Orange-Senqu River Basin

Orange-Senqu River Commission Secretariat
Governments of Botswana, Lesotho, Namibia and South Africa

UNDP-GEF
Orange-Senqu Strategic Action Programme
(Atlas Project ID 71598)

Delineation of Management Resource Units

Research Project on Environmental Flow Requirements of the Fish River and the Orange-Senqu River Mouth

Technical Report 22
Rev 0, 20 April 2012

UNDP-GEF
Orange-Senqu Strategic Action Programme

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This report has been issued and amended as follows:

Revision	Description	Date	Signed
0		20 April 2012	DL

Project executed by:

UNOPS

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Acronyms and abbreviations

EFR	*Environmental Flow Requirements*	*MRU*	*Management Resource Unit*
NRU	*Natural Resource Unit*	*RU*	*Resource Unit*

1 River Reach Demarcation and Delineation

1.1 Study Area

The study area for the Environmental Flow requirements includes the:

- Orange-Senqu River from the Fish River confluence downstream to the Orange-Senqu River Mouth including the Estuary and the immediate marine environment.
- Fish River in Namibia.

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 and therefore warrant their own specification of the EFRs. The geographic boundaries of each must also be clearly delineated (DWAF, 1999, Volume 3).

RUs are required, as it would be inappropriate to set the same numerical EFR for the headwaters of a river, and 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 done primarily on a biophysical basis within the catchment and called Natural Resource Units (NRUs). The more detailed approach is described in DWAF (2008).

Management requirements (DWAF, 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 DWAF (2008).

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 MRUs.

MRUs can be further delineated in even smaller assessment units and the approach is described in DWAF (2008).

The EFRs are determined for each MRU by means of either of 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 MRUs 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 MRU.

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

1.3 Resource Unit Considerations

1.3.1 *EcoRegions (Level I and 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 Flow 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) EcoRegional classification is based on 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), is based on 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.

EcoRegions are not available for Namibia and therefore geomorphological zonation (see Section 1.3.2) and local knowledge had to be used for the above-mentioned process.

1.3.2 *Geomorphological Zonation*

Rountree and Wadeson (1999) 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 riverine 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 an accurate indicator of channel characteristics and those probable or expected differences can be identified from an analysis of gradients (Table 1).

Table 1. Geomorphological zonation of river channels (adapted Rountree and Wadeson, 1999).

Longitudinal zone	Zone class	Characteristic channel features
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 500m strip on both sides of river maps was obtained from work undertaken as part of the Desktop EcoClassification (Louw *et al.,* 2010a) with additional back up of a visual assessment of Google Earth, personal observations and local knowledge. This information was used to determine homogeneity of impacts and used in the decision-making regarding the MRUs.

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.

2 Delineation Results: Orange-Senqu River

Resource Units of the Orange-Senqu River have already been described during a recent basin-wide study (Louw *et al.,* 2010b). The Natural Resource Units (NRUs) as previously determined are summarised in Section 2.1. Note, for the sake of simplicity, all numbering is maintained as during this previous study.

2.1 Natural Resource Units

The NRUs are derived from the EcoRegions and the geomorphic zones (geozones) and the rationale for the delineation is provided in Table 2. The EcoRegions and geomorphic zones are described in Figure 1.

Table 2. Description and rationale for the Orange-Senqu River Natural Resource Units.

NRU	EcoRegion Level 2	Geozone	Rationale	Delineation
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 Augrabies Falls (upstream border) and the change from river to estuary (i.e. downstream border).	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 and river where tidal fluctuations might still occur.	End of 28.01 (estuary) to sea. -28.3904; 16.7772

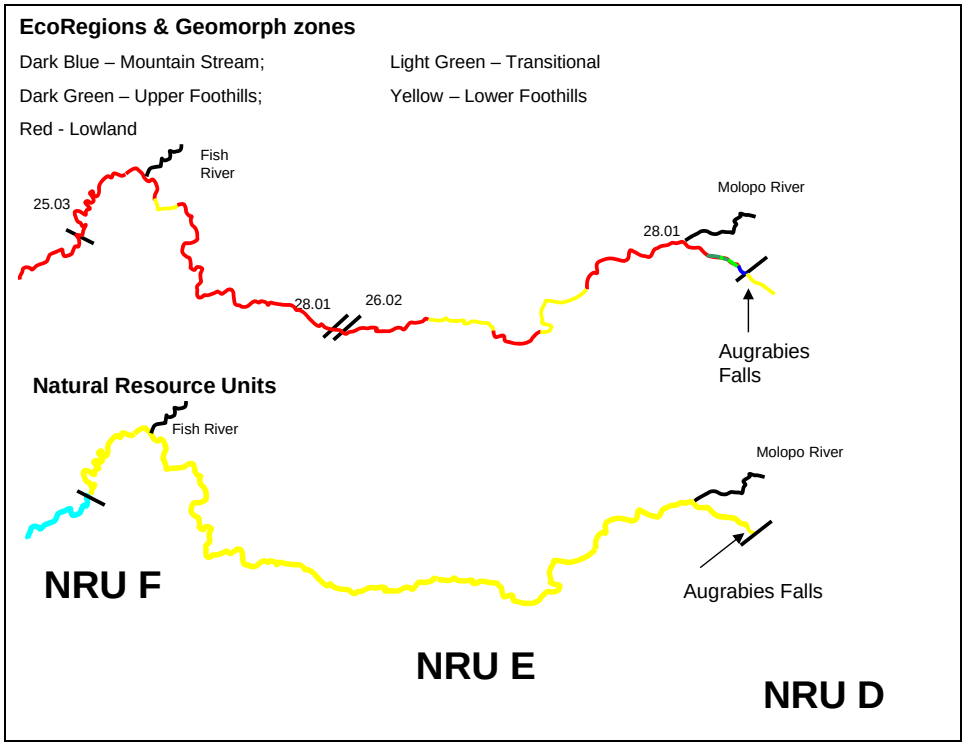

Figure 1. EcoRegions, geomorphic zones and resulting Natural Resource Units of the Orange-Senqu River.

2.2 Management Resource Units

To determine the Management Resource Units (MRUs), landuse as well as the operational use of the river is considered to determine whether the NRUs require adjustments. This is to ensure that the Management Resource Unit consists of relatively homogenous land use (disturbance). During the previous study, the MRUs downstream of the Fish River were not identified.

2.2.1 *Landuse and Landcover*

The landuse is grouped into four activities (Figure 2) that occur from the upstream sections of the Orange-Senqu River to downstream to the Orange-Senqu River Mouth:

- Nature Reserve: Ai-Ais Richtersveld Transfortier Park characterised by development associated with ecotourism. The most significant disturbances (apart from the change in flow regime) are the gravel road on the right bank (Namibia) and some remnants of old mining activities.

- Mining activities: Mining activities (current and defunct) are present along the whole stretch to the mouth. This stretch, however, is the only section dominated by mining as the only disturbance.
- Irrigation takes place in this section and within the Alexander Bay town on the next section. The irrigation is within the riparian zone and mostly on the left bank.
- This section consists of Alexander Bay next to the estuary and with some irrigation virtually in the town. On the Namibian side there is Oranjemund which is also mainly a mining town. Oranjemund is not in as close proximity to the river/estuary than Alexander Bay is.

Figure 2. Google Earth images of the different landuses within the MRUs of the Orange-Senqu River.

2.2.2 *System Operation*

Within the context of this study, the Lower Orange refers to the section of the Orange-Senqu River downstream of the confluence with the Fish River. The Orange-Senqu River along this reach, and for several hundreds of kilometres upstream of this, experience a natural negative water balance in that the incremental inflow from tributaries and interflow are less than the evaporation from the surface of the river. Hence all users in the Lower Orange-Senqu River have to be supplied from upstream. The most downstream flow control is the Vanderkloof Dam. This dam is located far upstream of the irrigation requirements located around Upington, Keimoes, Kakamas and Vioolsdrift/Noordoever and hence releases have to be carefully coordinated. Water is also released from this dam to generate hydropower and this water serves a dual purpose of water supply to irrigators and towns located along the river. In additional to these releases, there are significant return flows from irrigation practices along the river.

Water requirements on the Lower Orange (downstream of the confluence with the Fish River) are limited. The only significant use is an abstraction of some12 million m^3/annum at Brand Karos, some 30km upstream from the mouth, supplying a relatively small irrigation area as well as domestic water demands of Alexander Bay.

2.2.3 *MRU Results*

The MRUs are illustrated in Figure 3 while the rationale for MRU selection is provided in Table 3.

Table 3. Description and rationale of the Orange-Senqu River Management Resource Units.

MRU	EcoRegion Level 2	Geozone	Land cover	Rationale	Delineation
MRU Orange G	28.01 (70%) 25.03 (30%)	Lowland (100%)	National Parks, mining, irrigation	Although the landuse is vastly different, the operation is the same for this area i.e. a conduit for water through to the downstream mining areas which include irrigation and towns. It was therefore decided that one MRU is relevant. However, for EFR determination, this section includes a critical area. This area is within the Transfortier Park and as it is less disturbed than the downstream reaches, will include a greater variety of indicators for EFR assessment. An EFR site should then preferably be situated within this section. This would ensure that all the components of the ecosystem are catered for during EFR assessment.	Fish confluence -28.7041; 17.4681 to start of the estuary -28.56118; 16.5238
MRU Orange H (estuary)	25.03 (100%)	Lowland (100%)	Mining, irrigation, towns	As an estuary often has a different EFR than a river, this fact warrants a separate MRU from the upstream river section. The upstream border has been set by the estuarine specialists as the area which, under current conditions is the section that should be managed as the estuary. It is possible that under natural condition (with a frequently closed mouth), the estuary border could have been further upstream.	Estuary -28.56118; 16.5238 to mouth.

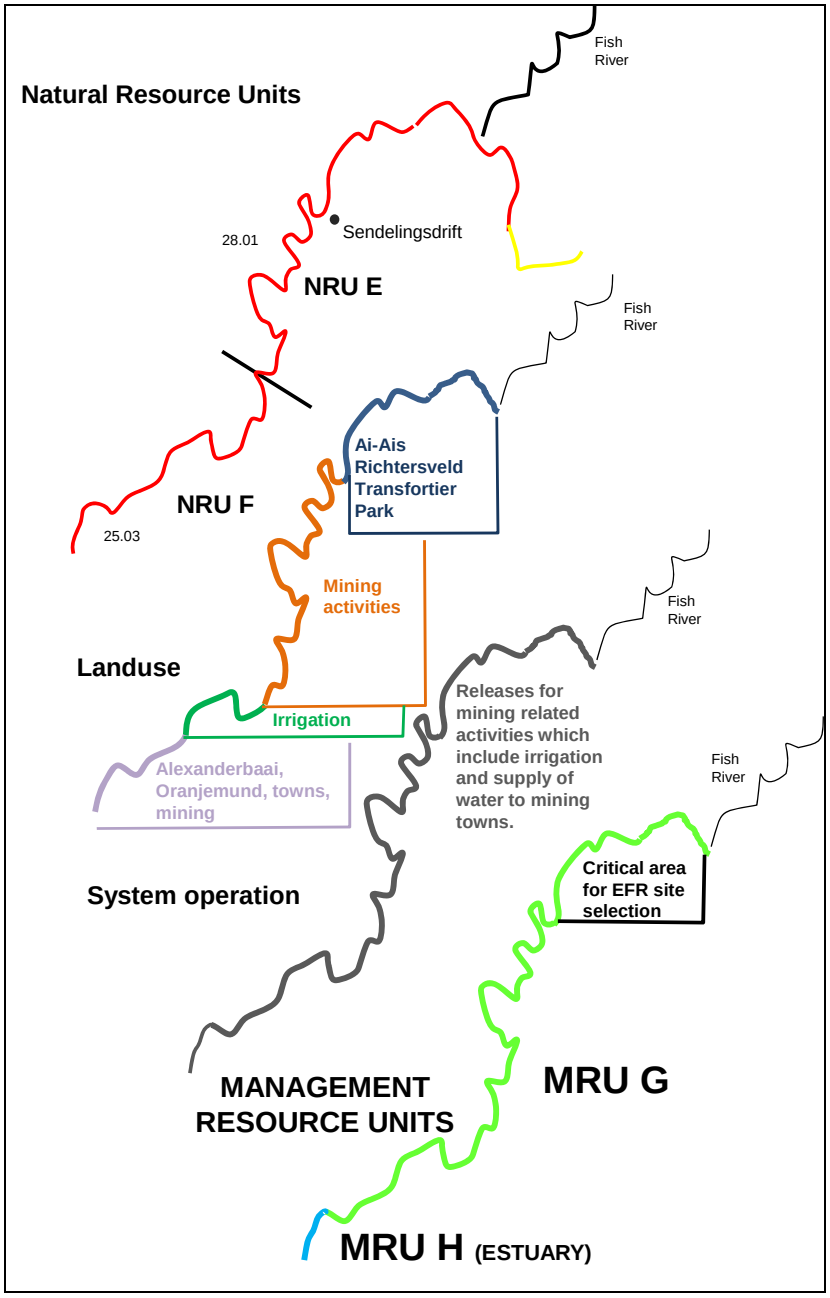

Figure 3. Landuse and operation of the Orange-Senqu River system leading to the delineation of the MRUs.

3 Delineation Results: Fish River

3.1 Natural Resource Units

The longitude profile indicating the geomorphic zones of the Fish River is provided in Figure 4. The NRUs were derived from the EcoRegions and the geozones. EcoRegional classification was not available for Namibia and therefore the geomorphic zones were used as a surrogate. These zones therefore provide the borders between the three NRUs. The rationale for the delineation is provided in Table 4 and the results provided in Figure 5.

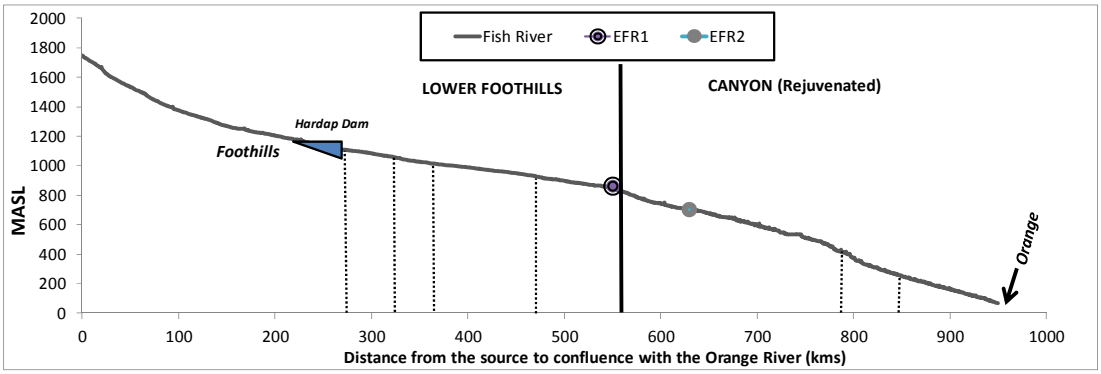

Figure 4. Longitude profile of the Fish River.

Table 4. Description and rationale for the Fish River Natural Resource Units.

NRU	Geozone	Rationale	Delineation
NRU Fish A	Lower foothills (100%)	The upper section of the Fish River falls within the Lower Foothills zone which is on average steeper than the downstream area.	Source to Hardap Dam. -24.505939 E17.045655 -24.495522; 17.858771.
NRU Fish B	Lower foothills (100%)	The downstream break lies between the Lower foothill geomophic zone and the rejuvenated source.	Lower Foothill zone downstream of Hardap Dam. -24.495522; 17.858771 -26.284259; 17.752712.
NRU Fish C	Rejuvenated (Canyon) (100%)	The above break to the Orange-Senqu River confluence.	Rejuvenated zone from EFR 1 to Orange-Senqu River. 26.284259; 17.752712.

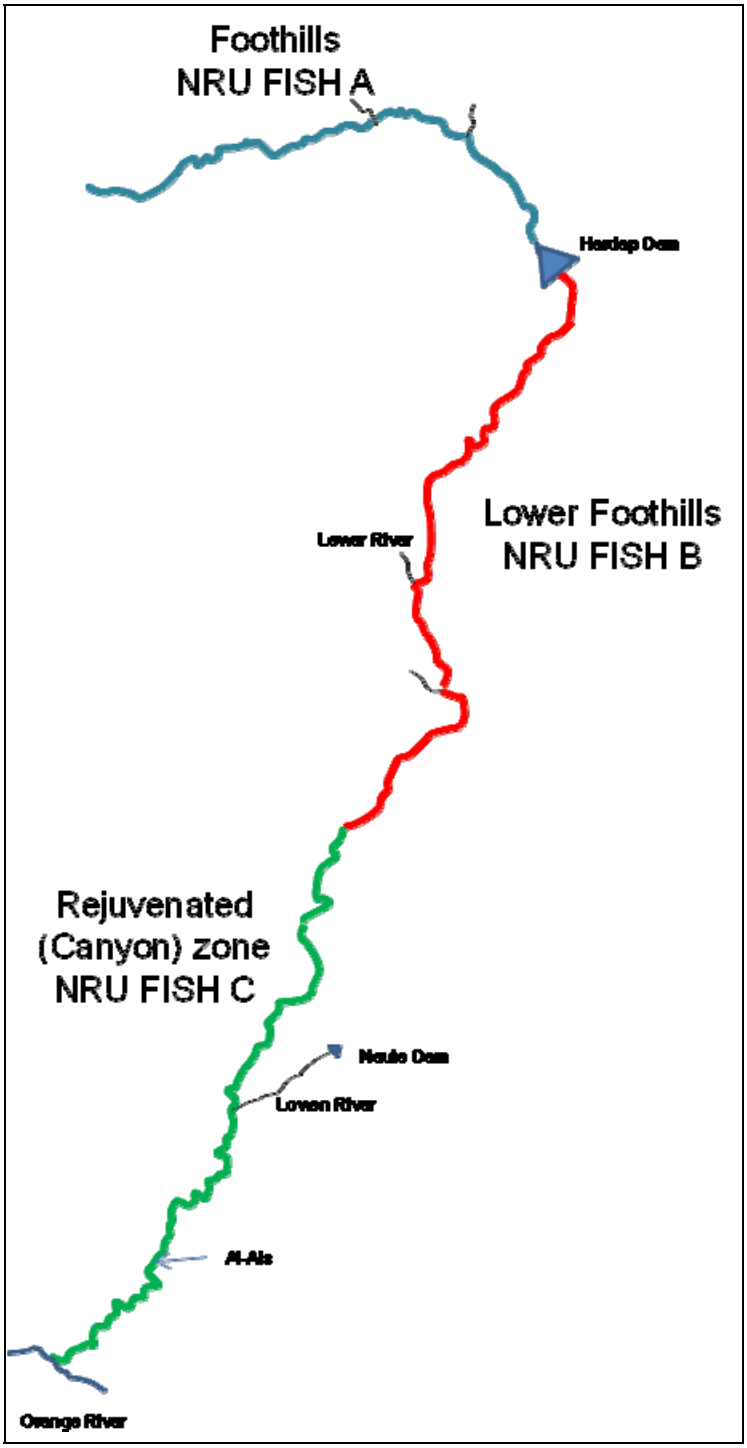

Figure 5. Natural Resource Units of the Fish River, Namibia.

3.2 Management Resource Units

To determine the MRUs, landuse as well as the operational use of the river is considered to determine whether the NRUs require adjustment. The MRU consists of relatively homogenous landuse (disturbance). The focus of the MRUs is downstream of Hardap Dam only. The upstream section, NRU Fish A, is not included in the assessment as the flow management options are limited.

3.2.1 *Landuse and Landcover*

The landuse (Figure 6) immediately downstream of Hardap Dam is dominated by intense irrigation activities for about 4 km. The town of Mariental is also situated here. Further downstream, the land use is mostly related to livestock farming, formal and subsistence farming. Downstream of Seeheim the Fish River Canyon becomes a prominent feature and the land use is related to Nature Reserves and the Ai-Ais Richtersveld Transfortier Park.

3.2.2 *System Operation*

The Fish River Catchment is located within Southern Namibia and is one of the largest river basins in Namibia. The river basin is relatively under-developed and has a low population density due to the highly arid and generally infertile nature of the soil. The Fish River Catchment rises to the south of Windhoek and flows in a generally southwards direction for a distance of 635 km before its confluence with the Orange-Senqu River about 100 km northwest of Noordoewer.

The total area of the Fish River Catchment is 95 680 km^2 and consists of 11 tributaries. The Kam, Schlip and Kalf tributaries originate in the central highland area south of Rehoboth before joining the mainstream of the Fish, whilst the Narub and Usib Rivers flow from the eastern foothills of the Naukluft Mountains. The Hutup, Lewer and Kanibes Rivers drain from the northern and eastern parts of the Schwarzrand Mountains. The Löwen and Gaub Rivers originate in the Groot Karas Mountains and the Konkiep in the western Schwarzrand (Crerar and Maré, 2005).

The total Fish River Catchment was divided into five sub-catchments by Crerar and Maré (2005) and is referred to as Hardap, Konklip, Lower Fish, Naute and Seeheim. The sub-catchments were based on the location of existing dams and key flow gauging stations. A summary of the characteristics of the sub-catchments are provided in Table 5.

Table 5. Characteristics of Fish River sub-catchments (from Crerar and Maré, 2005).

Sub-Catchment	Catchment Area (km²)		Natural Mean Annual Runoff (million m³/a)[1]
	Incremental	Cumulative	
Hardap	13 600	13 600	194.67
Naute	8 630	8 630	61.22
Seeheim	32 800	46 400	346.49
Konkliep	32 000	32 000	48.16
Lower Fish	8 650	63 680	88.01
Total	**95 680**	**95 680**	**738.55**

1 For the period 1920 to 1999 (hydrological years).

Although a total natural runoff of 739 million m³/a is generated from the Fish River Catchment, only 512 million m³/a reaches the Orange-Senqu River under natural conditions, as 224 million m³/a is lost due to evaporation and riverbed losses. These losses are exacerbated by the encroachment of vegetation into the riparian zone of rivers.

There are two major dams on the Fish River Catchment, the Hardap Dam in the Middle Fish River close to Mariental and the Naute Dam on the Löwen River close to Keetmanshoop. Hardap Dam has a gross storage capacity of 294 million m³ and is used to supply water to irrigation (2 200ha) and the total water requirement for Mariental. Naute Dam is significantly smaller than Hardap Dam and has a gross storage capacity of 84 million m³. Naute Dam supplies water to Keetmanshoop, as well as irrigation (290 ha). Water is supplied directly from the dams via pipeline and no releases are made from these dams.

3.2.3 *MRU Results*

The MRUs are illustrated in Figure 6 while the rationale for MRU selection is discussed below and summarised in Table 6.

MRU Fish A: The proposed Neckartal Dam forms a logical management border as the downstream operation of the new dam will be different from that of Hardap Dam as it will make environmental releases. Currently, Hardap Dam makes no downstream releases for the environment. The only releases are made to prevent the dam from spilling, as spilling causes flooding in Mariental. MRU Fish A is the section of river upstream of Neckartal Dam to Hardap Dam.

MRU Fish B: The rest of the river forms one MRU. It can be questioned why a break is not made at the confluence of the Löwen River on which Naute Dam is situated. Naute Dam is small and on

a tributary. It makes no releases to the downstream river. It would also not be practical to make releases for EFRs from this dam as the requirements will be floods. Being on a tributary, of small size, and probably small outlets, this is not a feasible option. The operation of the downstream Fish River from Neckartal Dam will therefore be managed from Neckartal Dam in terms of EFRs.

EFR sites have been selected in each MRU (Figure 6). Flow requirements will also be assessed at a broader level (not just focussing on EFR sites) by investigating a range of different types of pools occurring down the river.

Table 6. Description and rationale of the Fish River Management Resource Units.

MRU	Geozone	Land cover	Rationale	Delineation
MRU Fish A	Lower Foothills (85%) Canyon (15%)	Irrigation (1%) Livestock farming (99%)	The system operation downstream of Hardap Dam is similar to the stretch of River from Hardap Dam to the Neckartal Dam (soon to be constructed). An EFR site should be situated in the Lower Foothills section as it represents the larger section of the river and is assumed to be homogenous in terms of ecosystem functioning.	Hardap Dam --24.495522; 17.858771 to Neckartal Dam -26.6643361; 17.726105
MRU Fish B	Canyon (100%)	Nature reserves (90%) Other (Seeheim, livestock farming)	The rest of the Fish River will be managed from Neckartal Dam so no other operational break is required. As it is one geomorphic zone, the area is also ecologically similar, and one EFR will be applicable for the whole zone.	Neckartal Dam -26.6643361, 17.726105 to Orange-Senqu River.

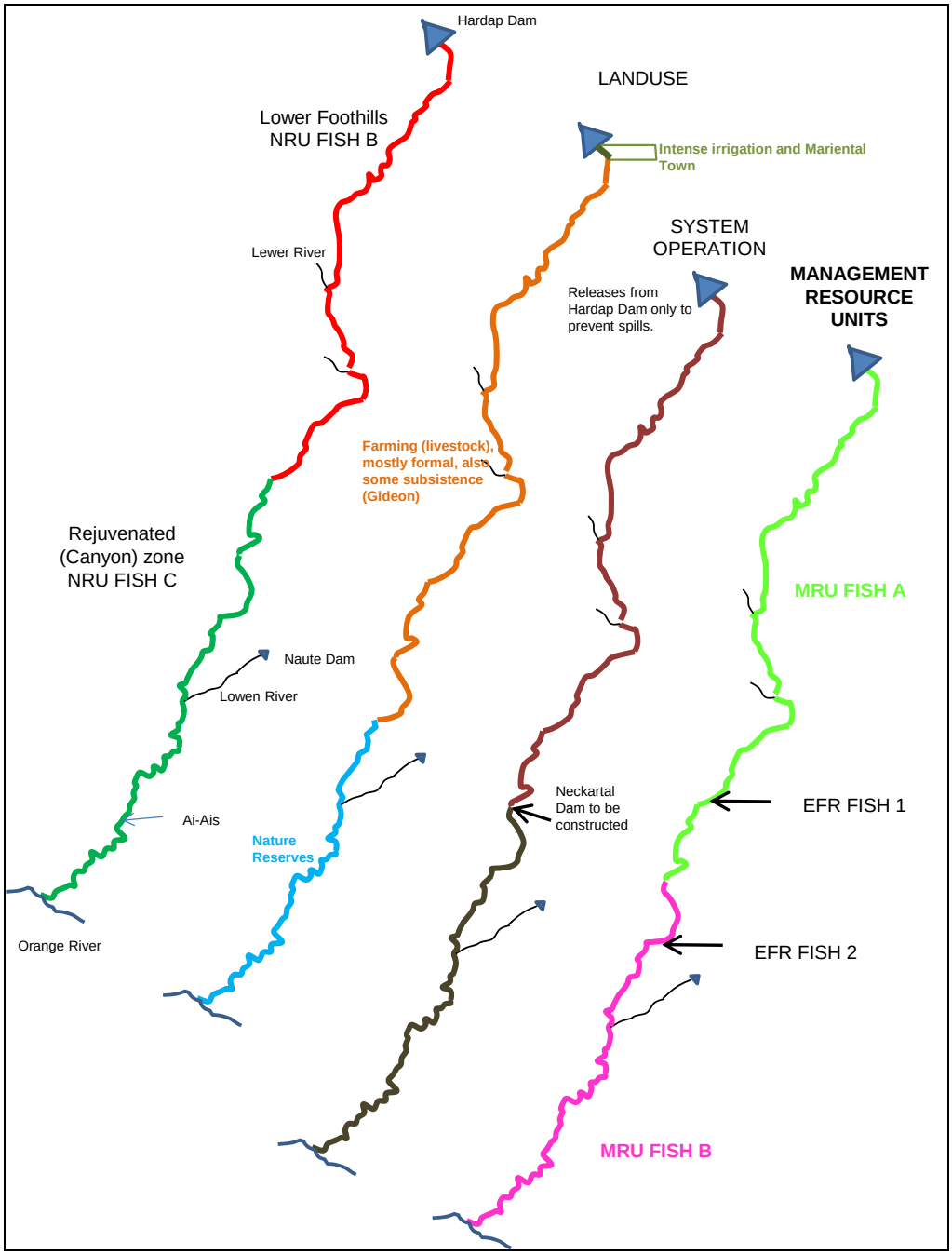

Figure 6. Management Resource Units of the Fish River, Namibia.

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