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DELINEATION OF MANAGEMENT RESOURCE UNITS

WORKING PAPER

Assessment of Environmental Flow Requirements

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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

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TERMINOLOGY AND 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	Quartenary 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 is the Orange River Catchment which traverses four countries, i.e. South Africa, Lesotho, Botswana and Namibia. The focus of the Resource Unit delineation is only for the rivers in which EFR sites will be selected, i.e. the Caledon River, Orange River downstream of Gariep Dam, the Kraai River and the Molopo River from its source to the Ramabatlama 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 (RUs). These are each significantly different to warrant their own specification of the Environmental Flow Requirements and the geographic boundaries of each must be clearly delineated. (DWAF, 1999, volume 3).

RUs are required as it would not be appropriate to set the same numerical EFR 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 EFR appropriate for that reach. The breakdown of a catchment into RUs for the purpose of determining the EFR for rivers is therefore 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, 1999, volume 3) also play a role in the delineation. An example could be where large dams and/or transfer schemes occur. Furthermore, the type of disturbance/impact on the river plays a role to select homogenous river reaches from a biophysical basis under present circumstances. These are called Management Resource Units (MRU) and the more detailed approach is described in Appendix A.

The delineation process considers all of the above issues. Overlaying all the data does not necessarily result in a logical and clear delineation and 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 to determine a logical and practical suite of MRUs.

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

The EFRs are determined for each MRU by means of either the following (Louw & Hughes, 2002):

- An EFR site is selected within the MRU and represents a critical site within the relevant river section. Results generated at the EFR site will then be relevant for the MRU as a whole.

- No EFR site is selected within the MRU and extrapolated results from adjacent MRU with EFR sites are used. The reasons for an EFR site not being selected within the MRU can be the following:

The characteristics of the river within the MRU do not meet the criteria for EFR sites.

Due to the number of MRUs within the study area, it is not practical and/or cost-effective to address an EFR site within each RU.

No estimations will be made for MRUs without EFR sites in as part of this study.

1.3 RESOURCE UNIT CONSIDERATIONS

1.3.1 EcoRegions (Level II)

The EcoRegion typing approach developed in the USA (Omernik, 1987) was applied and tested 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 current effort, used available information to delineate EcoRegion boundaries at a very broad scale (i.e. Level I) 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 zonation

Rowntree 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. After working in a number of different rivers around the country it has become clear that channel gradient is a good indicator of channel characteristics and that probable or expected difference can be identified from an analysis of gradients (Table 1.1).

Table 1-1 Geomorphological Zonation of River Channels (adapted Rowntree and Wadeson, 1999)

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 per 500 m strip on both sides of the river was provided electronically (**ftp://uranus.esrin.esa.int/pub/globcover_v2**) as maps as well as associated Excel spreadsheets. These spreadsheets provide a total summary of the hectares (ha) per quaternary catchments. This information is used to determine homogeneity of impacts and used in the decision-making regarding the MRUs. The data source (IWQS 500k rivers, Globecover regional land cover map) does not provide the same detail as that which DWA, RQS normally provides. One therefore also had to rely heavily on Google Earth, 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 impact on the hydrological characteristics of the river.

Orange River: Gariep Dam to Van der Kloof Dam

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

Orange River: Van der Kloof Dam to Prieska

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

Orange River: Prieska to Boegoeberg Dam

Mostly an inaccessible reach with little irrigation and developments.

Orange River: Boegoeberg Dam to Upington

Canal system, extensive irrigation for crops such as grapes.

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 less due to the river not being accessible. Irrigation occurs again at Onseepkans. between Onseepkans and Vioolsdrift. there is very little to no irrigation.

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 site outside of the cross-border Park, there are sections of mines and irrigation.

Caledon River: Source to Welbedacht Dam

Most of the area has Lesotho on the left bank (LB) with association sedimentation problems due to landuse protection. On the right bank (RB), formal irrigation and dry land irrigation take place. Many farm dams occur in the tributaries.

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

The only water flowing down the river is spills from the dam, inflows from tributaries and compensation water releases.

Molopo River (Upper)

The Molopo River originates at the Molopo Eye and water is directly abstracted to Mafikeng. The flow that is released in the river is used for agriculture. Further eyes occur lower down the river and this water is diverted into canal systems supplying Slurry as well as further agriculture. Within Mafikeng, the sewage systems are not functioning properly and the river (which usually does not flow at this stage), receives sewage discharge of bad quality. Various small dams in Mafikeng occur with the Modimola Dam just downstream of Mafikeng and the Dinoseng Dam further down. The river seldom flows in these reaches.

2 DELINEATION RESULTS: ORANGE RIVER

2.1 NATURAL RESOURCE UNITS

The EcoRegions and geomorphic zones are described in the map (Fig 2.1). The Natural Resource Units are derived from the EcoRegions and the geozones. The rationale for the delineation is provided in Table 2.1.

Table 2-1 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 geomorph 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 geomorph 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 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

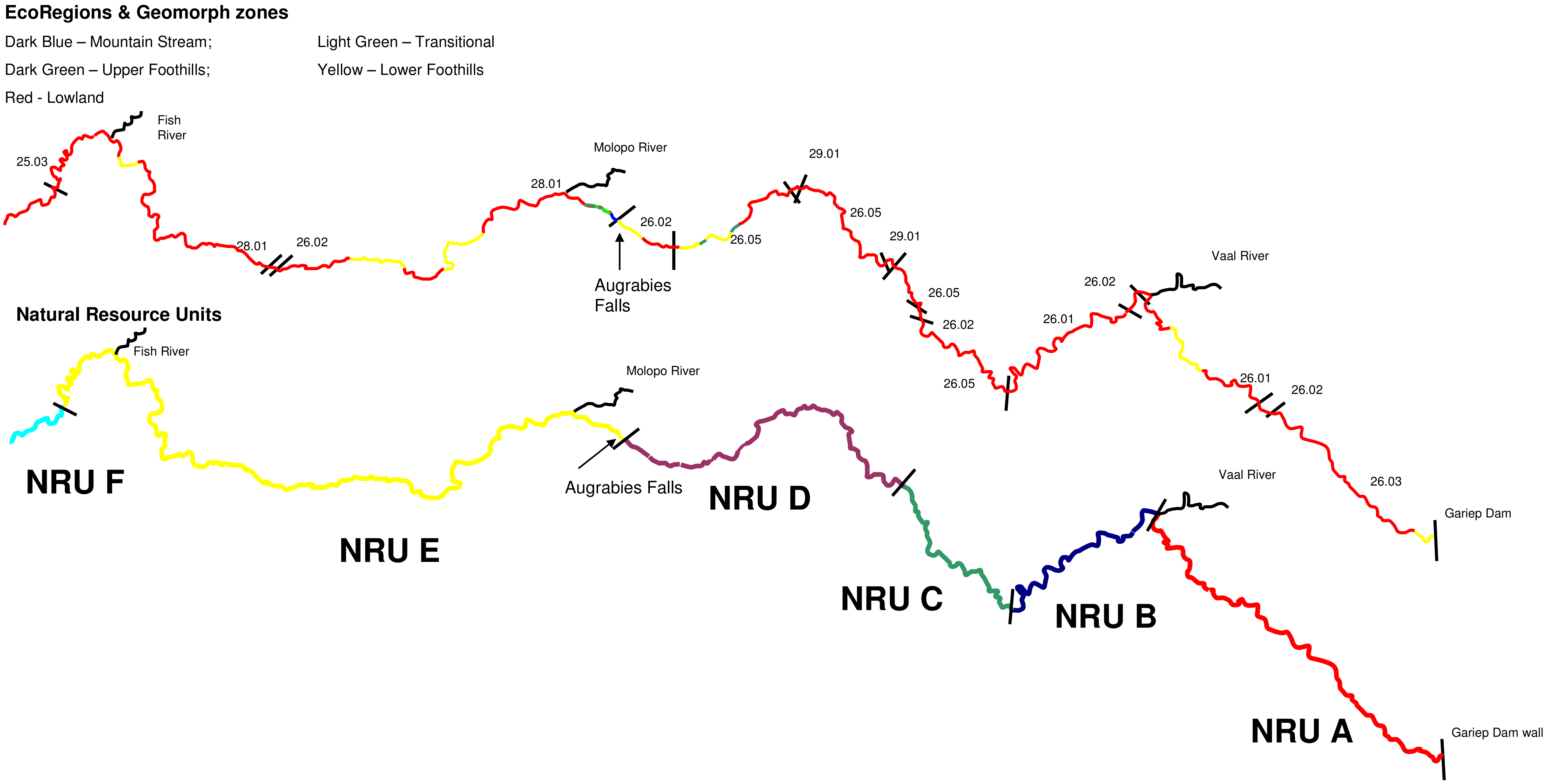

Figure 2-1 Natural Resource Units: Orange River

2.2 MANAGEMENT RESOURCE UNITS

The river is divided into MRUs and illustrated in Figure 2.2. The description of the MRUs and the rationale for selection is provided in Table 2.2.

Table 2-2 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. Van der Kloof 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 Van der Kloof 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. 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 not to 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	Van der Kloof 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.	Landuse 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 situation 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

All the MRUs are illustrated on Figures 6.1.

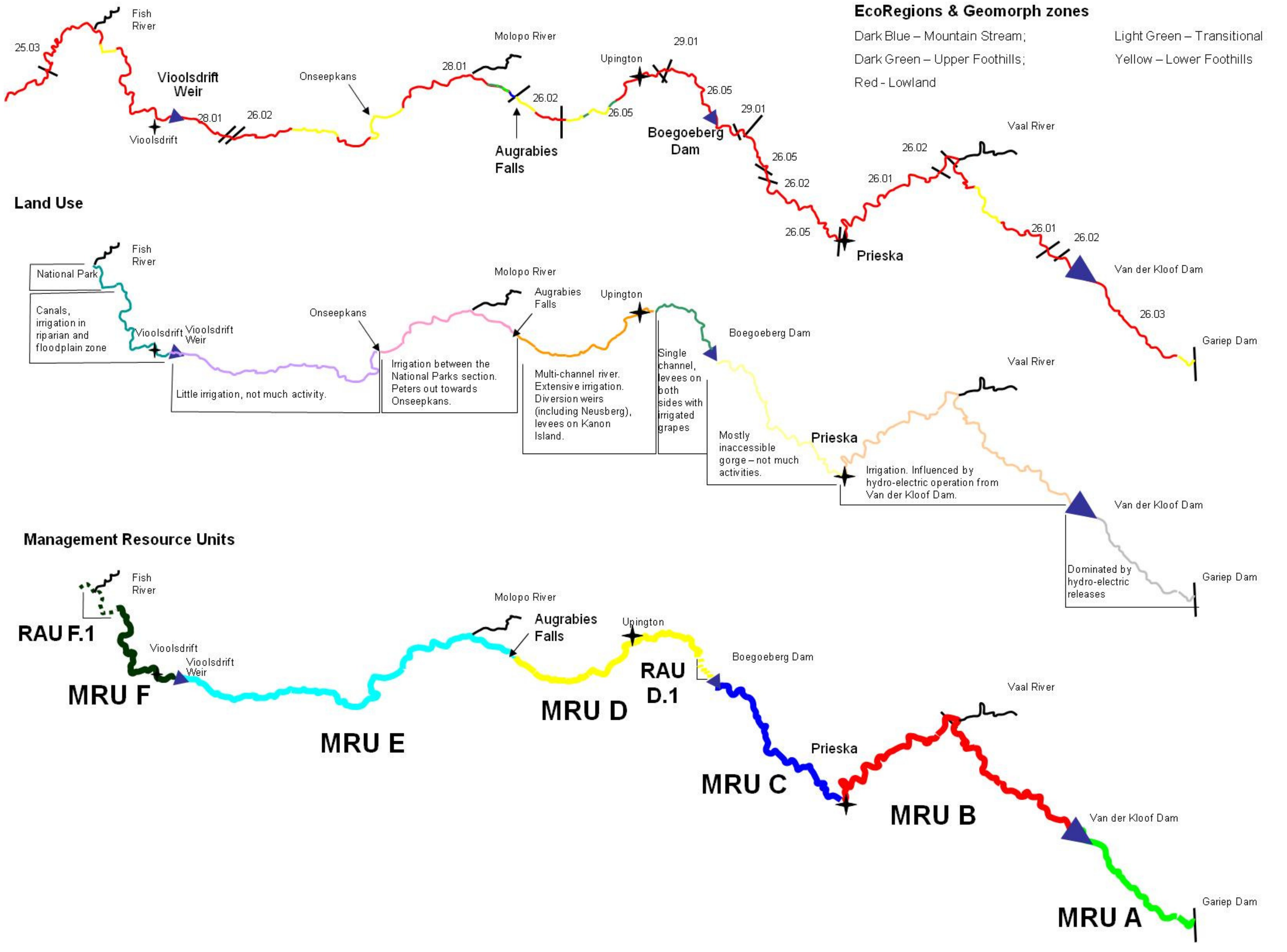

Figure 2-2 Management Resource Units

3 DELINEATION RESULTS: CALEDON RIVER

3.1 NATURAL RESOURCE UNITS

The EcoRegions and geozones are described in Fig 3.1. The Natural Resource Units are derived from the EcoRegions and the geozones. The rationale for the delineation is provided in Table 3.1.

Table 3-1 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 river is divided into MRUs and illustrated in Figure 3.2 and 6.1. The description of the MRUs and the rationale for selection is provided in Table 3.2.

Table 3-2 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 and than lower section which consists mostly of dryland farming LB: Subsitence farming, erosion and urban.	The section all falls within one geomorphic zone and with the same landuse 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

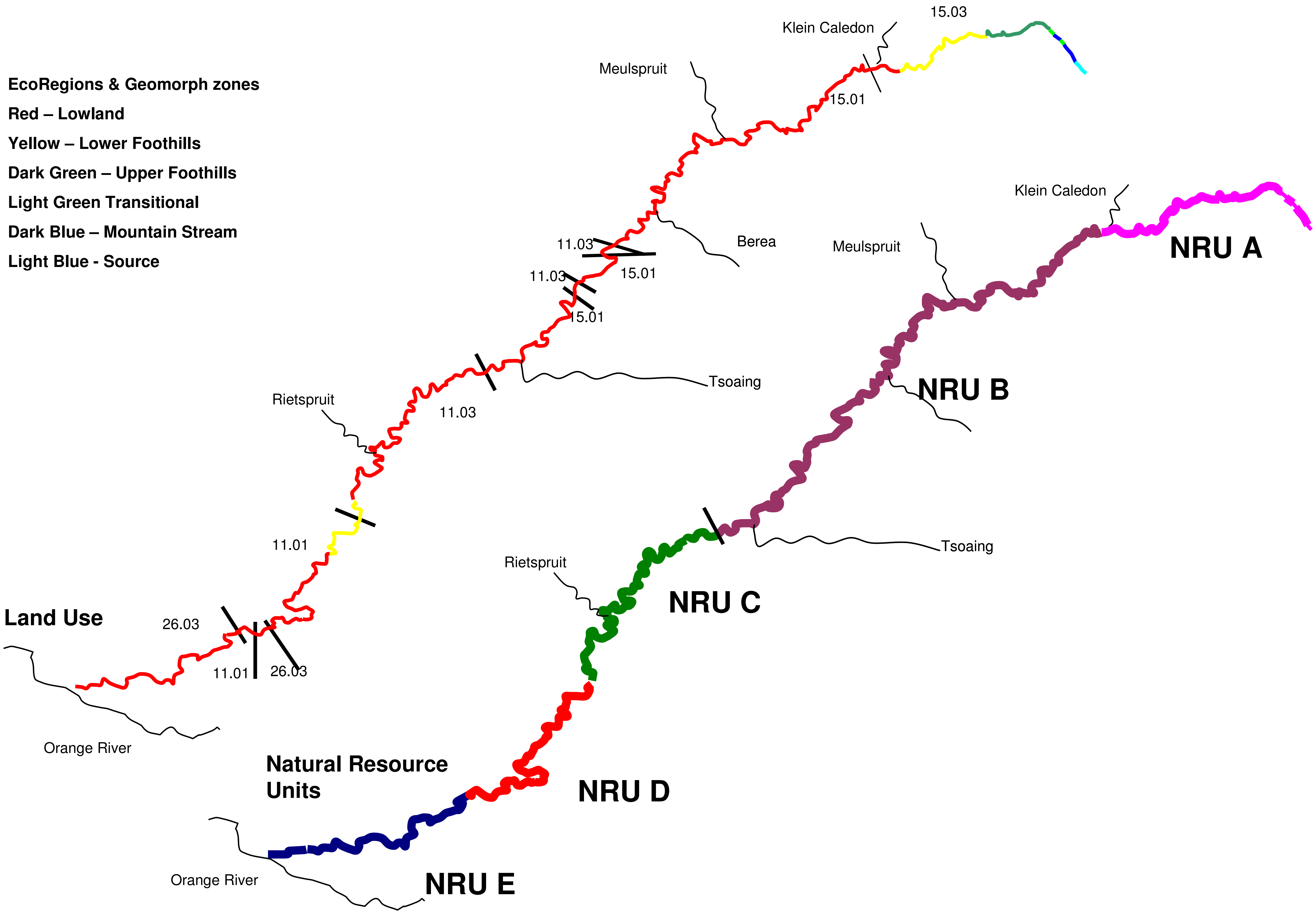

Figure 3-1 Natural Resource Units: Caledon River

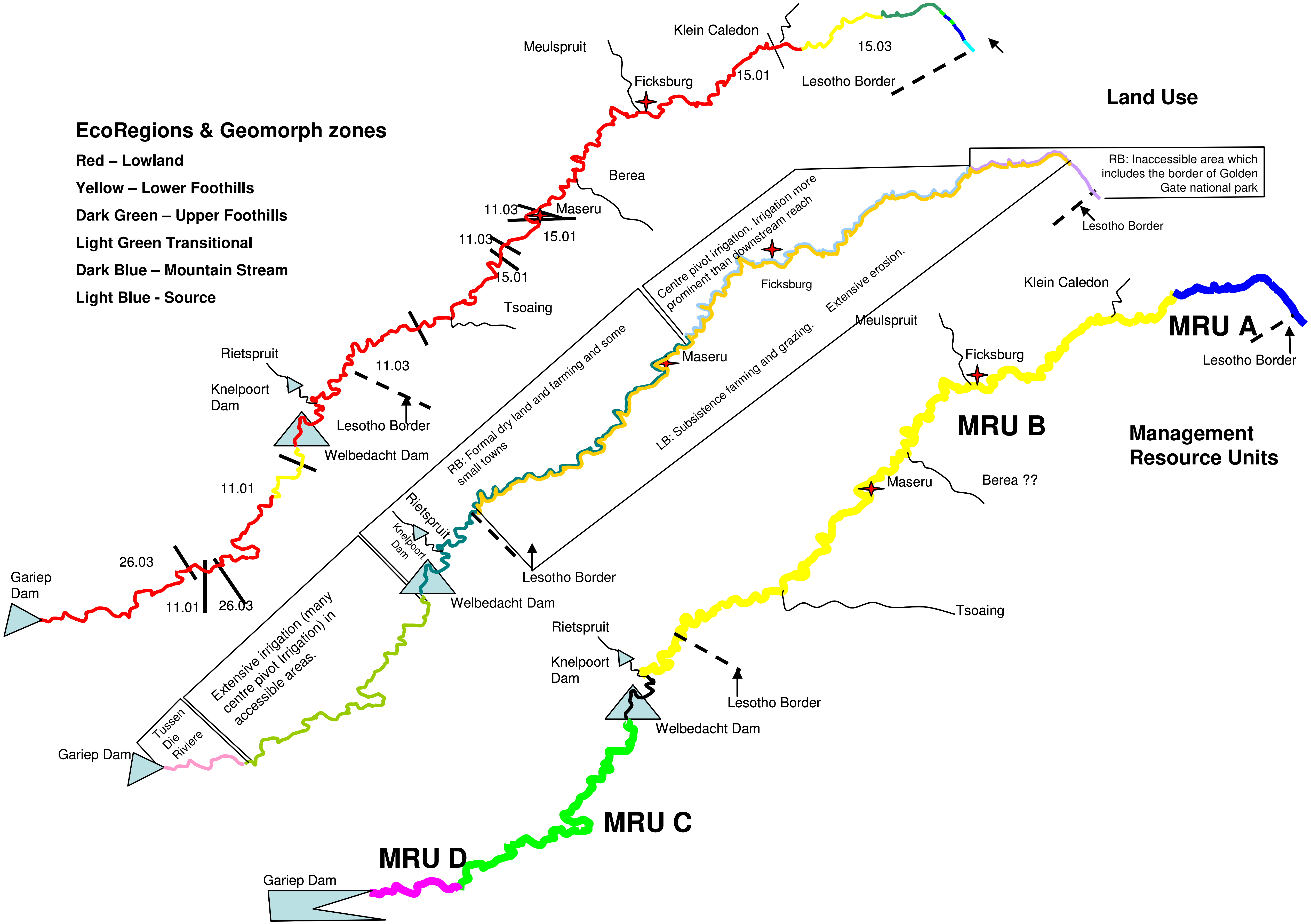

Figure 3-2 Management Resource Units: Caledon River

4 DELINEATION RESULTS: KRAAI RIVER

4.1 NATURAL RESOURCE UNITS

The EcoRegions and geozones are described in the map below (Fig 4.1). The Natural Resource Units are derived from the EcoRegions and the geozones. The rationale for the delineation is provided in Table 4.1.

Table 4-1 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 geomorph zone describes this long NRU A. The bottem 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 river is divided into MRUs and illustrated in Figure 4.2. The description of the MRUs and the rationale for selection is provided in Table 4.2.

Table 4-2 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.	Landuse 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	Landuse defines the MRU and the logical break of a change in landuse 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 landuse, 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

All the MRUs are illustrated on maps in Figure 6.1

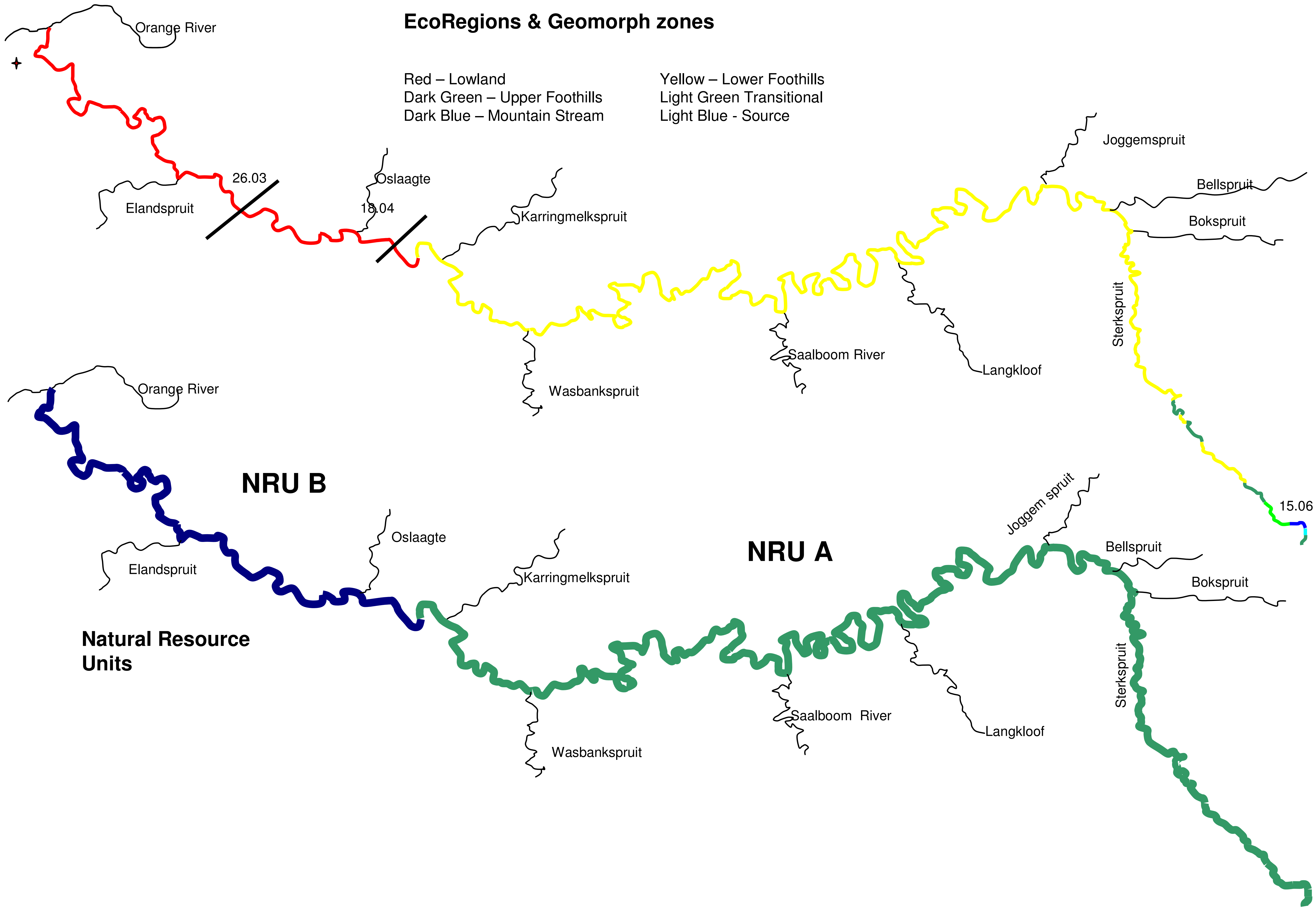

Figure 4-1 Natural Resource Units: Kraai River

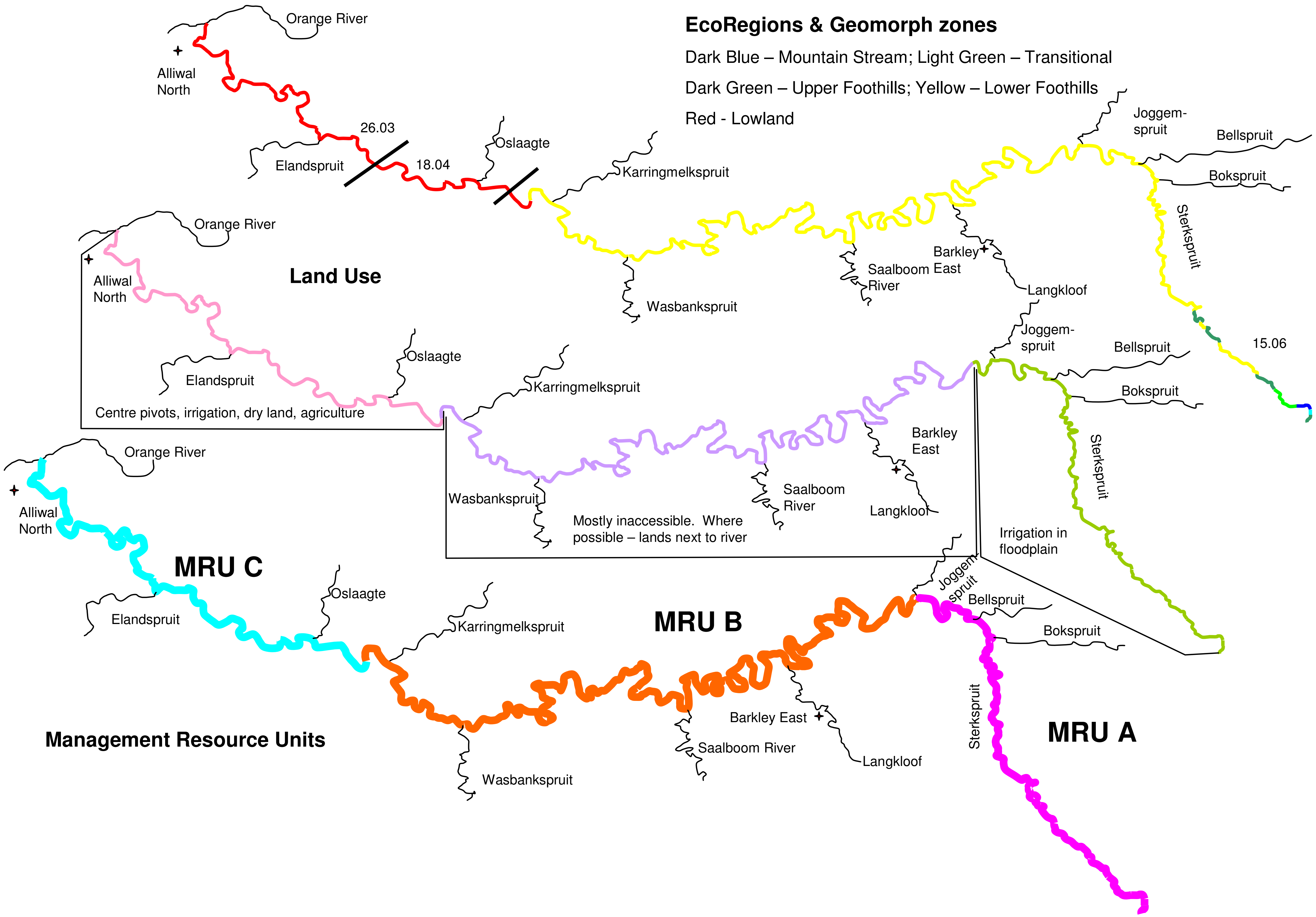

Figure 4-2 Management Resource Unit: Kraai River

5 DELINEATION RESULTS: UPPER MOLOPO RIVER

5.1 Natural Resource Units

The EcoRegions and geozones are described in the map below (Fig 5.1). The Natural Resource Units are derived from the EcoRegions and the geozones. The rationale for the delineation is provided in Table 5.1.

Table 5-1 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.	End of Upper Foothills to the Ramatlabama confluence -25.8737; 25.6139 -25.7641; 25.2174

5.2 MANAGEMENT RESOURCE UNITS

The river is divided into MRUs and illustrated in Figure 5.2. The description of the MRUs and the rationale for selection is provided in Table 5.2.

Table 5-2 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 landuse. 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 landuse. 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	EcoRegion Level 2	Geozone	Land cover 500m both banks	Rationale	Delineation	Quat
MRU UMolopo C	29.01 (100%)	Upper Foothills (100%)	Includes Mafikend and all its small dams, Bad water quality from, amongst others, 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 a trickle which is from return flows.	The section between the dams is isolated, has a specific landuse 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.	Landuse and all other criteria similar to the Botswana border and the Ramabatlama confluence.	Disaneng Dam wall to the Ramabatlama confluence -25.8237; 25.3129 -25.7641; 25.2174	D41A

All the MRUs are illustrated on maps in Figure 6.1.

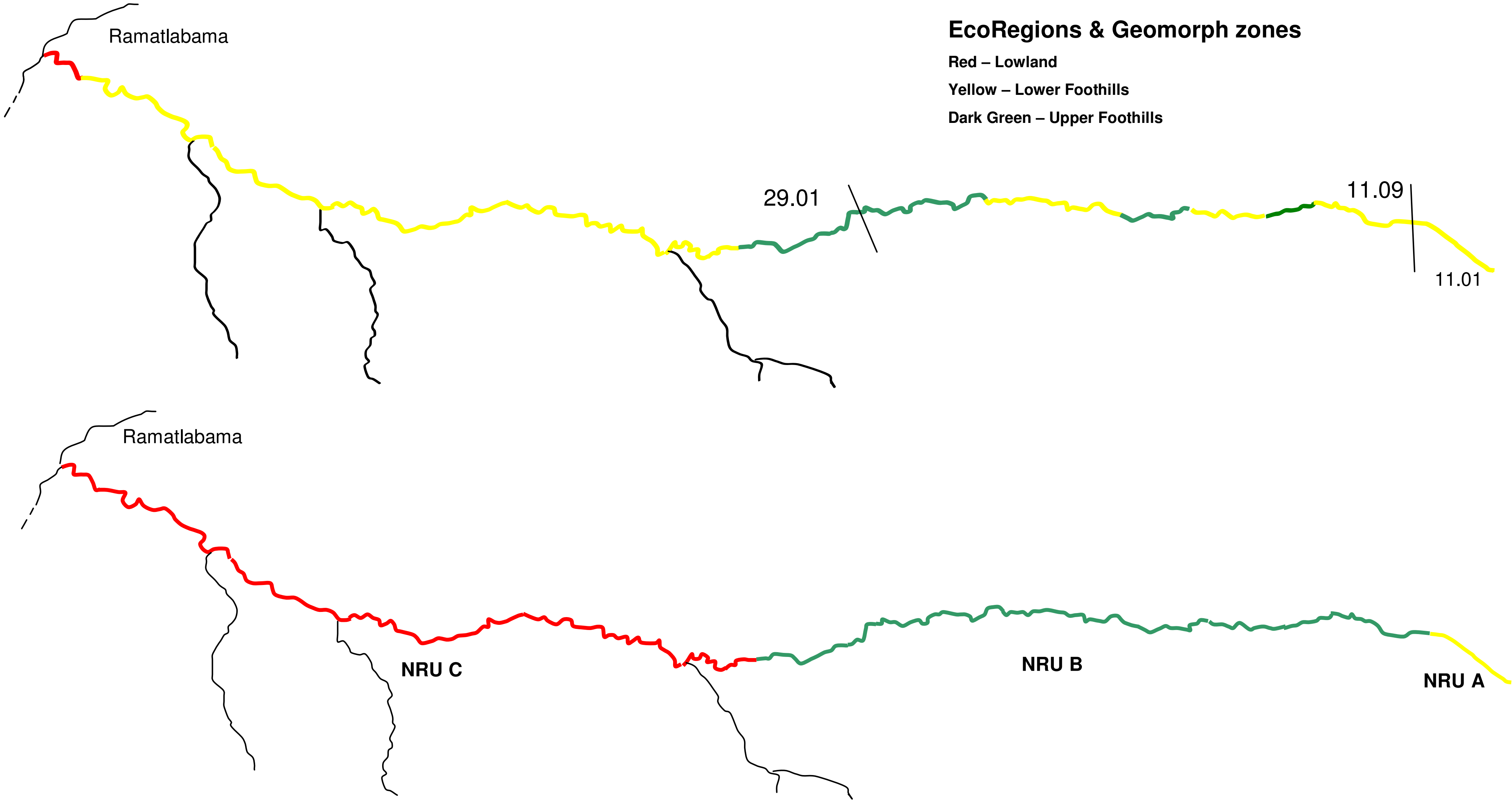

Figure 5-1 Natural Resource Units: D41A

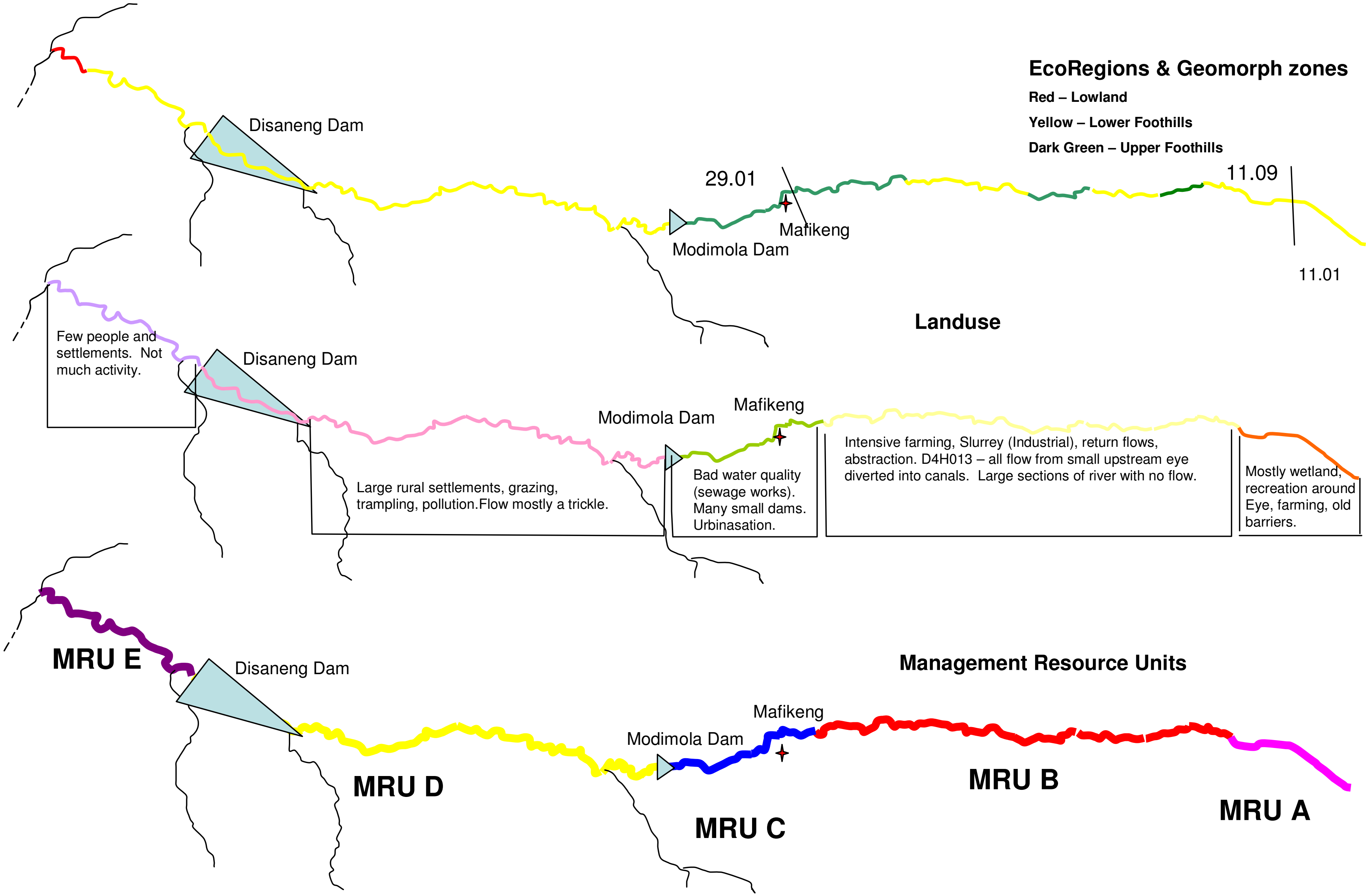

Figure 5-2 Management Resource Units: D41A

6 EFR SITE SELECTION

6.1 CRITERIA FOR SITE SELECTION

EFR sites (previously called IFR sites and referred to as EFR sites in South Africa) are selected through a multi-disciplinary process consisting of evaluating an aerial video (if available) or Google Earth images of the river to identify a range of possible sites, and groundtruthing to make a final selection from the various options. An EFR site consists of a length of river which includes one or various cross-sections for both hydraulic and ecological purposes (modified from Louw *et al.*, 1999).

EFRs are determined at each of the EFR sites, and it is therefore vital that:

- The sites are selected to provide as much information as possible about the variety of conditions in a river reach.
- The specialists that need to use these sites to set flow requirements for their discipline can relate to the habitat the sites represented.
- The persons involved in selecting the sites understand and are experienced in the use of sites in EFR studies.

The selection of EFR 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 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, and consequently, the biota dependant on this habitat and/or perennial flow are adversely affected. Pools are

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

The criteria in bold are the most important and therefore overrides the other criteria.

6.2 LOCALITY AND DESCRIPTION OF SITES

The locality of the EFR sites within the MRUs as identified during this study is provided in Table 6.1 and 6.2 and in Figure 6.1.

Table 6-1 Locality and characteristics of EFR sites

EFR site number	EFR site name	River	Decimal degrees S	Decimal degreees 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 EFR sites are provided in Table 6.1.

Table 6-2 Locality, characteristics and view of the EFR 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 *River* *Previous IFR site* *National RHP site* *Decimal Degrees* *EcoRegion (Level II)* *Geozone* *Altitude (m)* *RU* *Quaternary* *Farm name* *Hydrological gauge*	EFR O4 Vioolsdrift Orange - - -28.75525, 17.71696 28.01 Lowland 167 MRU Orange F D82F - D8H013	
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 C5 Caledon Rapid III - -28.65078, 28.3875 15.03 Lower Foothills 1640 MRU Caledon B D21A Kromdraai 106 -	
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 C6 Lower Caledon Caledon - D2Cale_Tusse -30.4523, 26.27088 26.03 Lowland 1270 MRU CaledonD D24J Inhoek 336 -	

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 K7 Kraai Kraai - - -30.8306, 26.92056 26.03 Lowland 1327 MRU Kraai C D31M Witkoppies 96/2 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 locality of sites is illustrated in Figure 6.1.

6.2.1 Site suitability

The site suitability of each site was assessed and is provided in Table 6.3 and 6.4. The detail assessment per component is provided in Appendix B. All scores are out of 5 with 5 referring to very high suitability (see below).

Very High: 4.1 – 5

High: 3.1 – 4

Moderate: 2.1 – 3

Low: 1.1 – 2

Very Low: 0 – 1

Table 6-3 Biophysical Site suitability for the Crocodile system

EFR sites	Geomorph	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 geomorph 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 geomorph 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 geomorph 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. Geomorph and invertebrates fall in the Very High range.

The above table illustrates the site suitability from a biophysical point of view. Any comments regarding outliers are also provided. From a biophysical point of view, the sites all fell into the High suitability apart from EFR 4 and EFR 6. The fish suitability is mostly the lowest for EFR 3, 5 and 6. This is mostly related to the natural lack of diversity of species for setting flow requirements. This is not necessarily applicable in systems where they do not naturally occur, and the evaluation process will require to be revised in future.

At this stage, only hydraulic site suitability is evaluated as the other information is only generated later during the project. As this does provide an indication of the complexity of the hydraulic modelling, it can be used as an initial estimate of confidence. For the purposes of determining flow requirements, the low flows and high flows are evaluated separately. Geomorphology and vegetation usually are the most crucial components for high flows and fish and invertebrate for low flows.

The suitability of the sites is therefore evaluated for both low and high flows and 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 6.4 Integrated Site suitability for the Crocodile 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 suibility. A long record of daily flows is more important than the hydraulics with the setting of floods. In this case therefore 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 have a high suitability, and a gauge is present. The hydraulic rating therefore 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 suibility. A long record of daily flows is more important than the hydraulics with the setting of floods. In this case however, the hydraulics have a high suitability, and a gauge is present. The hydraulic rating therefore 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. The lowest rating between hydraulics and the biophysical components therefore 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. The lowest rating between hydraulics and the biophysical components therefore 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 have a high suitability, and a gauge is present. The hydraulic rating therefore represents the overall rating

In conclusions, the overall suitability for low flows range from low (2) to moderate (3). This is mostly due to the complex sites in terms of hydraulics. The sites where low is shaded orange in Table 6.4 is however potentially not a problem as a logger was installed at these sites to obtain a wide range of calibrations. As no gauge and no 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 EFR determination increases proportionately more if a gauge with a long record of daily flows is sufficiently close to the site. The presence of such a gauge weighs higher than the hydraulic confidence. Apart from the EFR 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.

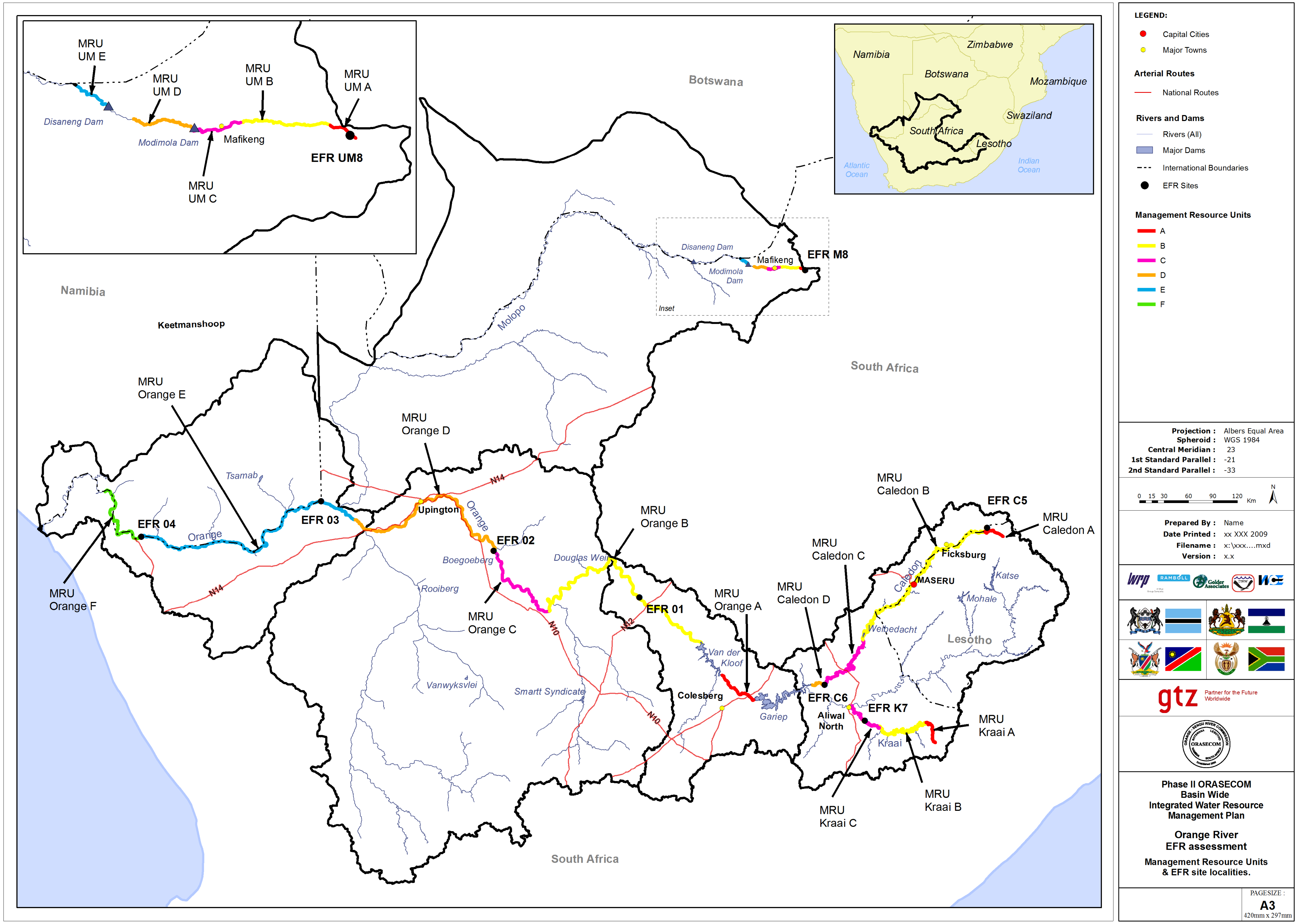

Figure 6-1 Management Resource Units and EFR sites

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