suitability.		

General comments:

- *FRAI application:* Site typical of reach and should be representative of fish assemblage present in the reach. Relatively high habitat diversity (flow-depth and cover features) at site.
- Due to survey conducted in mid-winter, fish results are of lower confidence. During these very cold periods (water temperature was 5° at time of sampling), the fish tend to move into deep pools and dams to avoid extreme temperature fluctuations. Their metabolism decreases and they become less active. Sampling success, even in these deep refuge areas, are therefore very low.
- Extensive sedimentation (catchment and bank erosion), as well as substrate algae on rocks (possible indication of nutrient enrichment).
- Other potential impact on fish may be related to presence of predatory alien fish species (known presence of trout and bass in the area).

Site EFR C6: Lower Caledon

Representative sections of the entire available habitat were sampled at the EFR site or within the reach using most applicable sampling techniques (Table E.27). Habitat Cover ratings are also provided for each sub-site in Table E.28.

Table E. 27: Description of fish sub-sites sampled in reach EFR 01: Hopetown

SUB-SITE	DESCRIPTION	SAMPLING EFFORT
Sub-site 1	FS, FD, SS & SD over bedrock / boulders. No vegetation. Sand/silt. Very high turbidity.	40 min EW
Sub-site 2	SD & SS along edge over sand with reed stems in water (IV).	10 min EW
Sub-site 3	SS & SD along edge over sand/silt. Some bedrock/cobbles. No vegetation. Downstream of rapid.	28min EW
Sub-site 4	SS, SD & FS over gravel, sand & silt. In main stream (include some SVS & FVS).	8 min EW
Sub-site 5	SS, SD with flow over sand, gravel, cobbles along edge of river.	8 min EW
Sub-site 6	SD along reeds (some rootwads).	8 min EB
Sub-site 7	SD in middle of river.	5 min EB
Sub-site 8	SD, SS over bedrock.	5 min EB
Sub-site 9	FS & FD	5 min EB
Sub-site 10	SS & SD along edge over gravel/sand/silt/cobbles.	3 small seine nets.

EW: Elec

Table E. 28: Fish habitat assessment (sampled) at the sub-sites (June 2010)

Velocity-Depth Category:	SLOW-DEEP					SLOW-SHALLOW				
SUB-SITE:	1	2	3	4	5	1	2	3	4	5
ABUNDANCE:	1	3	3	2	3	2	3	3	3	3
Overhanging vegetation:	0	1	0	0	0	0	1	0	0	0
Undercut banks & root wads:	0	2	0	0	0	0	2	0	0	0
Substrate:	3	1	2	2	2	3	1	2	2	2
Instream vegetation:	0	1	0	0	0	0	1	0	0	0
Water Column:	3	3	3	3		1	1	1	1	1
Velocity-Depth Category:	**SLOW-DEEP**					**SLOW-SHALLOW**				
SUB-SITE:	**6**	**7**	**8**	**9**	**10**	**6**	**7**	**8**	**9**	**10**
ABUNDANCE:	4	5	3	1	3	1	0	2	2	3
Overhanging vegetation:	2	0	0	0	0	2	0	0	0	0
Undercut banks & root wads:	3	0	0	0	0	3	0	0	0	0
Substrate:	1	3	4	3	2	1	0	4	3	2
Instream vegetation:	1	0	0	0	0	1	0	0	0	0
Water Column:	4	5	0	3	3	1	0	0	1	1
Velocity-Depth Category:	**FAST-DEEP**					**FAST-SHALLOW**				
SUB-SITE:	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
ABUNDANCE:	2	0	0	0	0	3	0	0	3	0
Overhanging vegetation:	0	0	0	0	0	0	0	0	0	0
Undercut banks & root wads:	0	0	0	0	0	0	0	0	0	0
Substrate:	3	0	0	0	0	3	0	0	2	0
Instream vegetation:	0	0	0	0	0	0	0	0	0	0
Water Column:	3	0	0	0	0	1	0	0	1	0
Velocity-Depth Category:	**FAST-DEEP**					**FAST-SHALLOW**				
SUB-SITE:	**6**	**7**	**8**	**9**	**10**	**6**	**7**	**8**	**9**	**10**
ABUNDANCE:	0	0	0	2	0	0	0	0	3	0
Overhanging vegetation:	0	0	0	0	0	0	0	0	0	0
Undercut banks & root wads:	0	0	0	0	0	0	0	0	0	0
Substrate:	0	0	0	3	0	0	0	0	3	0
Instream vegetation:	0	0	0	0	0	0	0	0	0	0
Water Column:	0	0	0	3	0	0	0	0	1	0

0 – absent; 1 – rare; 2 – sparse; 3 – common; 4 - abundant; 5 – very abundant

Two indigenous fish species, namely the Small-mouth Yellowfish (*Labeobarbus aeneus*) and Orange-Vaal Labeo (*Labeo capensis*) were sampled at the site during June 2010 (Table E.29). Another indigenous species, the Sharptooth catfish (*Clarias gariepinus*) was observed. A habitat profile of where the species was sampled or observed for this reach, is provided in Table E.30 (which indicates the general habitat preferences of fish species).

Table E. 29: Presence in number of individuals (and size range in mm) of different fish species sampled at the different sub sites (June 2010) and their relative size-flow guild

Species	Size Flow-guild classification	Sub-site 1	Sub-site 2	Sub-site 3	Sub-site 4	Sub-site 5	Sub-site 6	Sub-site 7	Sub-site 8	Sub-site 9	Sub-site 10
BAEN	*Large semi-rheophilic*		No fish	9 (30-60)	No fish			1 (250)	3 (150-300)	No fish	6 (40-60)
CGAR	n/a	1 observed									
LCAP	*Large semi-rheophilic*	2 (40-60)		8 (50-90)		31 (40-70)	1 (60)	2 (100-120)	3 (150-200)		18 (20 – 70)

Table E. 30: Fish habitat profile based on habitats where different fish species were observed or sampled at the site EFR C5

	SLOW-DEEP	SLOW-SHALLOW	FAST-DEEP	FAST-SHALLOW
Overhanging vegetation:	Sampled, no fish.	Sampled, no fish.	None available	None available
Undercut banks & root wads:	Sampled, no fish.	Sampled, no fish.	None available	None available
Substrate:	LCAP(A & J) & BAEN (A&J) over bedrock. LCAP (J) & BAEN (J) over sand/silt.	LCAP (J) & BAEN (J) over bedrock. LCAP (J) & BAEN (J) over sand/silt.	Sampled, no fish.	Sampled, no fish.
Instream vegetation:	Sampled, no fish.	Sampled, no fish.	None available	None available
Water Column:	BAEN (A) & LCAP (A)			

J- juvenile; A - adult

Suitability of the site to be utilised in ecological water requirement study in terms of fish is provided in Table E.31.

Table E. 31: **Suitability scores of site in terms of EFR application**

SUITABILITY SCORES		Comments
EFR SITE SUITABILITY	2.5	Flow sensitive habitats for fish (FS & FD) well represented at site. Moderate habitat diversity at site. Overall habitat diversity at site moderate with most flow-depth categories well represented. In the absence of *rheophilic* species in the area (none expected under natural conditions), next best guild for determining flow requirements should be the *large semi-rheophilic* guild. Two large *semi-rheophilic* species sampled at site during survey, which should be useful indicators for setting flows (due to their requirement for flowing habitats in some-life stages). However the low fish species diversity (natural and present) reduced the applicability and value of fish as a biotic group in setting flows for the site, resulting in overall moderate site suitability.

0: Not suitable, 1 - 1.9: very low suitability, 2 - 2.9: Moderate suitability,
3 - 3.9: High suitability, 4 - 5: Very high suitability.

General comments:

- *FRAI application:* Site have highest habitat diversity of average site in reach, therefore provides highest possibility of sampling any fish species that may be present in the reach.
- Due to survey being conducted in mid-winter, fish results are of lower confidence. During these very cold periods (water temperature was 5° at time of sampling), the fish tend to move into deep pools and dams to avoid extreme temperature fluctuations. Their metabolism decreases and they become less active. Sampling success, even in these deep refuge areas, is therefore very low.
- Extremely high turbidity at time of sampling could be a limiting factor for fish. This is atypical for this time of year (according to locals). Flow also higher than normal for this season.
- Extensive sedimentation/siltation.
- Other potential impact on fish may be related to presence of predatory alien fish species.

Site EFR K7: Lower Kraai

Representative sections of the entire available habitat were sampled at the EFR site, or within the reach, using most applicable sampling techniques (Table E.32). The habitat sampled is described and the sampling effort provided in Table E.32. Habitat Cover ratings are also provided for each sub-site in Table E.33.

Table E. 32: Description of fish sub-sites sampled in reach EFR 01: Hopetown

SUB-SITE	DESCRIPTION	SAMPLING EFFORT
Sub-site 1	Secondary channel on LB. FVS, FS, SS, SVS, SD over boulders, cobbles, gravel. Some sedimentation and overhanging vegetation from dead grass and trees.	8 min EW
Sub-site 2	FS & FD over cobbles, boulders, gravel.	19 min EW
Sub-site 3	SS & SD over cobbles and boulders (some siltation).	12 min EW
Sub-site 4	SS, SD & FD mostly over bedrock, with some boulders, cobles. High level of siltation.	7 min EW
Sub-site 5	FS & FD over bedrock & cobles. Some algae and siltation.	5 min EW
Sub-site 6	FD & SD over rocks.	10 min EW
Sub-site 7	SD & SS. Margin with overhang (Willows, sedges and rootwads).	8 min EW
Sub-site 8	SS & SD. Large bedrock overhanging and into water.	12 min EW

EW: Electro-fishing through wading. EB – Electro-fishing from boat. IV – instream vegetation.

Table E. 33: Fish habitat assessment (sampled) at the sub-sites (June 2010)

Velocity-Depth Category:	SLOW-DEEP					SLOW-SHALLOW				
SUB-SITE:	1	2	3	4	5	1	2	3	4	5
ABUNDANCE:	2	0	3	1	0	4	0	3	3	0
Overhanging vegetation:	2	0	0	0	0	2	0	0	0	0
Undercut banks & root wads:	3	0	0	0	0	2	0	0	0	0
Substrate:	3	0	4	2	0	3	0	4	3	0
Instream vegetation:	1	0	0	0	0	1	0	0	0	0
Water Column:	3	0	3	2	0	1	0	1	1	0
Velocity-Depth Category:	**SLOW-DEEP**					**SLOW-SHALLOW**				
SUB-SITE:	**6**	**7**	**8**			**6**	**7**	**8**		
ABUNDANCE:	3	4	4			0	1	2		
Overhanging vegetation:	0	3	0			0	2	0		
Undercut banks & root wads:	0	3	0			0	3	1		
Substrate:	4	1	4			0	1	3		
Instream vegetation:	0	0	0			0	0	0		
Water Column:	5	3	5			0	1	1		
Velocity-Depth Category:	**FAST-DEEP**					**FAST-SHALLOW**				
SUB-SITE:	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
ABUNDANCE:	0	4	0	0	0	1	3	0	1	3
Overhanging vegetation:	0	0	0	0	0	0	0	0	0	0
Undercut banks & root wads:	0	0	0	0	0	0	0	0	0	0
Substrate:	0	4	0	0	0	3	4	0	1	4
Instream vegetation:	0	1	0	0	0	0	0	0	0	0
Water Column:	0	3	0	0	0	1	1	0	1	1
Velocity-Depth Category:	**FAST-DEEP**					**FAST-SHALLOW**				
SUB-SITE:	**6**	**7**	**8**			**6**	**7**	**8**		
ABUNDANCE:	3	0	0			0	0	0		
Overhanging vegetation:	0	0	0			0	0	0		
Undercut banks & root wads:	0	0	0			0	0	0		
Substrate:	4	0	0			0	0	0		
Instream vegetation:	0	0	0			0	0	0		
Water Column:	5	0	0			0	0	0		

0 – absent; 1 – rare; 2 – sparse; 3 – common; 4 - abundant; 5 – very abundant

Two indigenous fish species, namely the Small-mouth Yellowfish (*Labeobarbus aeneus*) and Orange-Vaal Labeo (*Labeo capensis*) were sampled at the site during June 2010 (Table

E.34). A habitat profile of where the species was sampled or observed for this reach, is provided in Table E.35 (which indicates the general habitat preferences of fish species).

Table E. 34: Presence in number of individuals (and size range in mm) of different fish species sampled at the different sub sites (June 2010) and their relative size-flow guild

Species	Size Flow-guild classification	Sub-site 1	Sub-site 2	Sub-site 3	Sub-site 4	Sub-site 5	Sub-site 6	Sub-site 7	Sub-site 8
BAEN	*Large semi-rheophilic*	3 (40-120)	1 (280)	39 (40-100)	12 (40-60)	No fish	No fish	3 (30-60)	
LCAP	*Large semi-rheophilic*			3 (50-60)	2 (40-70)			2 (50/60)	3 (30-60)

Table E. 35: Fish habitat profile based on habitats where different fish species were observed or sampled at the site EFR C5

	SLOW-DEEP	SLOW-SHALLOW	FAST-DEEP	FAST-SHALLOW
Overhanging vegetation:	Limited available LCAP (J) & BAEN (J)	Limited available BAEN (J)	None available	None available
Undercut banks & root wads:	(Willows) BAEN & LCAP	None available	None available	None available
Substrate:	LCAP (J) & BAEN (J) over boulders.	LCAP (J) & BAEN (J) over bedrock & boulders.	BAEN (A)	No fish. Adequately sampled.
Instream vegetation:	None available	None available	None available	None available
Water Column:	Sampled, no fish.		Sampled, no fish.	

J- juvenile; A - adult

Suitability of the site to be utilised in ecological water requirement study, in terms of fish is provided in Table E.36.

Table E. 36: **Suitability scores of site in terms of EFR application**

SUITABILITY SCORES		Comments
EFR SITE SUITABILITY	2.8	Flow sensitive habitats for fish (FS & FD) well represented at site. Overall habitat diversity at site very good with all flow-depth categories well represented. Moderate habitat diversity at site. In the absence of *rheophilic* species in the area (none expected under natural conditions), next best guild for determining flow requirements should be the *large semi-rheophilic* guild. Two *large semi-rheophilic* species sampled at site during survey, which should be useful indicators for setting flows (due to their requirement for flowing habitats in some-life stages). The low fish species diversity (natural and present) however reduced the applicability and value of fish as a biotic group in setting flows for the site, resulting in overall moderate site suitability.

0: Not suitable, 1 - 1.9: very low suitability, 2 - 2.9: Moderate suitability,
3 - 3.9: High suitability, 4 - 5: Very high suitability.

General comments:

- FRAI application: Site has highest habitat diversity of average sites in reach, therefore provides highest possibility of sampling any fish species that may be present in the reach.
- Due to the survey being conducted in mid-winter, fish results are of low confidence. During these very cold periods, the fish tend to move into deep pools and dams to avoid extreme temperature fluctuations. Their metabolism decreases and they become less active. Sampling success, even in these deep refuge areas, is therefore very low.
- Fast waters were in general “dead zones” with very few individuals present. Most likely related to seasonal variation (during colder periods when their metabolism is low the fish move into slower water).
- Although fish did not utilise fast habitats, it remains important to maintain flow to ensure adequate water quality in slow habitats.

E.4 SUMMARY

A total of eleven indigenous fish species are native to the Orange River, one translocated species (OMOS) and three alien fish species, were sampled during the May/June 2010 survey at 4 EFR sites in the Orange River (Table E.37). These species represent all size-flow guilds present in the Orange River system, namely *small* and *large semi-rheophilic*, as well as *small* and *large limnophilic*. A habitat profile of where each species was sampled or observed during the survey is provided in Table E.38, (which indicates the general habitat preferences of fish species, as observed during the current survey). Suitability of each site to be utilised in setting flows (ecological water requirement) in terms of fish is provided in Table E.39.

Table E.37: Presence of different fish species sampled at the different sites (May/June 2010) and their relative size-flow guild

Species	Size Flow-guild classification	EFR O1	EFR O2	EFR O3	EFR O4
ASCL	*Large semi-rheophilic*				
BAEN	*Large semi-rheophilic*				
BHOS	*Small semi-rheophilic*				
BKIM	*Large semi-rheophilic*				
BPAU	*Small semi-rheophilic*				
BTRI	*Small semi-rheophilic*				
CCAR*	n/a				
CGAR	*Large semi-rheophilic*				
CIDE*	n/a				
GAFF*	n/a				
LCAP	*Large semi-rheophilic*				
MBRE	*Small semi-rheophilic*				
OMOS (T)	*Large limnophilic*				
PPHI	*Small limnophilic*				
TSPA	*Intermediate limnophilic*				

n/a – not applicable (alien species), T - translocated

Table E.38: Summarised fish habitat profile based on habitats where different fish species were observed or sampled during the survey (all sites combined)

	SLOW-DEEP	SLOW-SHALLOW	FAST-DEEP	FAST-SHALLOW
Overhanging vegetation	PPHI, TSPA, CGAR (A) BTRI, LCAP	PPHI, TSPA		
Undercut banks & root wads:		Roots: TSPA, PPHI, BTRI		
Substrate:	LCAP (A&J), MBRE (A&J), BKIM (A), BTRI (J&A), CGAR (J), CIDE* (J), BAEN,	LCAP (J), MBRE (A&J), BAEN (J) CCAR* (J), PPHI, TSPA (with veg. & rocks), BPAU (veg. & sand)	MBRE (A&J), BKIM (A), BAEN (A&J). BHOS, ASC (A&J) (more in FI), LCAP (J&A), BTRI (A),	LCAP (J&A), MBRE (A&J), BAEN (J), BHOS, ASCL (A&J) BTRI (A&J),
Instream vegetation:	CGAR (A), PPHI (A&J), TSPA (J&A), BPAU (A), GAFF*, MBRE, BPAU	OMOS (J), TSPA (A), PPHI, BTRI Sand & veg.: GAFF*, BPAU (A&J), MBRE		Sand & veg.: TSPA, BTRI
Water Column:	LCAP (A&J), MBRE (A), CCAR* BAEN, BTRI, CGAR (A), BKIM,	TSPA (A), OMOS (J), PPHI	LCAP (A) CGAR (A), BAEN, BKIM	

*Alien species; J- juvenile; A - adult

Table E.39: Summary of suitability scores of each site for setting ecological water requirements in terms of fish

EFR SITE	SUITABILITY SCORES	Comments
EFR02: Boegoeberg	3.5	Flow sensitive habitats for fish (FS & FD) very well represented at site. High habitat diversity with various secondary canals at site. In the absence of *rheophilic* species in the Orange River system, next best guild expected to be *large semi-rheophilic*. Various *large semi-rheophilic* species expected and sampled at site and will be important indicator group for fast-flowing habitats. Representatives of *small-rheophilic* and *limnophilic* guild also present at site.
EFR03: Augrabies	2.8	Flow sensitive habitats for fish (FS & FD) well represented at site. Moderate habitat diversity at site. In the absence of *rheophilic* species in the Orange River system, next best indicator guild (in terms of setting flows) expected to be *large semi-rheophilic*. Various *large semi-rheophilic* species expected and sampled at site and will be important indicator group for fast-flowing habitats. Representatives of *small-rheophilic* and *limnophilic* guild also present at site.

EFR04: Vioolsdrift	2.8	Flow sensitive habitats for fish (FS & FD) well represented at site. Moderate habitat diversity at site. In the absence of *rheophilic* species in the Orange River system, next best indicator guild (in terms of setting flows) expected to be *large semi-rheophilic*. Various *large semi-rheophilic* species (including BKIM) expected and sampled at site and will be important indicator group for fast-flowing habitats. Representatives of *small-rheophilic* and *limnophilic* guild also present at site.
EFR C5: Upper Caledon	2.2	Flow sensitive habitats for fish (FS & FD) very well represented at site. Habitat diversity at site representative of those expected under natural conditions (potentially some loss of deep areas due to sedimentation). In the absence of *rheophilic* species in the area (none expected under natural conditions), next best guild for determining flow requirements should be the *large semi-rheophilic* guild. One *large semi-rheophilic* species sampled at site during survey, which may be an important indicator group for fast-flowing habitats. However the low fish species diversity (natural and present) reduced the applicability of fish in setting flows for the site, resulting in overall moderate site suitability.
EFR C6: Lower Caledon	2.5	Flow sensitive habitats for fish (FS & FD) well represented at site. Moderate habitat diversity at site. Overall habitat diversity at site moderate with most flow-depth categories well represented. In the absence of *rheophilic* species in the area (none expected under natural conditions), next best guild for determining flow requirements should be the *large semi-rheophilic* guild. Two *large semi-rheophilic* species sampled at site during survey, which should be useful indicators for setting flows (due to their requirement for flowing habitats in some-life stages). However the low fish species diversity (natural and present) reduced the applicability and value of fish as a biotic group in setting flows for the site, resulting in overall moderate site suitability.
EFR K7: Lower Kraai	2.8	Flow sensitive habitats for fish (FS & FD) well represented at site. Overall habitat diversity at site was very good with all flow-depth categories well represented. Moderate habitat diversity at site. In the absence of *rheophilic* species in the area (none expected under natural conditions), next best guild for determining flow requirements should be the *large semi-rheophilic* guild. Two *large semi-rheophilic* species sampled at site during survey, which should be useful indicators for setting flows (due to their requirement for flowing habitats in some-life stages). However the low fish species diversity (natural and present) reduced the applicability and value of fish as a biotic group in setting flows for the site, resulting in overall moderate site suitability.

0: Not suitable, 1 - 1.9: very low suitability, 2 - 2.9: Moderate suitability,
3 - 3.9: High suitability, 4 - 5: Very high suitability.

Table E..40: **Summary of the spawning and migration specifications for the *larger semi-rheophilic* fish species (Skelton, 1993)**

Species	Flow and habitat needed
BKIM (*Labeobarbus kimberleyensis* – Largemouth Yellowfish)	Need gravel beds for spawning – mid to late summer. Eggs hatch within 2-3 days. Feed and free swimming 3-4 days later. Total flow duration needed for spawning – 5-7 days.
BAEN (*Labeobarbus aeneus* – Smallmouth Yellowfish)	Need gravel beds for spawning – mid to late summer. Eggs hatch within 2-8 days. Feed and free swimming 4-6 days later. Total flow duration needed for spawning – 6-14 days.
LCAP (*Labeo capensis* – Orange River Mudfish)	Need rocky rapids for spawning – summer. Eggs hatch within 3-4 days. Feed and free swimming 4-5 days later. Total flow duration needed for spawning – 7-9 days. Rapid growth.
LUMB (*Labeo umbratus* – Moggel)	Need shallow rocky areas or flooded grass banks for spawning – summer. Eggs hatch within 2 days. Feed and free swimming 2-4 days later. Total flow duration needed for spawning – 4-6 days. Rapid growth.
CGAR (*Clarias gariepinus* – Sharptooth Catfish)	Need vegetation – shallow grassy verges for spawning – summer. Eggs hatch within 1-2 days. Feed and free swimming 2-3 days later. Total flow duration needed for spawning – 3-5 days. Rapid growth. Known to migrate up to 60km upstream in fish river catchment.
ASCL (*Austroglanis sclateri* – Rock Catfish)	Not much known about this species. Lives in rocky habitat with flowing water, favouring rapids, where it most probably spawns.

APPENDIX F. HYDRAULIC SITE SUITABILITY

F.1 ORANGE RIVER SITE 2 - BOEGEBERG

F.1.1 Positive attributes

Reasonably uniform flow conditions at medium flows and above.

Location of gauging weir for determining discharges.

The data for the gauge (D7H008 - Zeekoebaart) is available at near real-time on the DWAF hydrology web site, making it useful for the collection of hydraulic data over the duration of the study.

F.1.2 Negative attributes

Location of site in bedrock morphology with rapidly varied flow conditions at low flows.

Multiple channels at medium/high-flows, making it difficult to predict stage-discharge relationships in the absence of a detailed topographical survey and two-dimensional hydraulic modelling.

Large and irregular nature of the bed substrate (cobbles, boulders & bedrock). Influence of vegetation on flow resistance, at high flows. This makes resistance and energy slope predictions difficult for all flows, compromising the accuracy of the stage-discharge relationship.

Non-horizontal water surface across the inundated channel width, at low-flows.

Possibility of pooled water at the cessation of flow.

F.2 ORANGE RIVER SITE 3 - AUGRABIES

F.2.1 Positive attributes

Reasonably uniform flow conditions at medium flows and above.

Location of gauging weir for determining discharges (though some distance upstream at Neusberg).

The data for the gauge (D7H014 -Neusberg) is available at near real-time on the DWAF hydrology web site, making it useful for the collection of hydraulic data over the duration of the study.

F.2.2 Negative attributes

Large and irregular nature of the bed substrate (cobbles, boulders & bedrock). This makes resistance and energy slope predictions difficult at low flows, compromising the accuracy of the stage-discharge relationship.

Possibility of pooled water at the cessation of flow.

F.3 ORANGE RIVER SITE 4 - VIOOLSDRIF

F.3.1 Positive attributes

Reasonably uniform flow conditions at medium flows and above.

Location of gauging weir for determining discharges.

The data for the gauge (D8H003 - Vioolsdrif) is available at near real-time on the DWAF hydrology web site, making it useful for the collection of hydraulic data over the duration of the study.

F.3.2 Negative attributes

Location of site in bedrock morphology with rapidly varied flow conditions at low flows.

Large and irregular nature of the bed substrate (cobbles, boulders & bedrock). This makes resistance and energy slope predictions difficult for all flows, compromising the accuracy of the stage-discharge relationship.

Non-horizontal water surface across the inundated channel width, at low-flows.

Possibility of pooled water at the cessation of flow.

F.4 CALEDON RIVER SITE 5

F.4.1 Positive attributes

None.

F.4.2 Negative attributes

Location of site in bedrock morphology with rapidly varied flow conditions, at low and medium flows.

Large and irregular nature of the bed substrate (cobbles, boulders & bedrock). This makes resistance and energy slope predictions difficult for all flows, compromising the accuracy of the stage-discharge relationship.

Non-horizontal water surface across the inundated channel width, at low-flows.

Possibility of pooled water at the cessation of flow.

F.5 CALEDON RIVER SITE 6

F.5.1 Positive attributes

Reasonably uniform flow conditions at medium flows and above.

F.5.2 Negative attributes

Location of site in bedrock morphology with rapidly varied flow conditions at low flows.

Large and irregular nature of the bed substrate (cobbles, boulders & bedrock). This makes resistance and energy slope predictions difficult for all flows, compromising the accuracy of the stage-discharge relationship.

Non-horizontal water surface across the inundated channel width, at low-flows.

Possibility of pooled water at the cessation of flow.

F.6 KRAAI RIVER SITE 7

F.6.1 Positive attributes

Reasonably uniform flow conditions at medium flows and above.

Location of gauging weir for determining discharges.

The data for the gauge (D1H001) is available at near real-time on the DWAF hydrology web site, making it useful for the collection of hydraulic data over the duration of the study.

F.6.2 Negative attributes

Possibility of divided and two-dimensional flow patterns at low flows.

Possibility of non-horizontal water surface across the inundated channel width, at low-flows.

Possibility of pooled water at the cessation of flow.

Due to these negative attributes, an additional low-flow cross-section was positioned downstream of the "main" cross-section.


ORASECOM