A Conservation Vision for the Freshwater Biodiversity of the Olifants, Inkomati and Usutu-Mhlathuze Water Management Areas

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Final Report
December 2006

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CSIR Report Number CSIR/NRE/ECO/ER/2006/0199/C

water & forestry
Department:
Water Affairs and Forestry
REPUBLIC OF SOUTH AFRICA

OBTAINABLE FROM:

Directorate: Resource Directed Measures
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The publication of this report emanates from DWAF project 2005-170 entitled:
Development of a planning capability for freshwater conservation

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DECEMBER 2006

This report should be cited as:

I.M. Kotzé, B. Reyers, L.Y. Schonegevel, J.L. Nel and D. Roux 2006. A Conservation Vision for the Freshwater Biodiversity of the Olifants, Inkomati and Usutu-Mhlathuze Water Management Areas: Final report. *CSIR Report Number CSIR/NRE/ECO/ER/2006/0199/C CSIR,* Stellenbosch.

Acknowledgements

We thank the CSIR and Department of Water Affairs and Forestry for providing the funds for the compiling of this document. We would also like to thank our external reviewers, Dr Pete Goodman, Dr Nick Rivers-Moore and Mr Mervyn Lotter for their enthusiastic input, advice and support during the course of this study.

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1. Introduction

1.1 The freshwater biodiversity crisis

Freshwater ecosystems[1] and the biodiversity they support comprise a valuable natural resource. They are a source of aesthetic, spiritual, cultural and recreational value, and provide direct and indirect goods and services on which human societies depend (*Information Box 1*). Their conservation is therefore critical to all humankind.

Yet this valuable resource is in crisis. Increasing evidence suggests that freshwater ecosystems may well be the most endangered in the world (Ricciardi and Rasmussen 1999; Sala *et al*. 2000; Jenkins 2003; WWF 2004; Driver *et al*. 2005; Revenga *et al*. 2005; Dudgeon *et al*. 2006). The rate and extent of freshwater biodiversity loss is confounded by lack of data, but where data exist the estimates are bleak. Over 20% of the global freshwater fish species have gone extinct, or become threatened or endangered (Moyle and Leidy 1992) - including 31% threatened fish species in South Africa (Bills and Skelton 2001). The global index of freshwater species shows a decline of 50% between 1970 and 2000, a decline more rapid than that recorded for equivalent terrestrial and marine indices (WWF 2004). Extinction rates for North American freshwater fauna are projected to be five times higher than for terrestrial fauna, at a rate equal to that of tropical forests (Ricciardi and Rasmussen 1999). Similar downward trends are documented for freshwater habitats. For example, Nel *et al*. (in press) found that over 50% of the freshwater ecosystems associated with main rivers in South Africa are critically threatened, a proportion much higher than those reported for the country's terrestrial ecosystems.

1.2 New approaches to freshwater biodiversity conservation are required

The freshwater biodiversity crisis is largely a consequence of the challenges inherent to conserving freshwater ecosystems, notably:

- Freshwater systems tend to lie at the lowest point in the landscape, and thus act as "receivers" of wastes, sediments and pollutants in runoff from the surrounding landscape. Managing entire catchments, which are often vast stretches of land, is therefore required.
- Because of the "openness" or fluidity of freshwater systems, they are subject to upstream, upland, and downstream impacts. Paying attention to connectivity becomes paramount, which also requires whole-catchment management.
- There is often fierce competition between multiple stakeholders for utilisation of water resources. Strong cooperative governance, which seeks to balance human and ecological needs within whole catchments, is therefore essential to manage resources sustainably and conserve freshwater biodiversity.

It is clear from these challenges that conserving freshwater ecosystems depends on whole-catchment management, where land and water are managed in an integrated way that aims to achieve ecological as well as socio-economic sustainability. This will inevitably require trade-offs

[1] This report uses the international term "Freshwater ecosystems" to refer to any inland water ecosystem. Thus, saline water ecosystems are also incorporated into this term.

between catchments which are allocated to high protection (restricted utilization) and those allocated to socio-economic development (high utilization). Assessing the impact of these trade-offs for conservation can be addressed within the relatively new discipline of **freshwater conservation planning**, which offers a proactive and systematic means of identifying those catchments that are essential for conserving biodiversity, and those that are not.

This concept also aligns well with the proposed **national water resource classification** process, to be implemented by DWAF as a requirement under the National Water Act (Act No. 36 of 1998). The proposed national water resource classification provides a mechanism for balancing protection and utilization by assessing and managing aquatic resources in terms of a selected "ecological state" (Roux 1999, Roux 2001). Each of the proposed states has specific implications regarding the manner and extent to which the resource can be utilized, as well as the types of services that can be provided by the resource on a sustainable basis (*Table 1*). Using catchments identified through the freshwater conservation planning process can help identify those catchments that should be afforded high protection in terms of national water resource classification. The system for undertaking national water resource classification is currently under development, using the Olifants/Doring primary catchment as a testing area (Nel *et al.* 2006b).

Information Box 1: Human dependence on biodiversity

It can be argued that biodiversity has intrinsic value in and of itself. The intrinsic value of biodiversity and the need for its conservation is a component that is recognised by the United Nations Convention on Biological Diversity, to which South Africa is a signatory, as well as our National Environmental Management: Biodiversity Act (Act No. 10 of 2004). Both of these instruments strive to conserve a representative sample of biodiversity as a natural heritage for current and future generations.

More recently, sound arguments have also been made for the need to recognize that biodiversity is fundamental for current and future social and economic livelihoods (Scholes and Biggs 2004; Millennium Ecosystem Assessment 2005). Our individual and collective dependence on biodiversity is absolute; without it, humans would not be able to survive. Apart from the direct benefits of biodiversity such as food and water, humans also derive benefit from its influence on climate regulation, water purification, soil formation, flood prevention and nutrient cycling; while the aesthetic and cultural impact of biodiversity is obvious (Daily 1997; Balmford et al. 2002). All of these benefits to people fall into the broad category of "ecosystem services", and can be summarised into provisioning, regulating and cultural services that affect people directly, as well as indirect supporting services that maintain the other services. In combination, these services benefit human well-being through impacting on security, quality of life, health and social relations, all of which influence the degree of freedom and the choices that are available to people. When ecosystem services are impaired this inevitably leads to a narrowing of livelihood choices and an increase in the vulnerability of the poor. Loss of biodiversity leads to ecosystem degradation and subsequent loss of important ecosystem services (Holmlund and Hammer 1999; Duraiappah et al. 2005). Moreover, this loss tends to harm poor rural communities more directly, since they have limited assets and infrastructure and are more directly dependent on common property resources for their livelihoods. Our path towards sustainable development, poverty alleviation and enhanced human well-being for all, is therefore completely dependent on how effectively we are able to manage and protect biodiversity.

Table 1: The River Health and water resource classification systems.

The relation between the categories used by the River Health Programme and those proposed by the national water resource classification system.

River health categories (Roux 2004)		***Water resource classification system (DWAF 2006)***	
Category	***Description***	***Proposed management class***	***Description***
A or B (Natural or good)	Ecosystem essentially in good state; biodiversity of in-stream and riparian habitats largely intact.	Class I: Minimally used	The configuration of water resources within a catchment results in an overall water resource condition that is minimally altered from its pre-development condition. Human activity has caused no or minimal changes to the historically natural structure and functioning of biological communities, hydrological characteristics, chemical concentrations and the bed, banks and channel of the resource.
C (Fair)	Ecosystem essentially in good state; biodiversity largely intact, although sensitive species may be lost, with tolerant or opportunistic species dominating	Class II: Moderately used	The configuration of water resources within a catchment results in an overall water resource condition that is moderately altered from its pre-development condition.
D (Poor)	Mainly tolerant species present or alien species invasion; disrupted population dynamics; species are often diseased.	Class III: Heavily used	The configuration of water resources within a catchment results in an overall water resource condition that is significantly altered from its pre-development condition.
E or F (Poor)	Mainly tolerant species present or alien species invasion; disrupted population dynamics; species are often diseased.	Unacceptably degraded resources	Due to over-exploitation, these rivers are already in a state that is ecologically unsustainable, and need to be rehabilitated to a sustainability baseline of Class III

1.3 Objectives and scope of this study

This study forms a component of a broader water licensing study in the Olifants, Inkomati and Usutu-Mhlathuze Water Management Areas. The main objective of this study is to:

Develop a conservation vision for the freshwater biodiversity of the 3 Water Management Areas which systematically identifies areas important for conserving freshwater ecosystems and their associated biodiversity

This conservation vision can inform business and management strategies of a variety of implementing agencies. It provides systematic and strategic guidance regarding the trade-offs between conservation and development, and can be used to provide strategic perspective to decision makers at the scale of a water management area. It should therefore be used to further develop an understanding of conservation imperatives and the impact of trade offs between systems in this region within the water licensing process.

1.4 Approach and stakeholder consultation to date

The approach to this study was guided by recommendations emanating from the national cross-sectoral policy process on conserving freshwater ecosystems and their associated biodiversity (Roux *et al*. 2006). This process collated operational policy objectives and guiding principles to advance the practical conservation of freshwater biodiversity across multiple sectors and spheres of government. The objectives and guidelines are a culmination of analysis, consultation and deliberation amongst the primary agencies responsible for conservation of inland water biodiversity in South Africa. The objectives and guiding principles can be summarized as follows:

- Objective 1: Set and entrench quantitative conservation targets for freshwater biodiversity
- Objective 2: Plan for representation of freshwater biodiversity
- Objective 3: Plan for persistence of freshwater biodiversity
- Objective 4: Establish a portfolio of freshwater conservation areas
- Objective 5: Enable effective implementation

Objectives 1-4 are addressed completely in this study, whilst objective 5 (enabling effective implementation) is not addressed as part of this project brief. Objective 5 should be regarded as an ongoing process that is initiated at the outset of the approach. Thus, although the development of an implementation strategy falls beyond the scope of this study, key implementing agencies were consulted in the development and review of the spatial biodiversity assessment (*Table 2*).

Table 2: Stakeholder consultation process to date

Date	Purpose	Participants
10 November 2006	*Expert review workshop of datalayers, approach and interim conservation planning outputs*	▪ *Ms Mamogala Kadiaka* ▪ *DWAF: Resources Directed Measures* ▪ *Dr Niel van Wyk,* ▪ *DWAF: Strategic Planning* ▪ *Dr Peter Goodman,* ▪ *Ezemvelo KwaZulu-Natal Wildlife* ▪ *Mr Mervyn Lotter,* ▪ *Mpumalanga Parks Board* ▪ *Dr Dirk Roux, CSIR* ▪ *Dr Belinda Reyers, CSIR* ▪ *Mrs Inge Kotzé, CSIR*

2. DESCRIPTION OF THE STUDY AREA

The Olifants, Inkomati and Usutu-Mhlathuze Water Management Areas are three of the 19 water management areas in South Africa, deriving their name from the main rivers that drain the area. These water management areas are situated in the north-eastern part of South Africa, traversing the Limpopo, Gauteng, Mpumalanga, KwaZulu-Natal Provinces of South Africa (Figure 1). A summary of the general characteristics of the area is provided below. For a more detailed description, the reader is referred to DWAF (2004a,b,c).

These water management areas incorporate the entire B, W, X primary catchments. The major rivers in these water management areas include the Olifants, Komati, Crocodile, Sabie, Sand, Mhlathuze, Mfolozi, Mkuze/Hluhluwe, Pongola, Usutu and Lake Sibaya (Figure 2). Large dams in this region include the Nooitgedacht and Vygeboom, Driekoppies and Kwena and Inyaka dams in Mpumalanga, and the Goedertrouw, Klipfontein, Hluhluwe, Bivane and Pongolapoort dams in KwaZulu-Natal. Transfer schemes include the Usutu, Thukela-mhlathuze, Mfolozi-mhlathuze and the Senekal Trust transfer. The study area falls within the high summer rainfall area of the country, with most of the surface flow originating from the escarpment in the West of the study region, where surface flow is then carried to the ocean by the Inkomati, Black and White Mfolozi, Mkuze, Usutu and Pongola rivers. South Africa shares many of these river with the neighbouring states of Swaziland and Mozambique. The Usutu, Pongola and Inkomati river systems flow through Swaziland, and the Inkomati, flows into Mozambique where it enters the sea in Maputo Bay. Fourteen sub-areas within the water management area form the management units used by the Regional Office of DWAF:

- The Olifants WMA has four sub-areas: namely the Upper Olifants, Middle Olifants, Steelpoort and the Lower Olifants,
- Incomati WMA consists of the four sub-areas: the Sabie/Sand sub area, Crocodile, the Upper Komati (west of Swaziland), Lower Komati (north of Swaziland) and,
- the Usutu-Mhlathuze WMA consists of six sub-areas: the Mhlathuze, Mfolozi, Mkuze/Hluhluwe, Pongola, Usutu and Lake Sibaya catchments.

A brief description of each WMA is provided below:

Olifants Water Management Area (DWAF, 2004a)

<u>Natural characteristics</u>

Topography in this region is characterised in the southern part by gently rolling hills, before the river cuts through the Drakensberg to enter in Lowveld region. It is a summer rainfall region, with the mean annual precipitation varying from 500mm in the Lowveld, reaching 1000mm in the escarpment region and then decreasing to 700mm in the southern Mpumalanga Highveld. Potential evaporation is well in excess of the rainfall in this region. Main tributaries of the Olifants river system include the Wilge, Elands and Ga-selati, Steelpoort, Blyde, Klaserie and Timbavati Rivers.

Development and economic activities

Key economic sectors in this region include mining (22.1%), manufacturing (18.2%), Electricity (15.9%), government (15.6%) and agriculture (7.0%). There is a large amount of mining activity in this WMA, including a large coal mining industry (within the Witbank-Middelburg urban complex), and to a lesser extent platinum, chrome, phosphorous and copper mining (Phalaborwa), associated heavy industry includes the steel manufacturing industry, six coal generated power stations, vanadium, chrome and mineral processing (Burgersfort). Witbank and Middleburg, Burgerfort and Phalaborwa are the major urban centres in the WMA containing the majority of the urban population for this WMA. The rest of the region is largely undeveloped with scattered rural settlements. The predominant land use is agriculture with extensive irrigation in and around the Loskop Dam and along the Olifants River, in the Blyde River catchment and the Ga-Selati catchment. Ecotourism is a vital industry in this region with a number of private game farms and the country's flagship game reserve, namely the Kruger National Park located in this area. The Olifants River system is a highly regulated system. The most significant dams in this region include the Witbank and Middleburg Dams, Bronkhorstspruit, Renosterkop and Rust De Winter Dams, Loskop Dam and Flag Boshielo Dam, and Blyderivierspoort Dam.

Inkomati Water Management Area (DWAF, 2004b)

Natural characteristics

The Inkomati Water Management Area is situated in the north-eastern part of South Africa, bordering Swaziland and Mozambique. The biggest part of this WMA is situated in what is commonly referred to as the Lowveld. This is the region below the northern most extent of the Drakensberg escarpment. . Topographically, this WMA has a western plateau divided by the Great Escarpment (an axis running along Graskop, Sabie, Nelspruit, Barbeton) and the sub-tropical Lowveld in the east, with altitudes ranging from over 2000m in the west to as low as 140m in the east. Rainfall varies from over 1200mm/annum in the west, to as little as 400mm/annum in the east. Evaporation largely exceeds the rainfall (varying from <14000mm in the west to 1900mm in the north). Main rivers include the Sabie/Sand, the Crocodile (east), Uanetse River and Komati Rivers. The Komati River first flows into Swaziland and re-enters South Africa before flowing into Mozambique, and then out into the Indian Ocean. Southern Mozambique is largely dependent on water from the upstream catchments in South Africa and an IncoMaputo Water Use agreement sets out the water sharing arrangements between these three countries.

Development and economic activities

Economic profile of the Catchment shows the most important sectors to be manufacturing (24.6%), agriculture (18.6%), government (16.4%) and trade (13,4%), other (27,0%). Landuse in water management areas is used as grazing for livestock, commercial forestry, irrigated agriculture, and mining and ecotourism activities.

The warm sub-tropical escarpment is suitable for growing many frost sensitive crops and tropical fruit. Irrigated agriculture is the economic mainstay of the water management area, with 95% of total water use allocated to irrigation. Intensive production of deciduous fruits, citrus. Sugercane is grown in the eastern parts (lower Crocodile and Komati River valleys), with two large sugar mills at Malelane and Komati. In the western, higher mountainous areas are suitable for forestry and supply the wood, pulp and paper industry. Tourism is an important and growing sector of the economy in the water management area associated with the game industry.

Important urban centres include Nelspruit, White River, Komatipoort, Carolina, Badplaas, Barbeton, Sabie, Bushbuckridge and Matsulu. Nelspruit is the capital of Mpumalanga and has the Nelspruit International Airport which plays a key role in supporting the ecotourism industry within the region. The Maputo corridor linking Maputo and Gauteng also plays an important role in the growth and economy of the WMA and the Province. A large number of rural settlements include Mhala, Mapulaneng, Nsikazi, Mkomazi and Mswati regions. Main dams in the region include the Vygeboom and Maguga Dam (in Swaziland) and Driekoppies Dam on the highly regulated Komati River, used mainly for irrigation purposes. Inyaka Dam on Marite River, a tributary of the Sabie River, to supply domestic and ecological reserve requirements along the Lower Sabie, the Bosbokrand Transfer Pipeline (BTP) to Sand River sub-catchment and the Kwena Dam on Upper Crocodile River. There are also a number of important canal systems that distribute water to irrigators in the Crocodile, Sabie and Sand River catchments. Numerous farm dams have also been constructed throughout the catchments.

Usutu-Mhlathuze Water Management Area (DWAF, 2004c)

Natural characteristics

This WMA is situated in the northern KwaZulu-Natal province, but also occupies the south-eastern corner of the Mpumalanga province (west of Swaziland). This WMA borders both Swaziland and Mozambique, and shares two the major rivers systems, namely the Usutu and Pongola with these countries. The Indian Ocean borders the WMA in the east and the Drakensberg range in the border in north-west. Altitude ranges from approximately 2000m to sea level. Rainfall varies from almost 1500mm/annum in the western mountainous areas to as low as 600mm/annum in the Pongolapoort Dam vicinity. The WMA consists of a number of catchments, namely the Mhlathuze, Mfolozi, Mkuze/Hluhluwe, Pongola, Usutu and Lake Sibaya catchments which all form part of the Usutu Basin (otherwise referred to as the Maputo River Basin). Mfolozi River Basin consists of two main tributaries, the Black and white Mfolozi, both which flow from the eastern Drakensberg Escarpment eastwards across the Zululand coastal plain into the Indian Ocean. Mkuze catchment: includes the drainage area of both the Hluhluwe and Mkuze rivers, reaching the sea through Lake St Lucia. Pongola rises in the eastern escarpment of the Drakensberg, flowing eastwards before joining the Usutu River and flowing through Mozambique into the Maputo River Basin. The Usutu River rises in the eastern escarpment of the Drakensberg, flowing eastwards through Swaziland and joining the Pongola River before crossing the Mozambique Border. Lake Sibaya Catchment is a coastal catchment north of Sodwana Bay. This area has relatively high rainfall and limited surface runoff due to the flat terrain and supports high groundwater recharge area with the KwaZulu-Natal coastal aquifer underlying much of this catchment.

Development and economic activities

Mainstays of the local economy: Manufacturing and Mining (35.5%), agriculture (15,2%), transport (12,5%), other (36.8%). Land use includes commercial agriculture irrigated crops, predominately sugarcane and citrus, dryland sugarcane, and significant amount of farm dams that support irrigation. Afforestation in the upper parts of most catchments, communal lands supporting cattle and subsistence farming. Conservation and ecotourism, with several nature reserves including Hluhluwe, Mfolozi, Mkuze, St Lucia, Sodwana and Itala. Lake St Lucia a proclaimed World Heritage site, also form key economic sectors within this region. Key industries in this region include pulp and paper manufacturing and aluminium smelting, dune mining of titanium and other heavy metals. The manufacturing sector is linked to railway infrastructure, harbour at Richards bay (largest coal exporting terminal). Main towns include Richards Bay, Mtunzini, Ulundi, St Lucia, Vryheid, Paulpietersburg, Piet Retief, Amsterdam, Hluhluwe, St Lucia and Mkuze, Jozini and Pongola. Larger dams include the Klipfontein Dam on the upper reaches of White Mfolozi River. Goedertrouw, Hluhluwe, Bivane and Pongolapoort. There are also a number of water transfer schemes in this area, namely the Usutu, Thukela-Mhlathuze, Mfolozi-Mhlathuze and Senekal Trust Transfer.

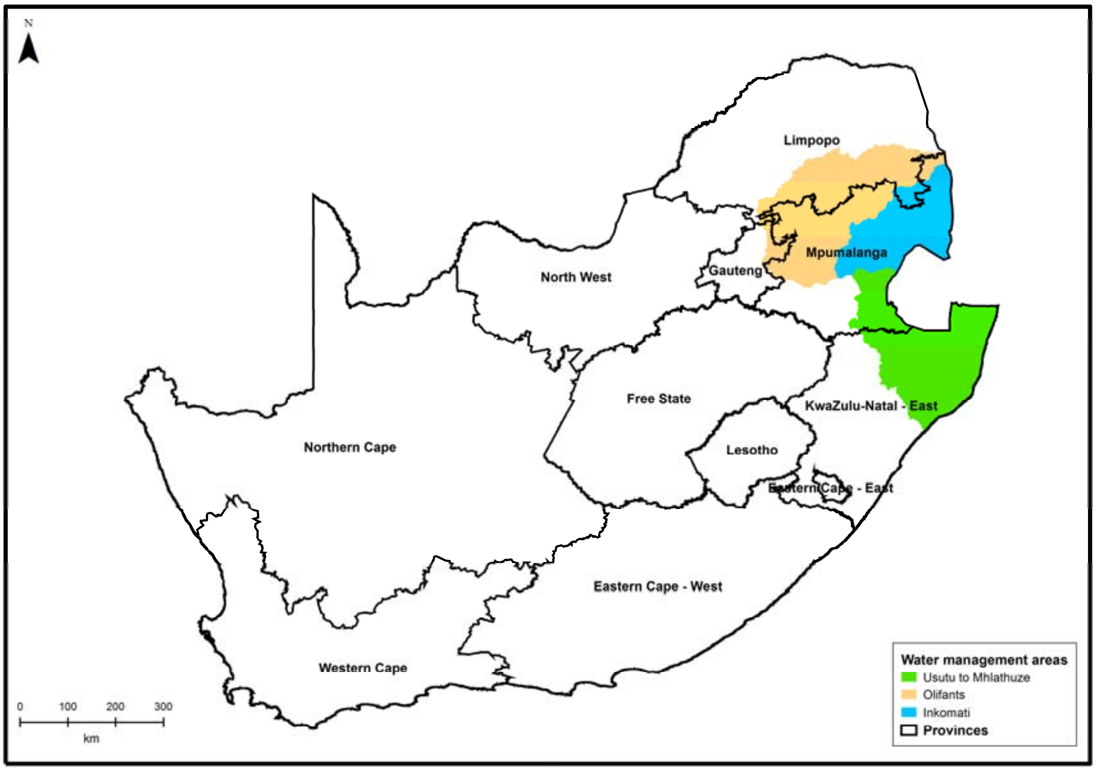

Figure 1. Map showing the location of the Olifants, Inkomati and Usutu-Mhlathuze Management Areas within South Africa.

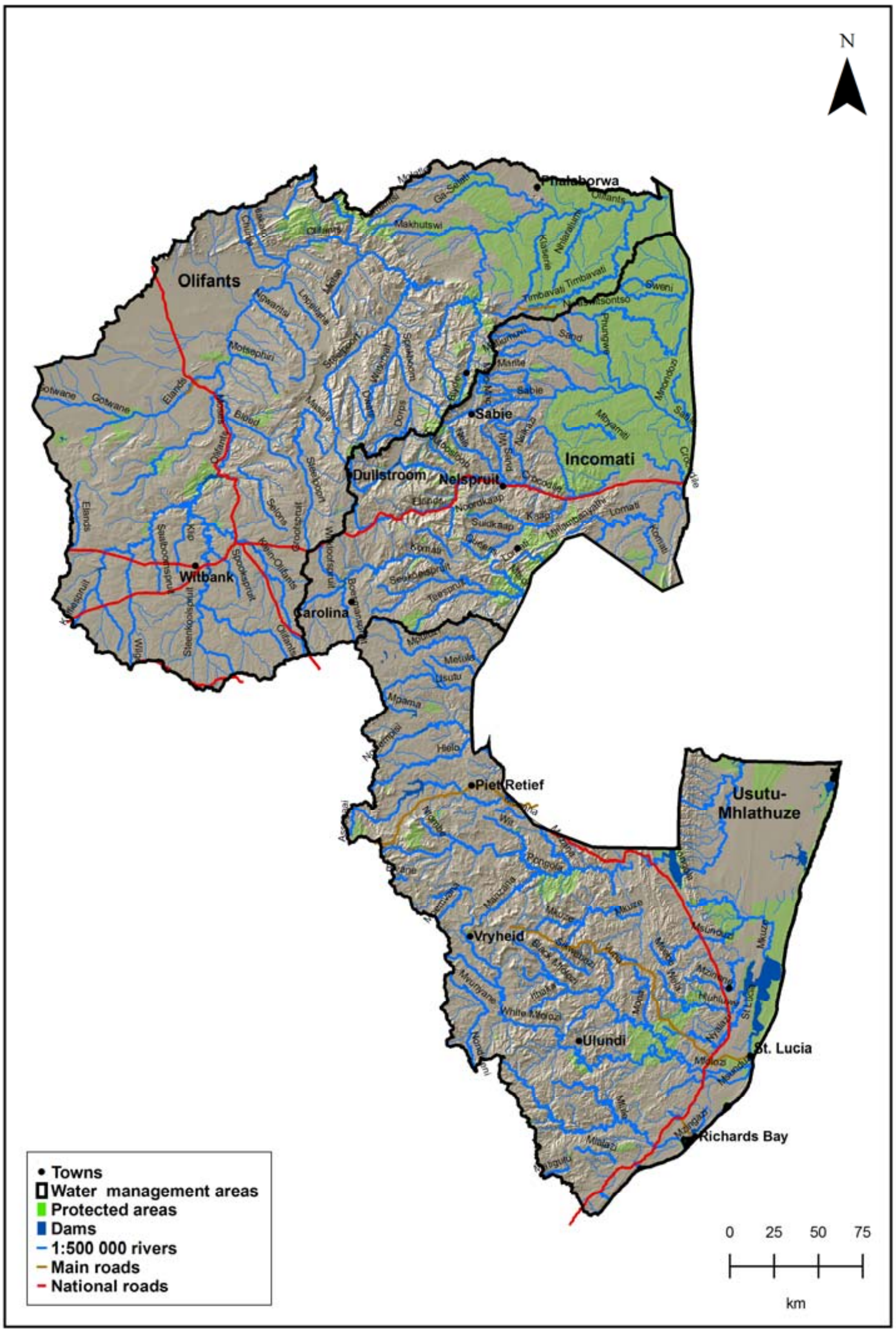

Figure 2. Map of the Olifants, Inkomati and Usutu-Mhlathuze Management Areas

The main map shows 1:500 000 rivers, sub-water management areas, and the major towns and roads.

3. PUTTING TOGETHER THE CONSERVATION VISION

The study followed a systematic conservation planning approach and was based on existing data on freshwater biodiversity in the region. We followed the criteria as set out in the National Spatial Biodiversity Assessment (Driver *et al.* 2005) in choosing the data sets in that they had to be comprehensive for the study region and of an adequate resolution and scale for the purposes of the assessment. The desktop nature and time available for the study resulted in a few key data gaps and limitations in developing the conservation vision. We highlight these under each of the sections below in order to make the process and its limitations transparent and facilitate the improvement of this assessment in subsequent iterations.

3.1 Planning units

In order to select areas important to the region's freshwater biodiversity, the planning units need to be defined at the appropriate scale. Planning units are geographic areas to which biodiversity and integrity data are attached and are the units of selection for the conservation vision. Using catchments as planning units has the advantage of highlighting that conservation of freshwater ecosystems depends on appropriate management of both land and water in a drainage basin. However, primary drainage areas are too large to provide sufficient detail required at the water management area level. Indeed, it has been found in previous freshwater conservation planning exercises (van Niewenhuizen 1998; Nel *et al*. 2006) that even the smaller quaternary catchments are too large a spatial scale to provide information in sufficient level of detail to use at a water management area level. For this reason, sub-quaternary catchments were modelled to use as planning units in this study. Focussing on sub-quaternary catchments as the units of selection also has the benefit of incorporating lateral connectivity (across aquatic-terrestrial gradients).

Sub-quaternary catchments were modelled using a combination of digital elevation data (US SRTM 90m[2]) and the DWAF 1:500 000 rivers[3] . Catchment boundaries were delineated around each river segment, defined as the stretch of river between confluences. This resulted in 2611 sub-quaternary catchments, which nest approximately within the 323 quaternary catchments (*Figure 3*).

3.2 Classifying river types

The 1:500 000 rivers GIS layer (DWAF 2004d) was used for the analyses in this study. This GIS layer is based on 1:500 000 topographical maps, however, it has been refined to include alignment of the rivers to within 50 m of the 1:50 000 topographical maps.

Limitation: *The use of the 1:500 000 rivers means that some of the smaller rivers are not included in the study. This highlights the need to review the conservation vision at the appropriate scale for final decision making.*

[2] available from the website: http://www.personal.psu.edu/users/j/z/jzs169/Project3.htm

[3] available on DWAF website: http://www.dwaf.gov.za/iwqs/gis_data/river/All.htm

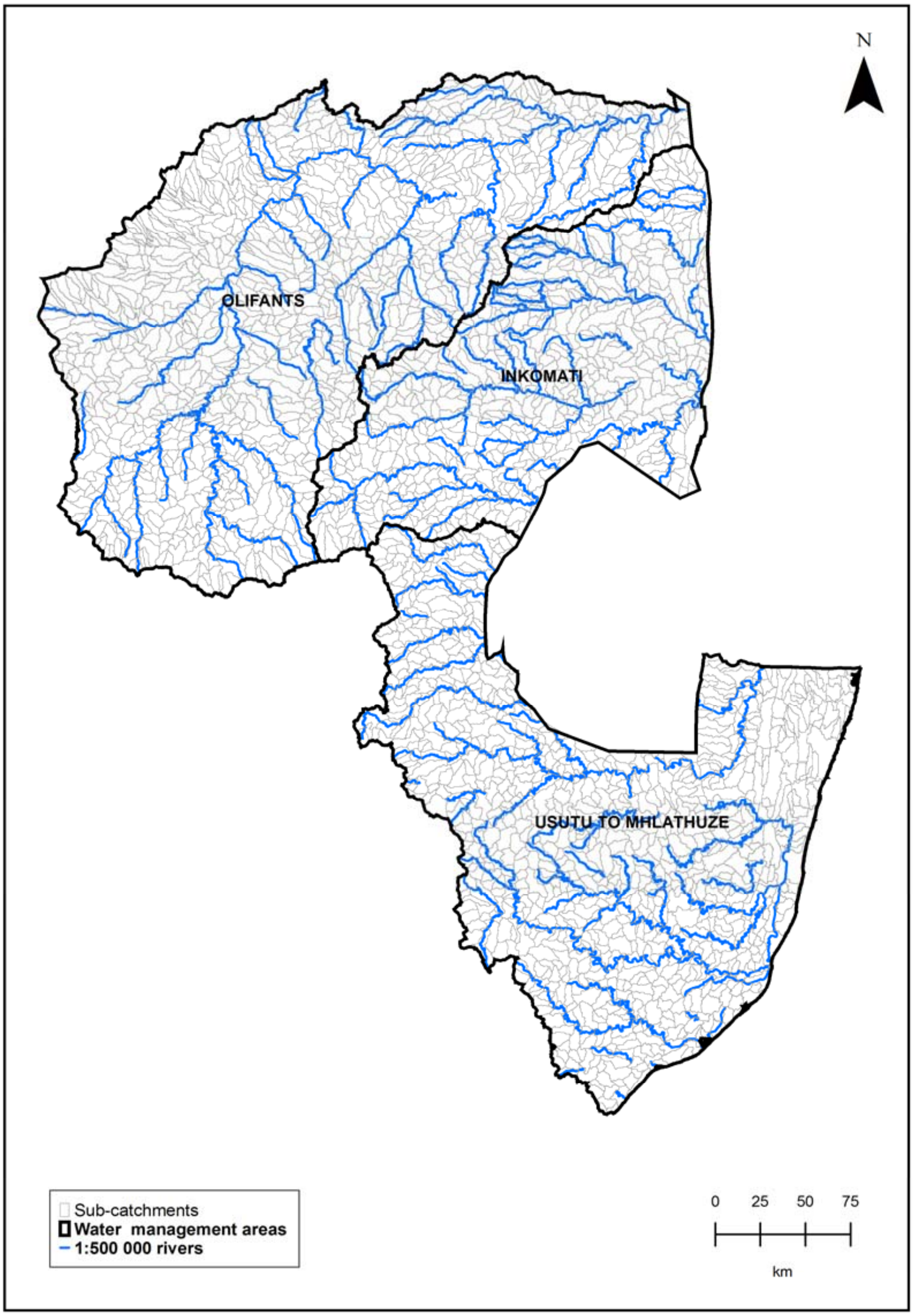

Figure 3. Sub-quaternary catchments within the Olifants, Inkomati and Usutu-Mhlathuz Study Area. Sub-quaternary catchments (n=2611) were used as planning units.

A hierarchical system, which classifies rivers according to three levels, was used to classify the rivers selected for this study. At the level of the landscape, rivers were classified according to landscape characteristics and flow variability to produce landscape-level river types (or Level 2 river types). These Level 2 river types were supplemented with a characterization of geomorphologic (longitudinal) zones at the level of individual streams to produce Level 3 river types. This longitudinal zonation serves as a surrogate for characterising the ability of a river reach to store or transport sediment, each zone representing a different physical template available for biotic habitation. Using this stream-level descriptor in conjunction with the Level 2 landscape characterization provides a surrogate of the biotopes expected within the river reach, which in turn can be used as a surrogate for biodiversity pattern within river ecosystems. An overview of the three levels used to type rivers in the Olifants, Inkomati and Usutu-Mhlathuze Water Management Area is provided below.

3.2.1 Freshwater ecoregions

Level 2 river ecoregions (Kleynhans *et al*. 2004) were used to characterise the landscape through which the river flows. These ecoregions represent areas within which ecological characteristics are similar; therefore, rivers in the same ecoregion will be more similar to one another than rivers in different ecoregions. Ecoregion boundaries in Kleynhans *et al*. (2004) were delineated by regional experts from various parts of the country. Delineation of Level 1 ecoregions involved evaluating maps of geographic phenomena such as climate, soils and geology, natural vegetation and physiography. These ecoregions were then used as a basis for the more detailed Level 2 ecoregion delineations, using the same information, but in more detail. For example, the physiographic aspects were described in terms of their terrain morphology, relief, altitude and slope in Level 2 delineations.

13 of the 31 Level 1 ecoregions in South Africa occur in the Olifants, Inkomati and Usutu-Mhlathuze Water Management Area (*Table 3*). These are further divided into 44 Level 2 ecoregions in the study area (*Figure 4)*, which have yet to be described.

Table 3: Description of the Level 1 ecoregions that occur in the study area.

(after Kleynhans et al. 2004)

Name	***Level 1 ecoregion***	***Level 2 ecoregions***	***Description***
Lowveld	3	01, 03, 06, 07, 08, 09, 10	This ecoregion is located in the eastern region of the study area, containing seven of the level 2 ecoregions. This region consists mainly of plains of moderate to low relief, and limited lowlands, hills and mountains. Dominant vegetation types include Mopane Bushveld and Mixed Lowland Bushveld. Mean annual precipitation is low (200mm) to high (1000mm) summer rainfall. Several large perennial streams traverse this region, including the White and Black Buffalo, Mkuze, Pongola, Great Usutu, Komati, Crocodile, Sabie, Olifants, Letaba and Luvuvhu rivers.
North eastern highlands	4	03, 04, 05, 06	The north eastern highlands is situated in the northern section of the study area, containing four level 2 ecoregions. Topography in this region consists of a transition zone between the Lowveld and the Northern escarpment, with mainly of plains of moderate relief, and open hills, lowlands, mountains of moderate to high relief. Dominant primary vegetation includes Lowveld Bushveld and North Eastern Mountain Grassland. Mean annual precipitation varies from 400mm to 1000mm, within a summer rainfall season. Towards the south of this region , two of thelarger rivers, namely the Great Usutu and the Pongola have their origins here.
Northern Plateau	5	02	The Northern Plateau tips the study area in the North West corner of the Olifants WMA. The topography is dominated by plains with a low to moderate relief, and vegetation consists mainly of Mixed Bushveld, with limited areas of North_Eastern Mountain Grassland also being prominent. The Sand River is the major river, which flows seasonally, with no perennial streams having their source in this region. This summer rainfall area has a mean annual precipitation of 300mm to 700mm.
Western bankenveld	7	05	The Western Bankenveld ecoregion is located in the south-western and south-eastern part of the study area, containing five level 2 ecoregions in the area. This ecoregion is characterized by a complex topography that varies from lowlands, hills and mountains to closed hills and mountains with the relief varying from moderate to high. Mixed Bushveld is the most definitive vegetation type of the region. Mean annual precipitation is low to moderate (400-700 mm), and rainfall seasonality is early to late summer. The Crocodile (West), the Elands (West) and the Pienaars Rivers flow through this region.
Bushveld basin	8	01, 02, 03, 04, 05	This ecoregion is extensive in the area (over 50%) and consists of three level 2 ecoregions in the WMA. This region consists predominantly of plains with a low relief, with Mixed Bushveld being the definitive vegetation type. Plains with a moderate relief and lowlands with a moderate relief occur in the eastern portion of this ecoregion. Perennial rivers traverse the region, e.g. the Marico, Elands (West), Crocodile (West) and Pienaars. Mean annual precipitation is 400-600 mm while the rainfall seasonality is early to mid summer.
Northern escarpment mountains	10	01, 02, 03	The topography of this high lying region consists of closed hills and mountains with a moderate to high relief. Towards the east of this region, a well-defined escarpment is present along the majority of the length of the region. Northeastern Mountain Grassland is the dominant vegetation type in the region with areas of Sour Lowveld Bushveld towards the east. Patches of Afromontane Forest occur regularly in a thin band in the east. Rivers such as the Blyde, Sabie and Letaba have their sources here, with perennial tributaries of rivers such as Crocodile, Komati and the Olifants in this region. Mean annual precipitation is between 500mm and 1000mm occurring in early to mid summer.

Name	***Level 1 ecoregion***	***Level 2 ecoregions***	***Description***
Name	Level 1 ecoregion	Level 2 ecoregions	Description
Lebombo uplands	12	01	Closed hills and mountains define this long, thin region with a moderate to high relief. The characteristic vegetation type of this region is the Lebombo Arid Mountain Bushveld, with distinct basalts and rhyolites in the region. Several large rivers traverse this region, including the Olifants, Sabie, Crocodile, Komati, Great Usutu, Pongola and Mkuze. However, no perennial streams originate in this region. Mean annual precipitation is between 400mm to 1000mm occurring predominately in early to mid-summer.
Natal coastal plain	13	01, 02, 03	The Natal coastal Plain is a low-lying area with plains of low relief. Coastal Bushveld/Grassland dominates the vegetation. Large rivers such as the Mfulozi, Mkuze and Mtlatuze traverse this region. Few perennial streams originate in this region and stream frequency is low to medium. Mean annual precipitation is moderate to high (600-1000mm) occurring mainly in mid to late summer.
Northern eastern uplands	14	01, 02, 03, 04, 05, 06	This region is very diverse with lowlands, hills and mountains with moderate and high relief, as well as closed hills and mountains with moderate and high relief, being the defining characteristics. Grassland and Bushveld types, mainly Natal Central Bushveld and Valley Thicket characterize the vegetation. Large rivers such as the Thukela, Mooi, and Buffalo traverse this region while the Mhlatuze have its source in the region. Mean annual precipitation: Moderate to moderately high. (MAP (modifying) 600 to 1000mm)
Eastern escarpment mountains	15	05	This high lying region is characterized by closed hills, mountains with moderate and high relief with prominent escarpments towards the east. The vegetation consists of a range of grassland types with Afro Mountain and Alti Mountain Grassland being the defining types. Several major South African rivers have their sources in this region, e.g. Orange, Caledon, Wilge, Thukela, Buffalo, Mooi, Mzimkulu, Mzimvubu, Mgeni and Mkomazi, Mean annual precipitation: Moderate to very high with MAP (mm) (modifying) 400 to 1000.
North eastern coastal belt	17	01	A diversity of terrain morphological types occurs with closed hills and mountains with a moderate to high relief being the most definitive. Altitude varies from sea level to 700 m.a.m.s.l. Vegetation types consist of Valley Thicket and a variety of Grassland and Bushveld types. Rivers such as the Mgeni, Mkomazi and Mzimkulu flow through this region. Mean annual precipitation: Predominantly high. (MAP (modifying) 700 to 1000mm).

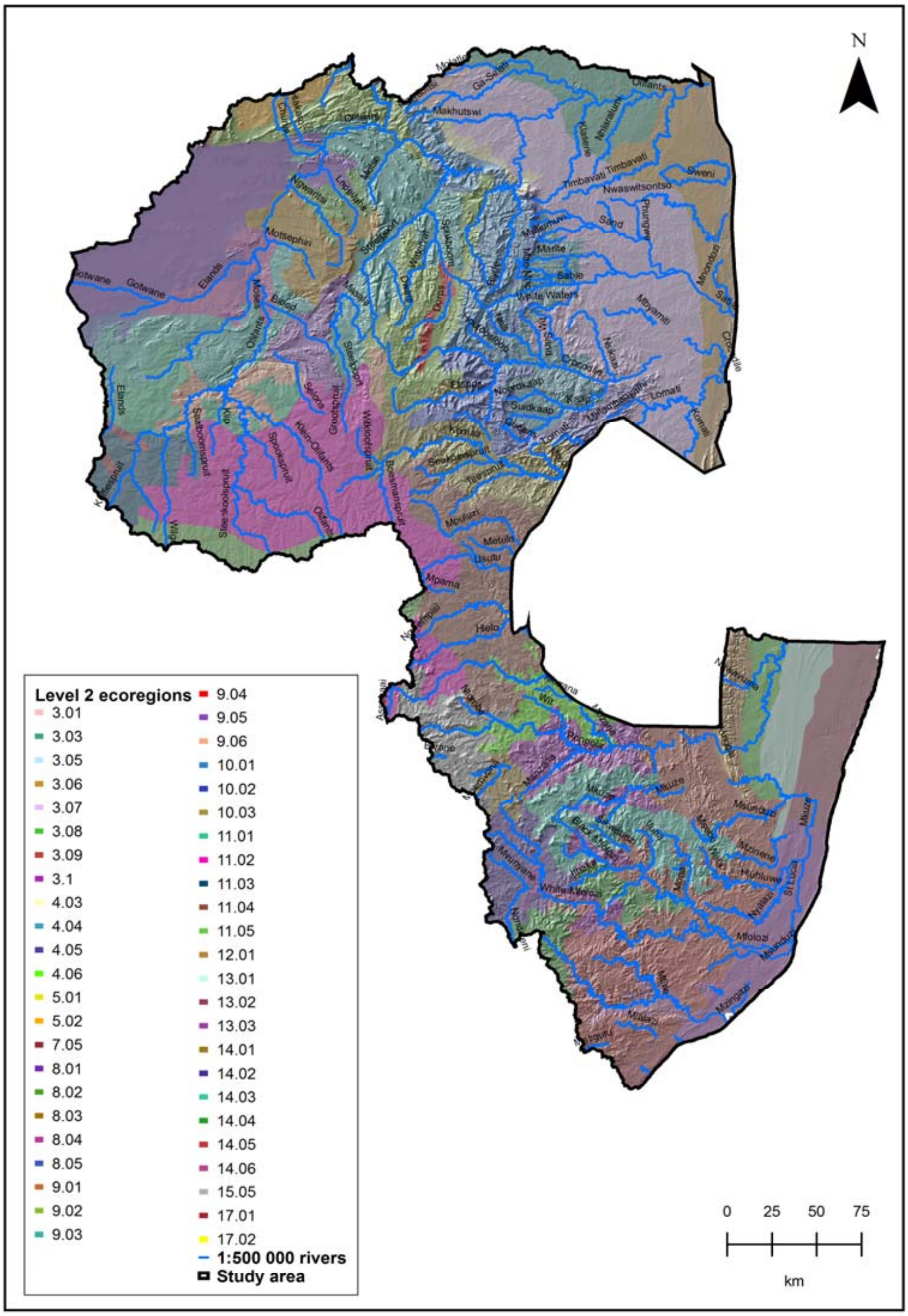

Figure 4. Level 2 ecoregions used as the first level of the river typing hierarchy

Level 1 ecoregions are described in Table 3; Level 2 ecoregions have not yet been described

3.2.2 Freshwater ecoregions combined with flow variation

Spatial and temporal distribution patterns of biota in South African rivers are strongly determined by flow variability. Thus, flow variability was explicitly incorporated into the river typing hierarchy by characterising rivers according to three broad categories:

- Permanent – those rivers that flow all year round;
- Seasonal – those rivers that flow annually but not permanently; and
- Ephemeral – those rivers that can go for several years without a flood event.

The hydrological index (Hannart and Hughes 2003) was used to characterize hydrological variability, measured as a ratio of flow variability to base flow in a river. For South African rivers, a hydrological index value of close to 1 will be found for regions of low variability (commonly referred to as perennial-type rivers) and a value of > 50 would indicate semi-arid regions of high variability (periodic- or ephemeral-type rivers). Hydrological index values for all 1986 quaternary catchments in South Africa were grouped into nine statistical classes (*Table 4*) using an automated version of the Worsley Likelihood Ratio test (Worsley 1979; Dollar *et al*. submitted). For the purposes of this study, and based on expert evaluation of the nine classes, rivers in quaternary catchments with a hydrological index class of 1-4 were assumed permanent, those in class 5 were considered seasonal, and those in classes 6-9 were considered ephemeral.

Table 4: Nine statistical classes of hydrological index.

Classes were derived by Dollar et al. (submitted) using the hydrological indices derived by Hannart and Hughes (2003). These indices were lumped into three descriptions of flow variability for the purposes of this study.

Class	Hydrological index (HI) thresholds	Flow variability descriptors used in this study
1	*HI ≤ 4.394*	*Permanent*
2	*4.394 < HI ≤ 7.535*	
3	*7.535 < HI ≤ 13.745*	
4	*13.745 < HI ≤ 16.110*	
5	*16.110 < HI ≤ 37.819*	*Seasonal*
6	*37.819 < HI ≤ 64.169*	*Ephemeral*
7	*64.169 < HI ≤ 92.705*	
8	*92.705 < HI ≤ 98.124*	
9	*98.124 < HI*	

Ecoregions (forming the first level of the river typing hierarchy) were spatially combined with the three flow variability classes to produce 65 Level 2 river types (*Figure 5*). Of these 65 Level 2 river types, 31 have their range completely within the study area, and a further 11 have over 80% of their range within the Olifants, Inkomati and Usutu-Mhlathuze Water Management Area. Thus, Level 2 river types in the Olifants, Inkomati and Usutu-Mhlathuze Water Management Area exhibit a high degree of endemicity, with 42 types (64%) considered to be unique, or endemic, to the area.

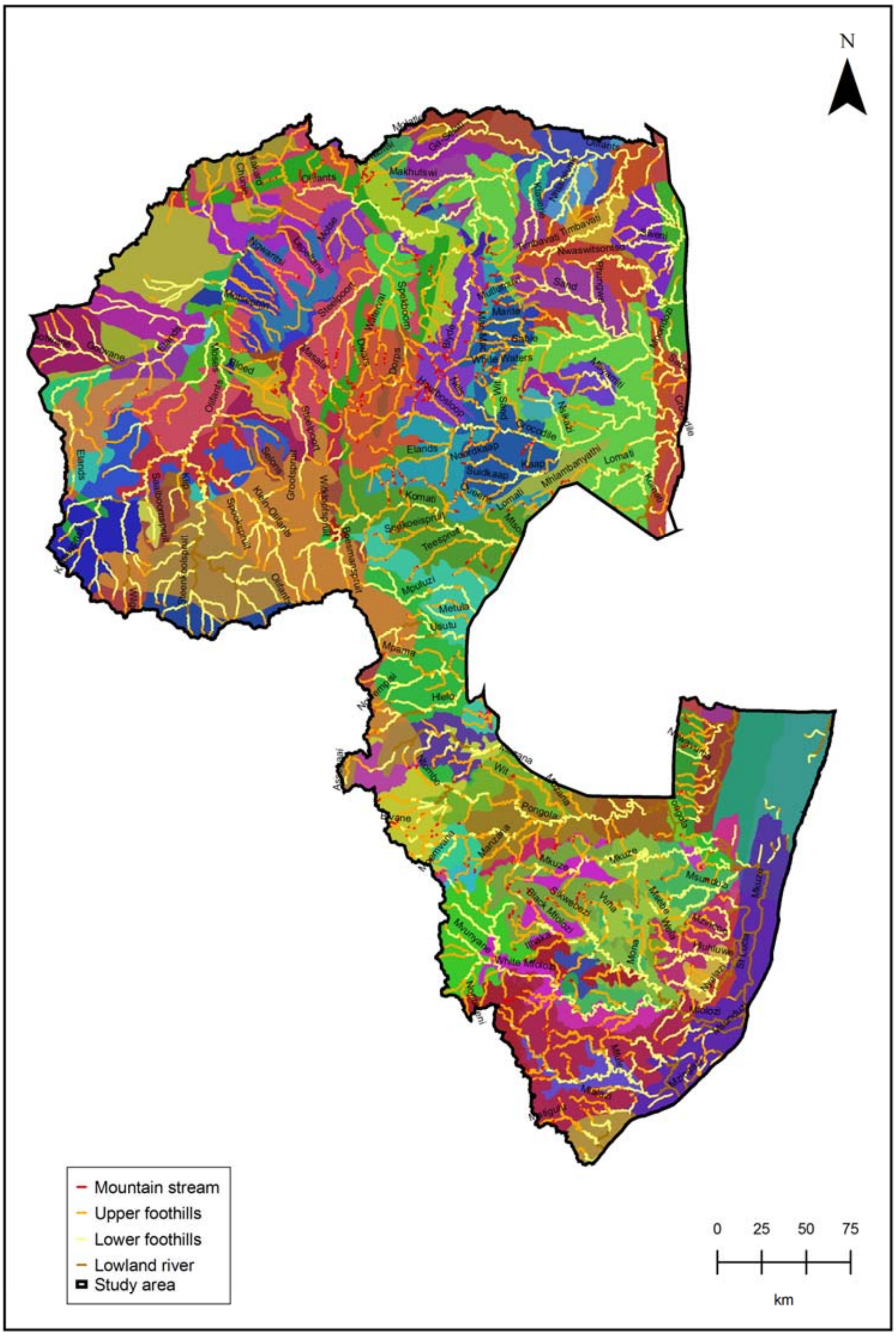

Figure 5. Level 3 river types for the Olifants, Inkomati and Usutu-Mhlathuze Water Management Area.

Shaded areas represent the 65 unique Level 2 river types (which is a combination of the flow variability and the Level 2 ecoregion classification). These Level 2 river types were classified further at the level of individual streams using longitudinal zones as indicated in the legend.

3.2.3 Level 2 river types combined with longitudinal zones

River ecosystems are essentially a manifestation of the landscapes that they drain. They are the result of the natural flow regime which drives the system, as well as the sediment which is transported or deposited in the system. Generally, a river's longitudinal profile shows a downstream decrease in the slope gradient which leads to a decrease in stream velocity. This in turn, results in changes in the types of sediments found in the river channel. Larger, more coarse sediments are typically associated with the steeper headwater rivers whereas finer, while siltier sediments occurs in the lowland rivers (Rowntree and Wadeson 1999; Roux *et al*. 2002). The combination of the longitudinal zones and Level 2 river types can therefore be used to describe the different physical habitat templates available for biotic habitation (Nel *et al*. 2006).

Longitudinal zones were derived for all rivers using techniques from Rowntree and Wadeson (1999) and a semi-automated procedure developed at the Directorate: Resource Quality Services, Department Water Affairs and Forestry (*Figure 6*). For the purposes of depicting biodiversity at the scale appropriate for conservation planning in the Olifants, Inkomati and Usutu-Mhlathuze Water Management Area, the resulting longitudinal zones were combined into four zones (*Table 5*). The grouped longitudinal zones were combined spatially with the Level 2 river types to derive 203 combinations, which can be considered Level 3 river types. These were used as the final river types in the conservation vision.

Table 5: Longitudinal zones used in the Olifants, Inkomati and Usutu-Mhlathuze conservation vision.

The corresponding longitudinal zones described by Rowntree and Wadeson (1999) are also provided. Note: Source zones as described by Rowntree and Wadeson (1999) do not occur in this area.

Lumped longitudinal zone	Rowntree and Wadeson (1999) zones
Mountain stream	*Mountain headwater streams, mountain streams*
Upper foothills	*Transitional zones and upper foothills*
Lower foothills	*Lower foothills*
Lowland river	*Lowland river*

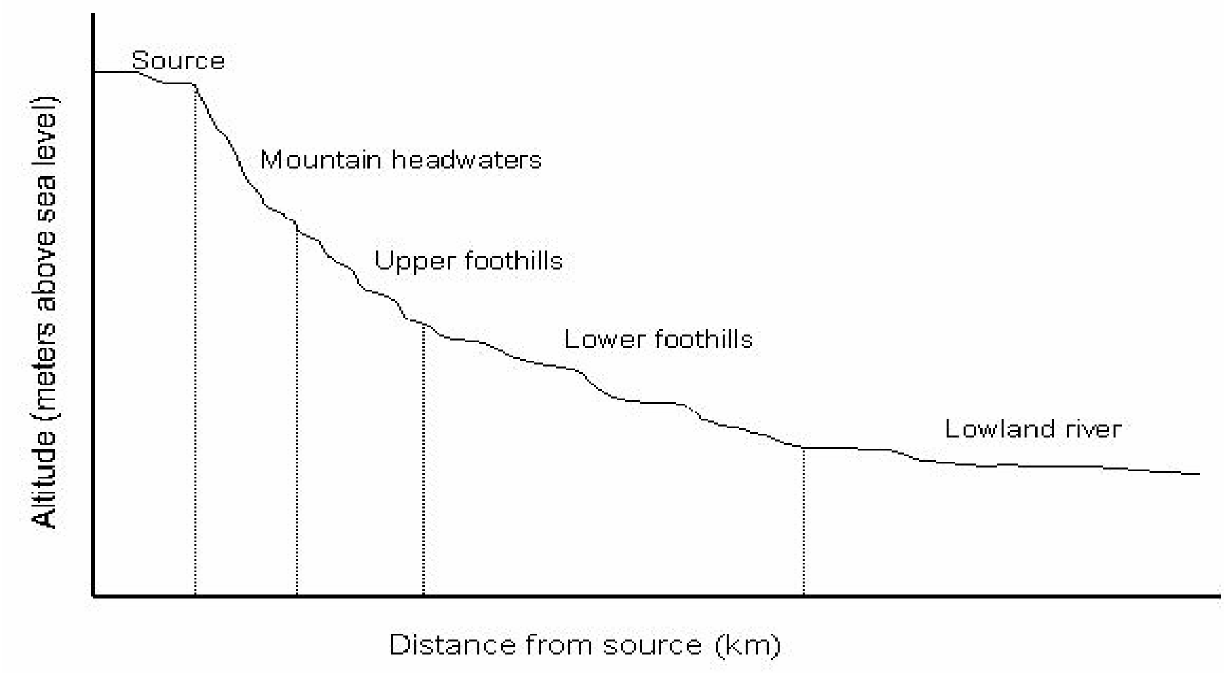

Figure 6. Stream level river classification (longitudinal zonation).

***Limitation:** The river types produced in this study have not been verified as to their surrogacy effectiveness i.e. how well they represent actual freshwater biodiversity. Further work verifying these river types is required..*

3.3 Classifying wetland types

Wetlands occur in areas where soils are saturated or inundated with water for varying lengths of time and at different frequencies. For this report, a wetland is defined as **any inland water environment excluding rivers, and including areas of marine water, the depth of which at low tides does not exceed ten metres**. This is similar to the definition applied in the recent national wetland inventory project (Ewart-Smith 2006) which adapted the RAMSAR definition (Davis 1994) to South African conditions; with the exception that rivers are included in the Ewart-Smith (2006) definition.

Wetlands are ecologically, socially and economically valuable resources. They support a wide diversity of fish, amphibians, water birds and plants, and deliver important ecosystem services, such as water storage, reduced surface water flow and erosion control, reduced impact of flash floods, sustained stream flow, increased groundwater recharge, and water purification. This conservation assessment acknowledges the need for representing pristine or near-pristine examples of each wetland type, as well as the need to maintain all wetlands for the ecological functions and services they provide. In order to achieve this representation, it is necessary to map localities of wetlands, and classify them into different wetland types.

Numerous typing systems have been developed for wetlands in South Africa (e.g. Dini and Cowan 2000; Jones and Day 2003; Farinha *et al*. 2005; Kotzé *et al*. 2005) and in conjunction with the National Wetlands Map (Beta version) would form the basis for a useful wetland classification for the region. However, the National Wetlands Map has just been released for interrogation and delineates potential wetland boundaries. These delineations have yet to be verified using interpretation of aerial photography and field verification and were not used for the purposes of this study.

Two GIS layers, described below, were combined to map the wetland boundaries of the Olifants, Inkomati and Usutu-Mhlathuze Water Management Area (*Figure 7*):

(i) Mpumalanga wetlands
This GIS layer is available from Mpumalanga Parks Board (Lotter and Ferrar 2006), and contains boundaries of known and sampled wetlands for Mpumalanga Province.

(ii) KwaZulu-Natal wetlands
These were sourced from the Ezemvelo KZNl Wildlife (Scientific Services), and contains boundaries of known and sampled wetlands for KwaZulu-Natal Province.

Combining the descriptions of drainage, landform and vegetation group for each wetland produced 69 different wetland types of which 64 were used as the final wetland types in the conservation vision. Five wetland types were excluded based on their small size, See Section 3.7.2 for a description of this process.

Limitation: *By using the Kwazulu-Natal and Mpumalanga wetlands data this study leaves a data gap in the northern areas of the study area i.e. wetlands of Limpopo and Gauteng Provinces. Unfortunately equivalent wetlands data were not available for these regions.*

Limitation: *Conservation planning aims to conserve both biodiversity pattern (e.g. species, ecosystems) and biodiversity process (e.g. migration, dispersal). The later are essential in ensuring the persistence of biodiversity pattern. This usually requires data on both pattern, as well as process elements. As only data on river and wetland types (pattern) were available, this study does not explicitly include process data. It does however try to include some processes implicitly through a focus on integrity, connectivity and size(see below). However, data on freshwater biodiversity processes should be considered for future iterations of this vision.*

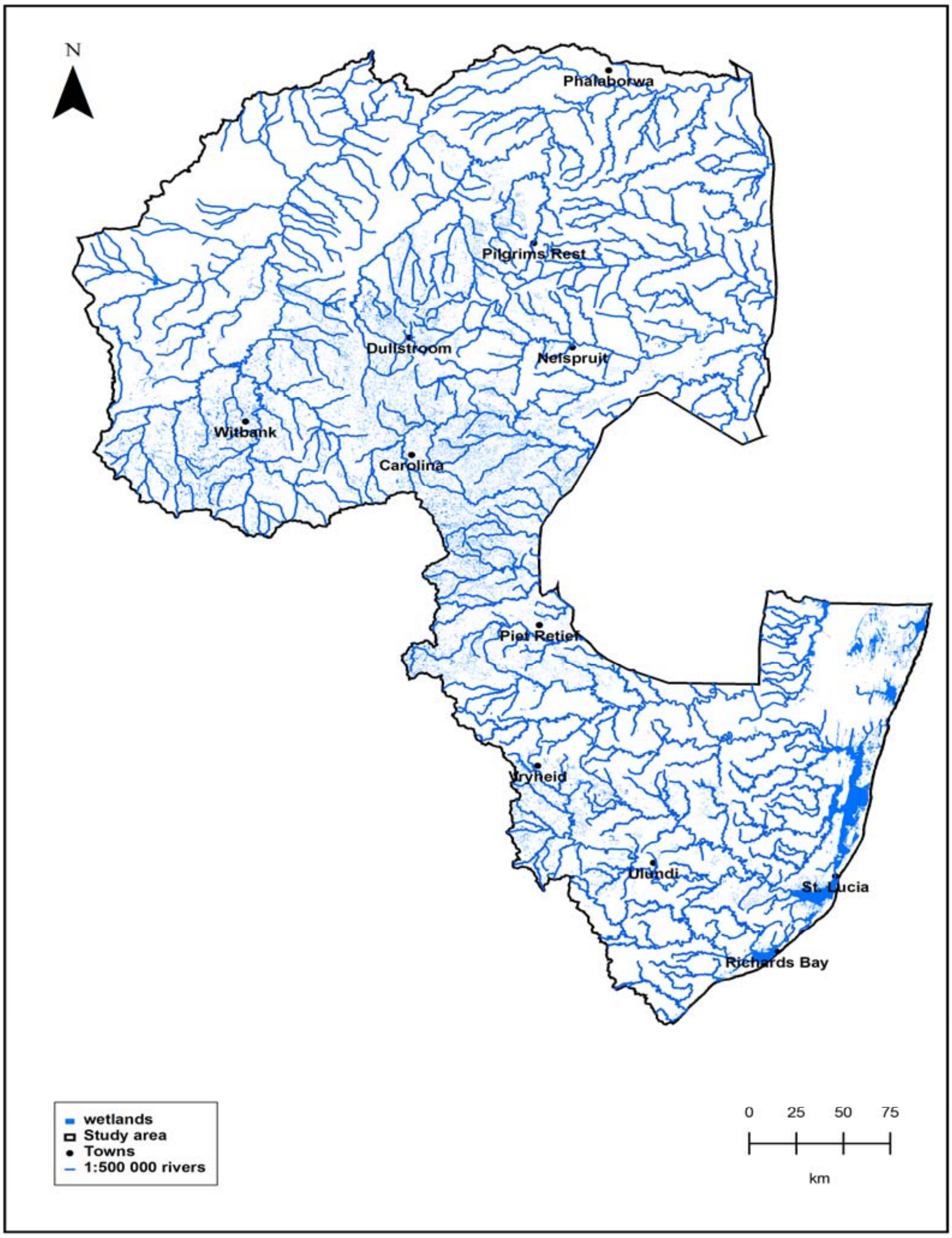

Figure 7. Wetland delineations in the Olifants, Inkomati and Usutu-Mhlathuze Water Management Area.

3.4 Setting quantitative conservation targets

A first step in promoting the systematic and purposeful conservation of freshwater biodiversity is to incorporate a clear and explicit conservation vision into the strategies and business plans of those implementing agencies responsible for managing freshwater ecosystems. This vision should then be translated into quantitative conservation targets. Conservation targets (also referred to as biodiversity targets) set minimum, quantitative requirements for biodiversity conservation in order to: allow an evaluation of whether or not existing conservation efforts adequately represent the biodiversity of a region; provide guidance for planners who are balancing a number of competing demands for natural resources in a region, and provide water resource management and biodiversity conservation agencies with common quantitative measures for which to aim (Groves 2003).

Conservation targets reflect scientific best judgement, and the adoption and implementation of these targets is a reflection of societal norms and values. There is no correct way of setting targets because of the uncertainty around requirements of structural, compositional and functional elements of biodiversity. Therefore, the setting and adoption of conservation targets should be informed through evolving understanding of the effect of anthropogenic activities on biodiversity. A conservation target should thus be subject to review over time.

The following guidelines from Roux *et al*. (2006) were considered in setting conservation targets:

(i) At least 20% of each freshwater ecosystem type should be maintained in an A or B integrity category, where A or B refers to the highest level of protection afforded by the water resource classification system of DWAF (i.e. Management Class I; see *Table 1*). This recommendation stems from the World Conservation Union's Caring for the Earth strategy (IUCN 1989), which stipulates that a minimum of 20% of a country's natural aquatic assets require protection - dropping below this threshold (i.e. failing to meet a minimum conservation target of 20%) implies that the ecosystem is inadequately represented in the country, and has become critically endangered.

(ii) In order to maintain freshwater ecosystem functioning, whole river systems rather than isolated reaches should, wherever possible, be selected for contributing towards the national biodiversity target. Where this is not attainable, river ecosystems that are designated for conservation should, where relevant, be connected through river systems that are in a state that supports ecological connectivity - for example allowing migration of a key species. River systems that provide connectivity should be considered part of an overall conservation portfolio design for freshwater conservation, i.e. maintenance of their ecological state will be necessary for achievement of the overall biodiversity target. However, where connecting rivers are in less than an A or B integrity category, they should not contribute towards satisfying the 20% conservation target.

(iii) Where a particular freshwater ecosystem that has been identified as important for achieving targets, but through past or current over-utilization has been modified to a state that does not conform to conservation objectives, restoration or rehabilitation should be undertaken subject to feasibility. Rehabilitation efforts should strive to return the chemical, physical and biological attributes of a water resource to that associated with a defined (not necessarily pristine) ecological state.

3.4.1 Conservation targets for river types

The conservation target was calculated as 20% of the total length of each Level 3 river type. These targets should only be achieved within river reaches that have an ecological integrity category of A or B. In this study river types which could not achieve their targets in an A or B state could then use C category rivers. This was thought to be suitable for the water licensing focus of this study. Some river types had less than 20% of their total length in an A, B or even C state; targets for these 50 river types were reduced to 100% of the intact length (i.e. A or B state) remaining. See Section 3.5. below for a description of these ecological integrity classes.

3.4.2 Conservation targets for wetland types

The conservation target for wetland types was calculated as 20% of the total area of each wetland type. These targets should only be achieved within wetland types whose modelled ecological integrity is natural. Those wetlands selected to achieve targets need to be in their near-pristine condition to maintain the full range of structural, compositional and functional biodiversity (i.e. their habitats and associated biota, as well as their functions). These wetlands should be awarded the highest level of protection. Of the 64 wetland types 8 did not have enough remaining natural area to meet the 20% target. 2 of these wetland types were small and were excluded from the conservation vision, targets for the remaining 6, in a similar fashion to the river type targets, were reduced to 100% of the natural area remaining. This ranged from 10 – 18% of the original area for 5 types and 1% for 1 type. Although a small target, the latter was included due to the large size of this wetland type (>100 ha).

Limitation: *Conservation planners have highlighted that not all biodiversity is equal and as such differential conservation targets should be set that take into account differences in value, threat, endemism and other characteristics of regional biodiversity. Due to the limited data available, this study could not assign weighted targets to river and wetland types and all types are thus treated equal.*

3.5 Ensuring persistence through ecological integrity

Ideally, those ecosystems that are currently considered to be of high integrity should be selected where possible for the conservation vision. These are the ecosystem that accurately represent the biodiversity of the region, and in which ecological and evolutionary processes operate within their natural ranges. For example, the flow regime is often considered to be a ”master variable” of freshwater ecosystems, vital in shaping aquatic and riparian communities, and the physical characteristics of river-floodplain ecosystems in both time and space (Rowntree and Wadeson 1999; Richter and Richter 2000; Richter et. al. 2003). Conservation plans should give preference to selecting freshwater ecosystems where there is a realistic chance of maintaining or restoring natural flow regimes. This often translates to selecting freshwater ecosystems of high ecological integrity first, since these are the ones most likely to have natural or near-natural flow regimes.

From a practical point of view, selecting ecosystems that are currently of high integrity also: (i) facilitates operational management since ecosystems operating close to natural conditions tend to be more self-sustaining, and require less conservation management; and (ii) improves the cost efficiency of conservation management as no rehabilitation is required.

Explicit consideration was given to mapping the current ecological integrity of both rivers and wetlands. Ecological integrity for rivers was based on actual data wherever possible, and supplemented with data modelled from land cover. Wetland ecological integrity was based entirely on land cover.

3.5.1 River ecological integrity

3.5.1.1 Main rivers

Existing ecological integrity data tend to focus on main rivers. For example, national present ecological status (Kleynhans, 2000) derived for the Water Situation Assessment Model provides integrity data for main rivers within each quaternary catchment. Here, main rivers are defined as rivers that pass through a quaternary catchment into a neighbouring quaternary catchment. In situations where no river passes through the quaternary catchment, the longest river system is chosen as the main river. This definition was adopted for the purposes of the ecological integrity analyses.

River ecological integrity categories used for main rivers were based on the present ecological status categories, which range from A (natural) to F (critically modified). For the purposes of this assessment, rivers with an overall present ecological status category of natural or largely natural (Category A or B respectively) was considered “intact” and suitable for contributing towards achievement of quantitative conservation targets. In some cases main rivers in a C class (moderately modified) could contribute to the target if necessary. Ecological integrity was mapped using the present ecological status (Water Situation Assessment Model data; Kleynhans 2000) data set for main rivers:

Only 4 653km^2 (40%) of main rivers in the Olifants, Inkomati and Usutu-Mhlathuze Water Management Area are considered intact and able to contribute toward achieving conservation targets (*Figure 8*). 38% of main rivers are moderately modified, i.e. in a C ecological integrity category. This is similar to the national trend (Nel *et al*. in press). Main rivers in South Africa are heavily utilized and regulated to improve water security for socio-economic use, and there are widespread water transfer schemes across the country to cater for areas where water requirements exceed the natural water availability (Braune 1985; O’Keeffe 1989; DWAF 2004d). Smaller tributaries are often less regulated and may be in a better condition than main rivers. Thus, tributaries have a role to play in meeting conservation targets, and are important to include in the assessment.

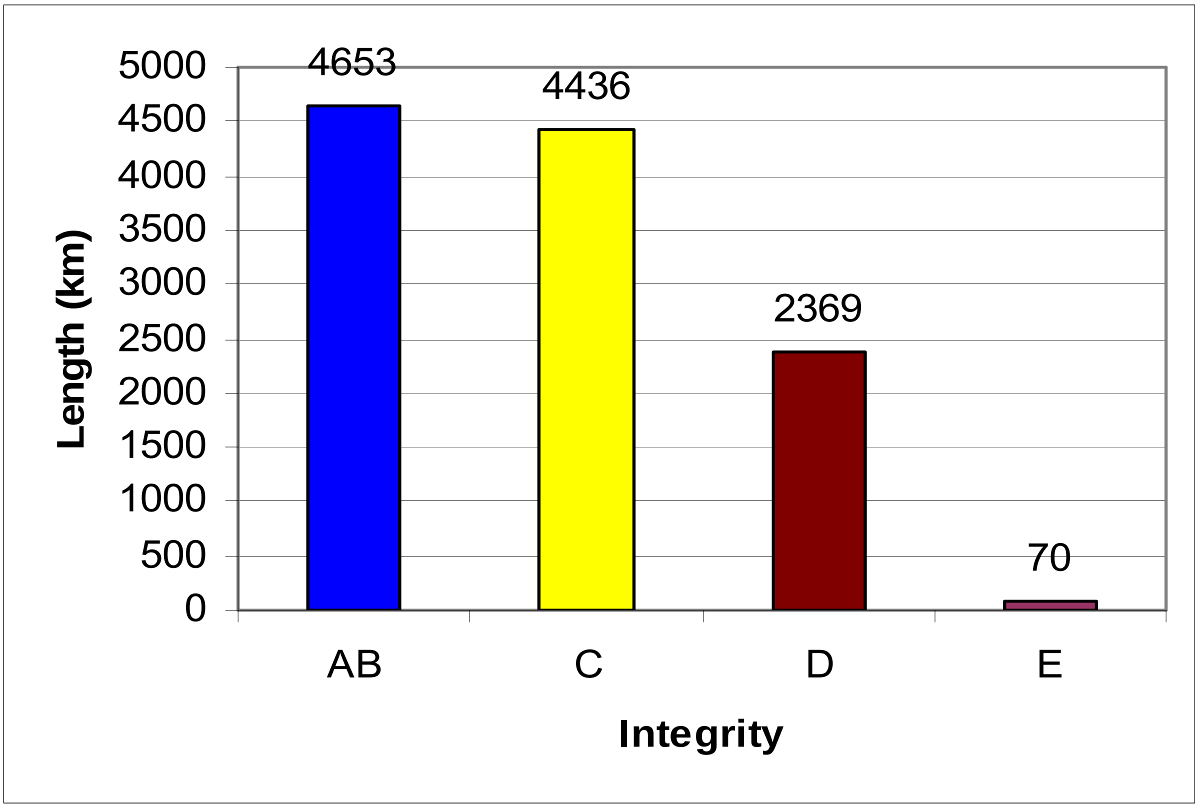

Figure 8. Main river integrity in the Olifants, Inkomati and Usutu-Mhlathuze Water Management Area and South Africa.

National data after Nel et al. (in press). River length was calculated by summing the length of main river reaches in each present ecological status category and expressing this as the total length of main rivers in the Olifants, Inkomati and Usutu-Mhlathuze Water Management Area.

3.5.1.2 Tributaries

"Tributaries" were defined as any 1:500 000 river that is not a quaternary main river. Ecological integrity for tributaries was derived using the percentage of natural land cover as a proxy, based on the study by Amis *et al*. (in press) which found that where no other data exist, the percent natural vegetation serves as a good proxy. The National Land Cover 2000 GIS layer was used to distinguish natural and transformed land cover classes. The "Waterbodies" land cover class contains both natural and man-made waterbodies. To differentiate between natural and man-made waterbodies, the 1:50 000 farm dams were overlaid with the National Land Cover 2000 GIS layer; waterbodies coinciding with farm dams were thus coded as transformed.

Table 6. National Landcover (NLC 2000) Categories indicating which categories were considered natural (scored as 1) vs transformed (scored as 0).

It should also be noted that for the purposes of this study, the1:50 000 farm dams coverage was unioned with the NLC 2000 coverage and where a farm dam intersected with a waterbody, the waterbody was scored as transformed (0).

ID	***Description***	***Natural***
1	Forest (indigenous)	Yes
2	Woodland (previously termed Forest and Woodland)	Yes
3	Thicket, Bushland, Bush Clumps, High Fynbos	Yes
4	Shrubland and Low Fynbos	Yes
5	Herbland	Yes
6	Unimproved (natural) Grassland	Yes
7	Improved Grassland	No
8	Forest Plantations (Eucalyptus spp)	No
9	Forest Plantations (Pine spp)	No
10	Forest Plantations (Acacia spp)	No
11	Forest Plantations (Other / mixed spp)	No
12	Forest Plantations (clearfelled)	No
13	Waterbodies	Yes
14	Wetlands	Yes
15	Bare Rock and Soil (natural)	Yes
16	Bare Rock and Soil (erosion : dongas / gullies)	No
17	Bare Rock and Soil (erosion : sheet)	No
18	Degraded Forest & Woodland	No
19	Degraded Thicket, Bushland, etc	No
20	Degraded Shrubland and Low Fynbos	No
21	Degraded Herbland	No
22	Degraded Unimproved (natural) Grassland	No
23	Cultivated, permanent, commercial, irrigated	No
24	Cultivated, permanent, commercial, dryland	No
25	Cultivated, permanent, commercial, sugarcane	No
26	Cultivated, temporary, commercial, irrigated	No
27	Cultivated, temporary, commercial, dryland	No
28	Cultivated, temporary, subsistence, dryland	No
29	Cultivated, temporary, subsistence, irrigated	No
30	Urban / Built-up (residential)	No
31	Urban / Built-up (rural cluster)	No
32	Urban / Built-up (residential, formal suburbs)	No
33	Urban / Built-up (residential, flatland)	No
34	Urban / Built-up (residential, mixed)	No
35	Urban / Built-up (residential, hostels)	No
36	Urban / Built-up (residential, formal township)	No
37	Urban / Built-up (residential, informal township)	No
38	Urban / Built-up (residential, informal squatter camp)	No
ID	DESCRIPTION	Natural
39	Urban / Built-up (smallholdings, woodland)	No
40	Urban / Built-up (smallholdings, thicket, bushland)	No
41	Urban / Built-up (smallholdings, shrubland)	No
42	Urban / Built-up (smallholdings, grassland)	No

ID	Description	Natural
43	Urban / Built-up, (commercial, mercantile)	No
44	Urban / Built-up, (commercial, education, health, IT)	No
45	Urban / Built-up, (industrial / transport : heavy)	No
46	Urban / Built-up, (industrial / transport : light)	No
47	Mines & Quarries (underground / subsurface mining)	No
48	Mines & Quarries (surface-based mining)	No
49	Mines & Quarries (mine tailings, waste dumps)	No

Two categories of integrity were assigned to tributaries: "Intact" (equated to the A or B ecological integrity categories of main rivers), or "Not intact" (assigned a category of "Z"). The following steps were used to calculate these categories for each river reach:

(i) Calculate three disturbance indices:
- Catchment disturbance index (% natural vegetation within each sub-quaternary catchment)
- Riparian disturbance index (% natural vegetation within a 500 m GIS buffer of a river)
- Macro-channel disturbance index (% natural vegetation within a 100 m GIS buffer of a river)

(ii) Assign the minimum of these three indices to each river reach.

(iii) Assume any river reach with natural vegetation ≥ 80% to be "intact", or in a Category A or B, and able to contribute towards achieving river conservation targets. Assign a Category Z, or "not intact", to any river reach below this threshold.

Figure 9 shows the ecological integrity of the river types when considering both tributaries and main stems rivers. Interestingly, in this study area modelled ecological integrity for tributaries does not support the notion that tributaries are less impacted than main rivers, with 38% of the river length (main rivers and tributaries) in the Olifants, Inkomati and Usutu-Mhlathuze Water Management Area being in an intact state, as opposed to 40% when considering main rivers alone. This highlights the degree to which land transformation has impacted on the freshwater systems of Mpumalanga and to a lesser extent KwaZulu-Natal, although this result does not diminish the importance of tributaries for conserving biodiversity, in which conserved tributaries could be viewed as refugia for river biodiversity, replenishing other parts of the river system from time to time. For this replenishment to occur, however, it is important that the longitudinal connectivity between the tributaries and its main river be maintained.

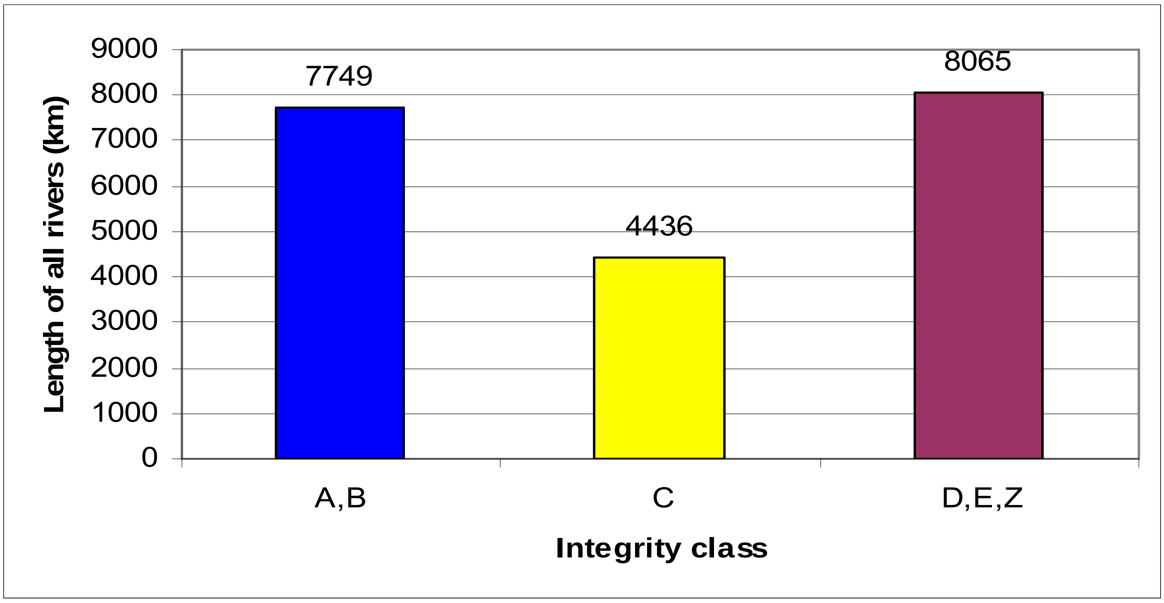

Figure 9. Ecological integrity of main rivers and tributaries.

Limitation: *The modelled tributary ecological integrity data are preliminary and need to be refined to consider other impacts on integrity e.g. cumulative upstream impacts of dams and water transfer schemes, pollution and abstraction. These refinements should then be field verified.*

3.5.2 Wetland ecological integrity

There are many field approaches to assessing wetland condition. However, in the absence of field data, we used a desktop modelling approach based on percentage natural land cover (similar to the approach used for deriving ecological integrity of tributaries in Section 3.5.1.2). The land cover classes were reclassified in the same way as was done for tributaries into natural and transformed categories.

Two categories of integrity were assigned to wetlands: “Intact”, or “Not intact”. The following steps were used to calculate these categories for each wetland:

(i) Calculate three disturbance indices:
- Catchment disturbance index (90% natural vegetation within each sub-quaternary catchment)
- Core disturbance index (90% natural vegetation within a 50 m GIS buffer of a wetland)
- Buffered core disturbance index (90% natural vegetation within a 100 m GIS buffer of a wetland)

(ii) Assign the minimum of these three indices to each wetland.

(iii) Assume any wetland with a natural vegetation of ≥ 90% to be “Intact” and able to contribute towards achieving river conservation targets. Assign a category of “Not intact” to all other wetlands below this threshold.

Limitation: *In a similar fashion to the tributary integrity, the integrity of wetlands may well be overestimated in this study. This overestimation is due to: differences in scale – this may result in underestimation of intense and highly localised impacts that are smaller than the minimum mapping unit of the National Land Cover 2000 GIS layer; underestimates of the extent of land degradation - the National Land Cover 2000 GIS layer does not accurately detect land degradation; and deleterious land practices are not always mapped.*

3.6 Ensuring persistence through connectivity

Most freshwater ecosystem functions are, directly or indirectly, maintained through connectivity. Thus, identifying areas that are important for conserving biodiversity pattern needs to be augmented with management zones aimed at controlling impacts in systems that are connected to these conservation areas. Longitudinal connectivity requires managing upstream and downstream catchment impacts and lateral connectivity involves managing impacts from the surrounding landscape. The following section describes how longitudinal and lateral connectivity have been incorporated in this conservation assessment.

3.6.1 Longitudinal connectivity

Longitudinal connectivity should be maintained in both space (through a connected river network) and time (through maintenance of the natural hydrological regime). Ideally, whole river systems should be selected; however, it is seldom possible to find whole river systems in a consistently high ecological state (where the river is Category A or B throughout its entire tertiary or primary length). In many freshwater conservation plans attempts are made to connect whole river systems in A, B and sometimes C integrity categories. In this assessment the conservation vision was programmed so as to favour the selection of sub catchments connected by main rivers in A, B and C integrity classes until conservation targets were achieved. However, the selection of whole river systems was not emphasised in this study due to its focus on water licensing where upstream and downstream connectivity are explicit.

3.6.2 Lateral connectivity

Lateral connectivity refers to the interconnectedness that exists across an environmental gradient between aquatic, riparian and terrestrial ecosystems. As a result, the ecological integrity of the whole catchment needs to be managed appropriately in order to conserve riverine and wetland biodiversity. The need for lateral connectivity was incorporated into the Olifants, Inkomati and Usutu-Mhlathuze conservation vision by including entire sub-quaternary catchments within which selected river reaches or wetlands occurred, highlighting that these sub-quaternary catchments will require appropriate land use practices in order to meet the level of protection awarded to the water resource.

3.7 Ensuring persistence through size

Any area included in the conservation vision should be sufficiently large to allow biodiversity features to recover from natural disturbances and have populations that are large enough and reproduce sufficiently to remain viable in the long term. The actual extent of what constitutes "sufficient size" will vary between systems and what is being conserved, and should be assessed on a case-by-case basis. Size of river reaches and wetlands was assessed prior to inclusion in the conservation portfolio.

3.7.1 River size

Each river reach chosen for inclusion in the Olifants, Inkomati and Usutu-Mhlathuze conservation portfolio was evaluated in terms of its size. In most cases, only reaches over 5 km were chosen for conservation purposes. However, there were a few instances, mainly in headwater streams, where the only option to conserve a representative stretch of river was in a reach of < 5 km, which was connected to rivers of lower integrity (Categories C-F). Because headwaters are by definition shorter rivers and can be important and viable for specific aquatic biota even with their small size, it was decided that they should be included in the conservation vision unless their contribution to the overall target of that river type was < 2%. This had no effect on the number of river types in the study.

3.7.2 Wetland size

Minimum size thresholds, depending on type of landform, were also set for representative habitat wetlands. For wetlands, a size threshold of 2 ha was applied for representation within the conservation portfolio. This means that no wetland smaller than 2 ha was considered for representation of a particular wetland type leaving 64 final wetland types.

4. ASSESSING THE OLIFANTS, INKOMATI AND USUTU-MHLATHUZE CONSERVATION VISIONS

4.1 Conducting the conservation vision

The areas included in the conservation vision are not intended as formal protected areas only. Rather, they reflect areas that need to be managed appropriately to conserve the full spectrum of freshwater biodiversity for both present and future generations. There exists a suite of strategies and policies that could be employed in combination to implement appropriate land and water management (e.g. formal protected area strategies, integrated water resource management strategies, extension and stewardship strategies).

In conducting the conservation vision, the distribution of river and wetland types and their conservation targets (Section 3.4) are taken into account. This is all assessed within a framework of connectivity, integrity and size discussed previously as criteria necessary to ensure persistence. To maximise efficiency in achieving this vision, it makes sense to plan for all freshwater ecosystems together (e.g. representative river types, representative wetland types), because in many places conservation targets for wetland and river type representation may be achieved simultaneously. Moreover, conserving wetland types will require appropriate management of the riverine habitat , and vice versa - conserving river types selected for representation will require appropriate management of the associated wetlands.

The section below outlines the selection protocol used to derive the conservation vision for the Olifants, Inkomati and Usutu-Mhlathuze Water Management Area, as well as the results. This conservation vision reflects the areas required to achieve all biodiversity targets where possible, i.e. rivers and wetlands together. Since one of the objectives of this study was to test how this spatial assessment would interface with the water licensing process for rivers from a freshwater biodiversity perspective, a separate section is provided which considers the conservation vision for achieving river type targets alone (Section 4, *Figure 13*).

4.1.1 Selection protocol

The process of using decision support software to aid decision-making on the most efficient way of meeting multiple criteria is frequently applied in conservation planning, since conservation visions attempt to achieve multiple conservation targets in an efficient manner, taking into account complementarity. However, to date, most conservation planning software has been developed for terrestrial ecosystems and has limited utility in aiding decision-making for inland water conservation visions. A recent marine conservation planning software (MARXAN; Ball and Possingham 2000) has been developed, which is more suited to inland water environments because it builds connectivity into its algorithm. This is now supported by user-friendly software, CLUZ (Smith 2005), that interfaces with a geographic information system (ARCVIEW ver 3.2, ESRI 1997). The MARXAN/CLUZ software was used to select sub-quaternary catchments for inclusion into the conservation vision.

MARXAN selects near-optimal solutions to achieving conservation targets by costing visions produced by simulated annealing algorithms, where effective portfolios have the lowest costs. Cost parameters are outlined briefly in *Information Box 2*. Using the cost parameters, we ran MARXAN/CLUZ to determine the best possible options for achieving conservation targets for river and wetland types. Input data included 2611 modelled sub-quaternary catchments with their river types and integrity, and wetland types and integrity; as well as the targets for each river and wetland type. An additional input data layer consisted of the boundary lengths of all planning units which share a main river. This data layer is used to ensure connectivity in the selection process.

The following steps were used, in the order listed below, to select sub- quaternary catchments for inclusion in the Olifants, Inkomati and Usutu-Mhlathuze Water Management Area conservation vision:

1. Select planning units with rivers in an A or B state and wetlands in an intact state until all possible targets are achieved. MARXAN conducts this step while ensuring efficiency through a focus on complementarity. This means that MARXAN tries to select planning units which complement one another in terms of the river and wetland types they contain thereby selecting the minimum planning units possible
2. Select planning units with rivers in a C state or wetlands with between 80-90% of their vegetation intact to achieve remaining targets
3. Note the river and wetland types for which targets remain unachieved. This is used later in the rehabilitation process.

In many conservation plans there are often choices between 2 or more planning units which contribute similarly to conservation targets. These are referred to as ties. Because MARXAN can deal with more than a single criterion e.g. target achievement, additional information was used to resolve ties:

1. Select the planning unit which shares a river with an already selected planning unit. This ensures connectivity
2. Select a planning unit which lies in an existing protected area. This reduces management and opportunity costs
3. Select a planning unit which coincides with an already identified freshwater priority area in the region. In the case of Kwazulu Natal these priority areas are primary catchments which connect to priority estuaries (*Figure 10*). This ensures alignment with existing fine scale initiatives on the ground.
4. Select a planning unit which contains a special aquatic feature not already considered in the vision. These special features are perennial pans in Mpumalanga (*Figure 10*). These have been identified as important biodiversity features in Mpumalanga's freshwater biodiversity assessment.

These criteria are considered simultaneously and not in the order that they are listed.

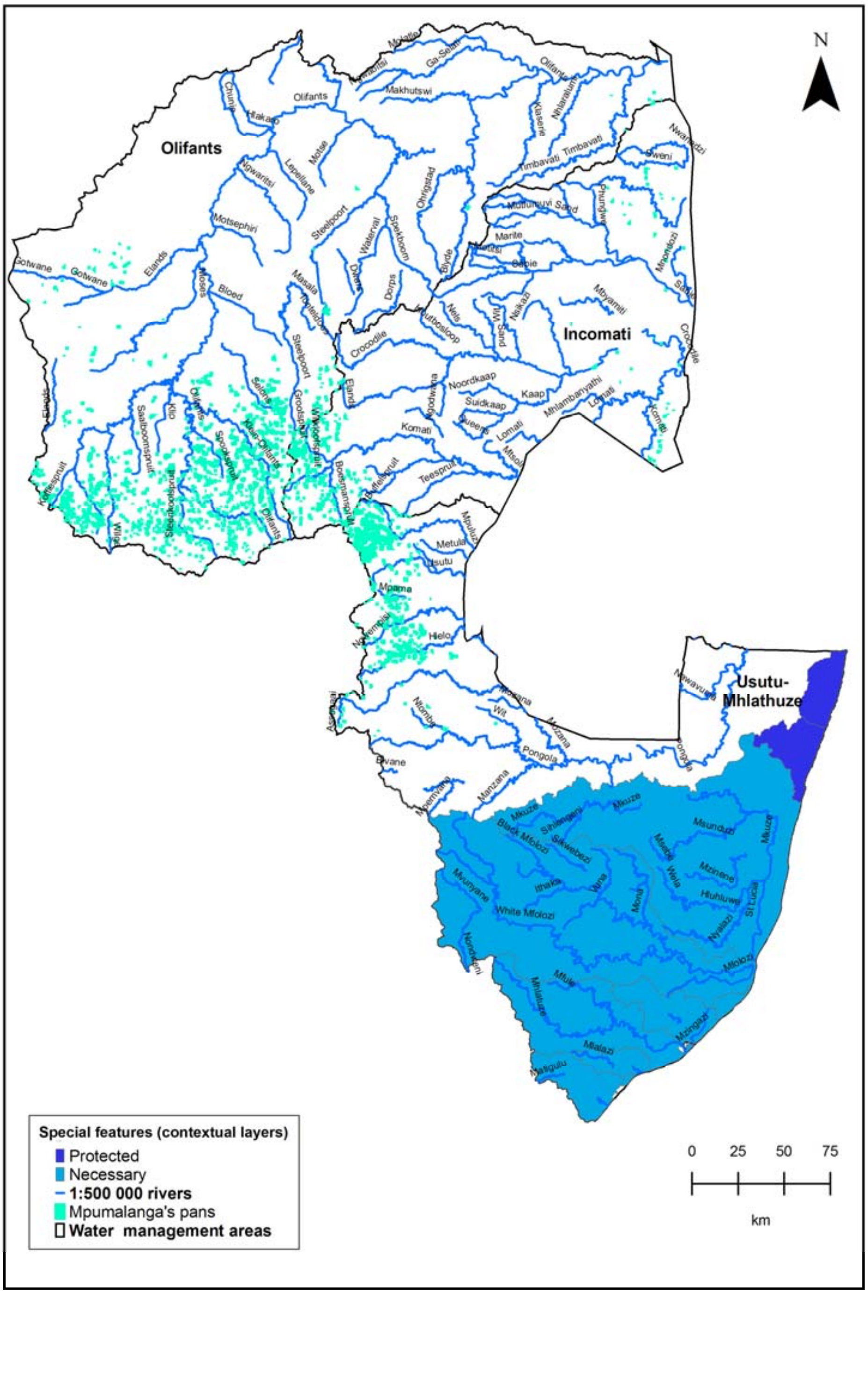

Figure 10. Additional special features include Kwazulu- Natal's priority primary catchments classified as protected or necessary which connect to priority estuaries and the perennial pans in Mpumalanga.

Information Box 2: MARXAN portfolio costs and costs applied for the Olifants, Inkomati and Usutu-Mhlathuze conservation portfolio

MARXAN establishes an efficient conservation portfolio by cost. The portfolio cost consist of three parts, which are explained below in terms of the costs applied to the Olifants, Inkomati and Usutu-Mhlathuze conservation portfolio.

1) The combined planning unit cost

Each planning unit is assigned a cost value. MARXAN calculates the combined cost of all the selected planning units (i.e. those in each portfolio). The Olifants, Inkomati and Usutu-Mhlathuze sub-quaternary catchments were assigned a basic cost of 1000. Planning units containing perennial pans, protected areas; and/or primary catchments identified as necessary to support priority estuaries were then "discounted" by 900. Where there are choices between two sub-quaternary catchments with similar biodiversity components, this discounting encourages MARXAN to select the preferred sub-quaternary catchments.

2) The boundary cost

The boundary cost measures the amount of edge that selected planning units in a portfolio share with unselected units. This means that a portfolio containing one connected patch of units will have a lower boundary cost than a number of scattered, unconnected units. Selecting for longitudinal connectivity can be encouraged by assigning a boundary cost to boundaries between sub-quaternary catchments that have rivers running through them into neighbouring sub-quaternary catchments. MARXAN then multiplies this value by the Boundary Length Modifier (BLM) constant, which is a user-defined number. Increasing this number increases the cost of having a fragmented portfolio.

A boundary cost of 1000 was assigned to boundaries between sub-quaternary catchments that had rivers running through them into neighbouring catchments. A Boundary Length Modifier of 10 was used.

3) Target penalty factor (or species penalty cost)

MARXAN calculates whether the target for each biodiversity feature is met by a portfolio and includes a cost for any target that has not been met. In the Olifants, Inkomati and Usutu-Mhlathuze conservation portfolio, the penalty cost was set at 100 000.

The total cost of a portfolio combines these three costs and is calculated as:

*Combined planning unit cost + (boundary cost * BLM) + Combined species penalty factors*

We repeated the selection process 100 times in MARXAN using 5 million iterations. Of those 100 runs MARXAN identifies the best solution as the one with the lowest cost. This solution was used as the final conservation vision (*Figure 11*).

4.1.2 Refining the conservation vision: a focus on water licensing

As is clear from *Figure 11* the number of planning units required to meet the river and wetland targets is large (915 planning units; 35% of study area). Separate analyses of rivers and wetlands in MARXAN revealed that, whilst conservation targets for both river and wetland types can be achieved simultaneously in many places, some areas required for wetland types are not necessarily required for river types, and vice versa. This is evidenced by the patterns of **irreplaceability** displayed by MARXAN outputs (*Figure 12)*. Irreplaceability is a measure of the likelihood that a particular sub-quaternary catchment will be required in the conservation vision for achieving targets. A planning is totally irreplaceable (irreplaceability = 1) if it contains a biodiversity feature whose targets can be achieved nowhere else in the planning domain.

Because areas required for achieving targets for river types are not always congruent with those areas required for wetland types, incorporating both rivers and wetlands into the conservation vision requires larger tracts of land than one only for rivers (see Section 4, Figure 12a), or only for wetlands. (Figure 12b).

Due to the focus on water licensing in this study the conservation vision developed above was used as the freshwater biodiversity conservation vision (*Figure 13*,) while a refined vision was developed to feed into the water licensing process. This refined vision was termed the water licensing conservation vision and focused primarily on rivers while keeping wetlands in the background. This would result in a smaller land requirement with some compromised wetland targets. The selection protocol for the water licensing conservation vision is outlined below.

1. Select planning units with rivers in an A or B state until all possible targets are achieved.
2. Select planning units with rivers in a C state to achieve remaining targets

In this case ties were resolved by selecting a planning unit identified as part of the freshwater biodiversity conservation vision where choices existed. This would imply that the resultant conservation vision would align as closely as possible with the freshwater biodiversity conservation vision.

The water licensing conservation vision (*Figure 13*) uses 486 planning units and occupies 19% of the study area. However, some wetland type targets have been compromised. The section below provides a detailed analysis of the 2 conservation visions. These conservation visions are not posited as alternatives, in fact they serve different purposes with the freshwater biodiversity conservation vision highlighting the minimum requirements if one hopes conserve a representative sample of the region’s biodiversity and the water licensing conservation vision highlighting the areas where rivers need attention in order to ensure the flows and processes to protect river biodiversity.

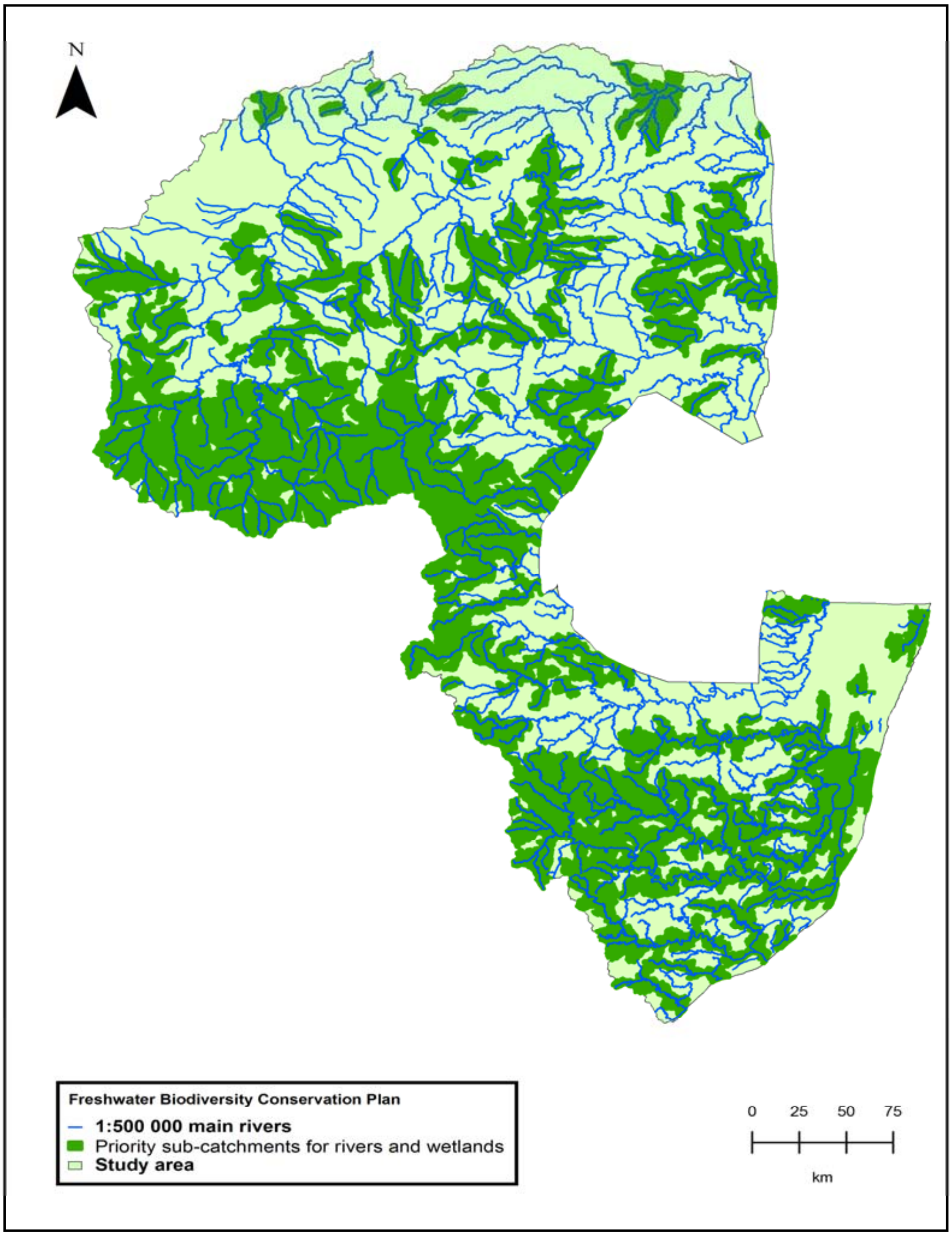

Figure 11. The Freshwater Biodiversity Conservation Vision for the Olifants, Inkomati and Usutu-Mhlathuze Water Management Area.

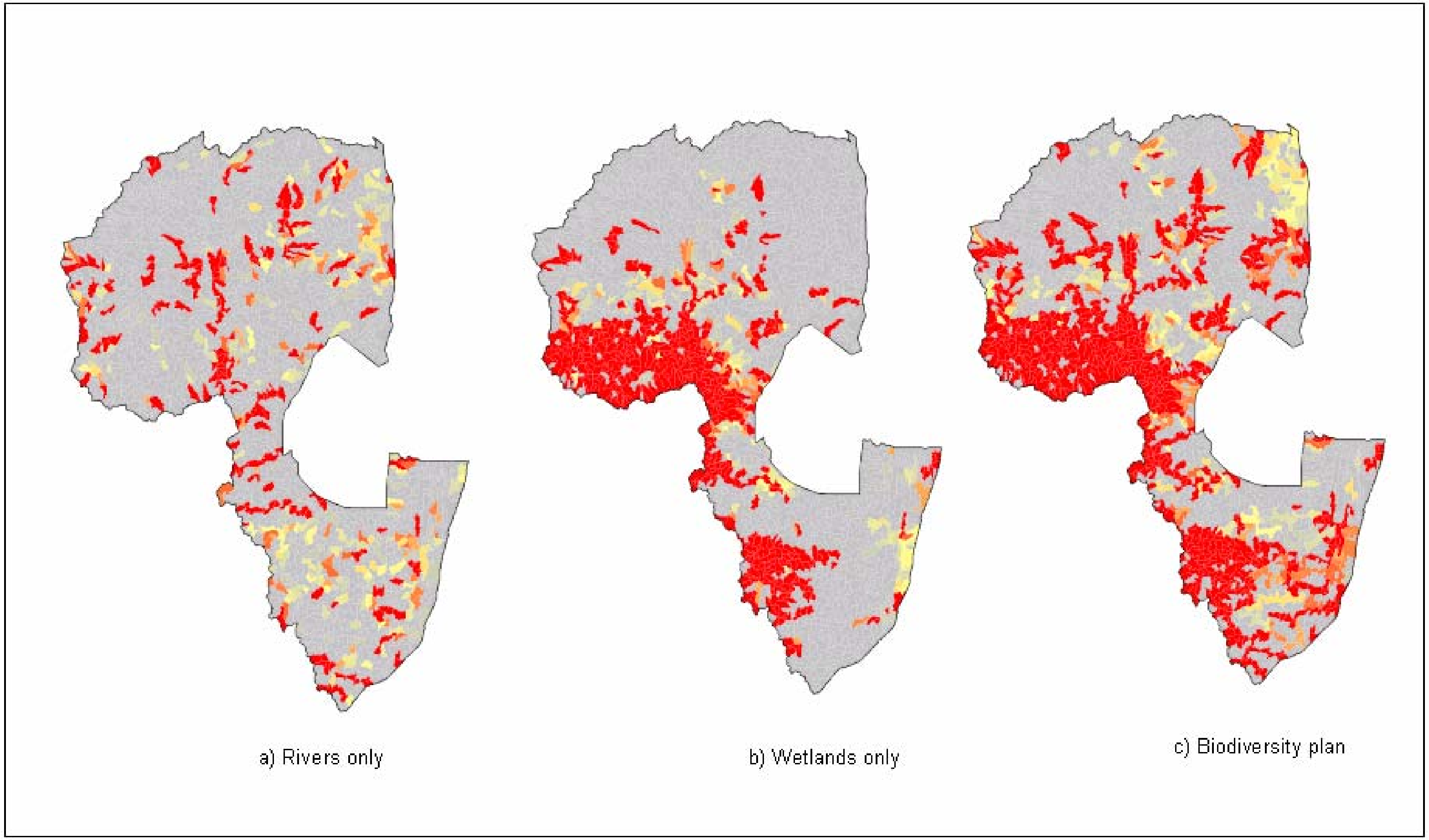

Figure 12. Irreplaceability for (a) rivers, (b) wetlands, and (c) rivers and wetlands combined.
In many instances areas important for rivers and wetlands are not the same, resulting in(c) having many areas of high irreplaceability
The red shading indicates areas of high irreplaceability, medium irreplaceability shown in yellow and low irreplaceability shown as grey.

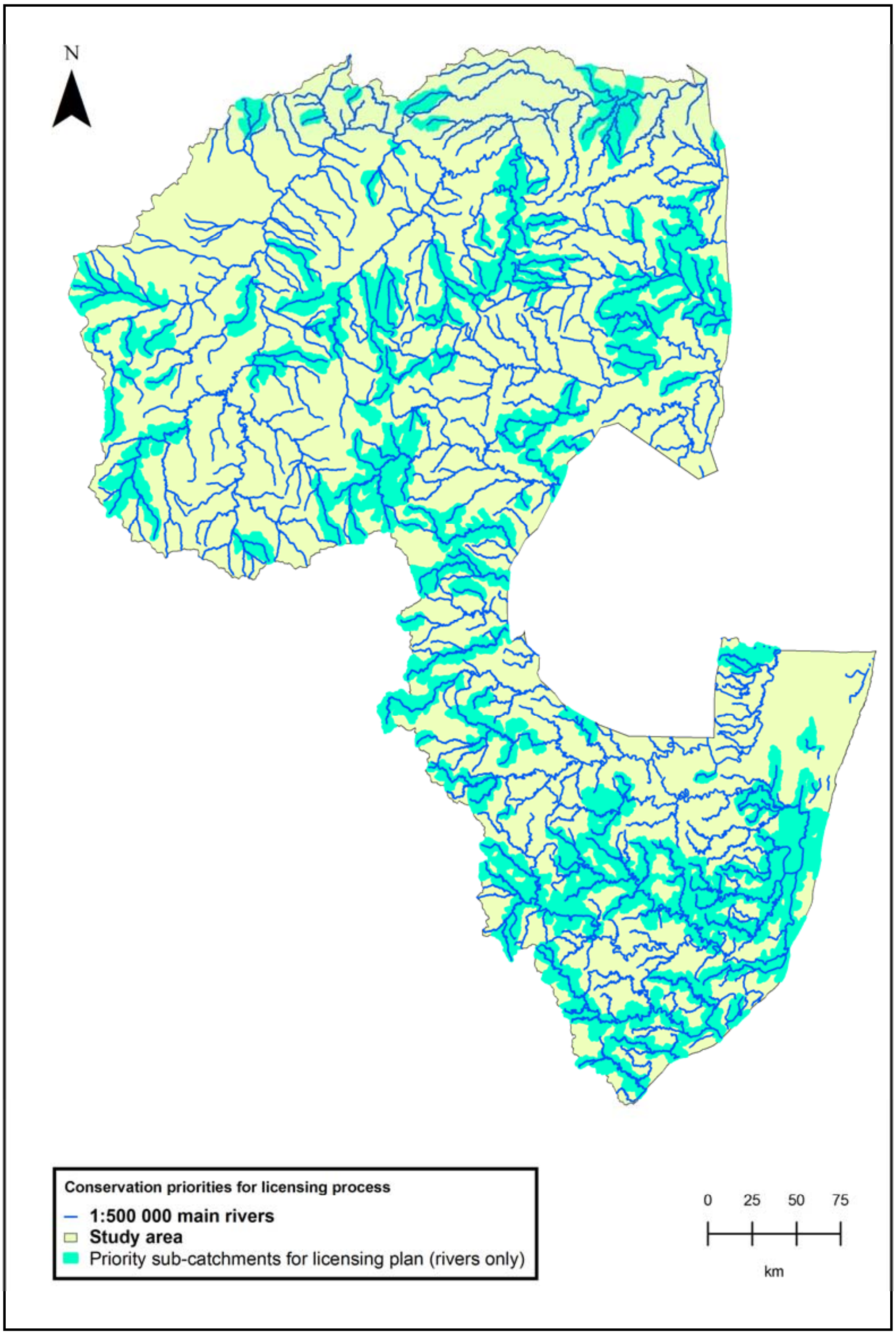

Figure 13. *The conservation vision for the water licensing process in Olifants, Inkomati and Usutu-Mhlathuze Water Management Area (Rivers only).*

4.2 Assessment of targets achieved

The water licensing conservation vision, although requiring a smaller percentage of the study area (19% vs. 35% in the freshwater biodiversity conservation vision), compromises some of the freshwater biodiversity conservation targets through the fact that it is not driven by wetland targets, pans, and estuaries. However, it does take these into consideration through using the freshwater biodiversity conservation vision to help resolve ties. Below an assessment of target achievement is made to highlight the differences between these 2 visions.

Figure 14 and *15* show the river and wetland type target achievement for the freshwater biodiversity and water licensing conservation visions, respectively.

4.2.1 Target achievement of river types

As both visions were driven by river type target achievement, all possible targets were achieved in both visions in rivers of A, B or C state (*Figure 14*). The sub-quaternary catchments selected as part of the visions (*Figure 13*) would achieve the conservation targets of 53% (108) of the 203 river types in the Olifants, Inkomati and Usutu-Mhlathuze Water Management Area in an intact state (A/B class), a further 41 river types can meet their targets when including rivers in a “C” state”. Therefore 73% of the river types can meet their targets in an A, B or C state. A further 2 river types can meet at least 75% of their target in the study area. However, it is not possible to meet conservation targets of the remaining 52 river types (26%), as these meet less than 75% of the 20% target set for river types (*Figure 14*).

The freshwater biodiversity vision selected 14% more sub catchments than the water licensing vision in order to represent wetland types. These additional sub catchments coincidently contain river lengths which add to the river type targets already achieved. The freshwater biodiversity vision represents an average of 34% of the river length of each river type, while the water licensing vision represents an average of 32% of the length of each river type. This overachievement of river type targets is to be expected when working at the broad sub-catchment scale and can be corrected during a finer scale implementation phase.

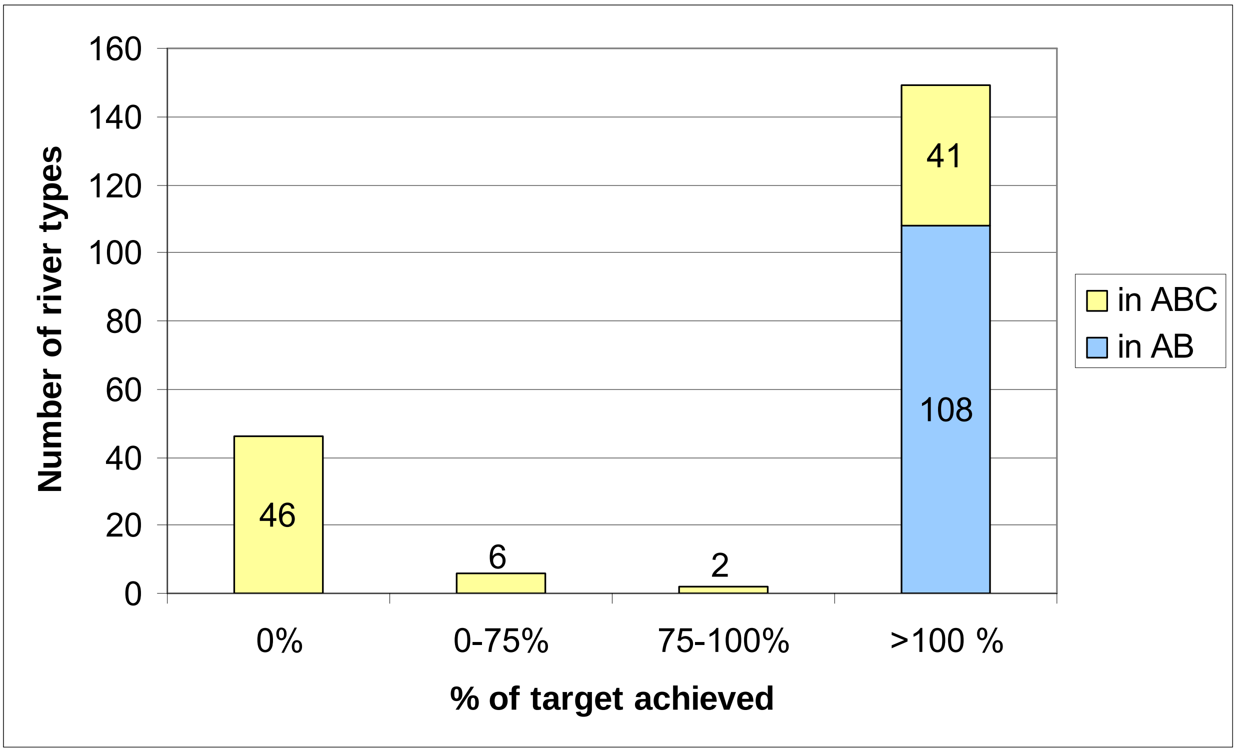

Figure 14. Target achievement for the 203 rivers types in the water licensing and biodiversity visions. Both visions are the same in terms of these categories of target achievement.

4.2.2 Target achievement of wetland types

This is where the major difference between the 2 visions becomes apparent. The water licensing vision only focused on river type target achievement, while the freshwater biodiversity vision also focused on wetland type target achievement. Due to this difference in approaches the water licensing vision only met the required target for 23% (15) of the wetland types. 73% (47) of the wetland type targets couldn't be achieved. However, of these 47 wetland types the vision did capture more than 75% of the target area required for 10 (16%) of them. The biodiversity vision met all targets for the 62 wetland types with remaining natural areas (*Figure 15*). It is important to note that 6 of these types had reduced targets due to limited remaining natural areas.

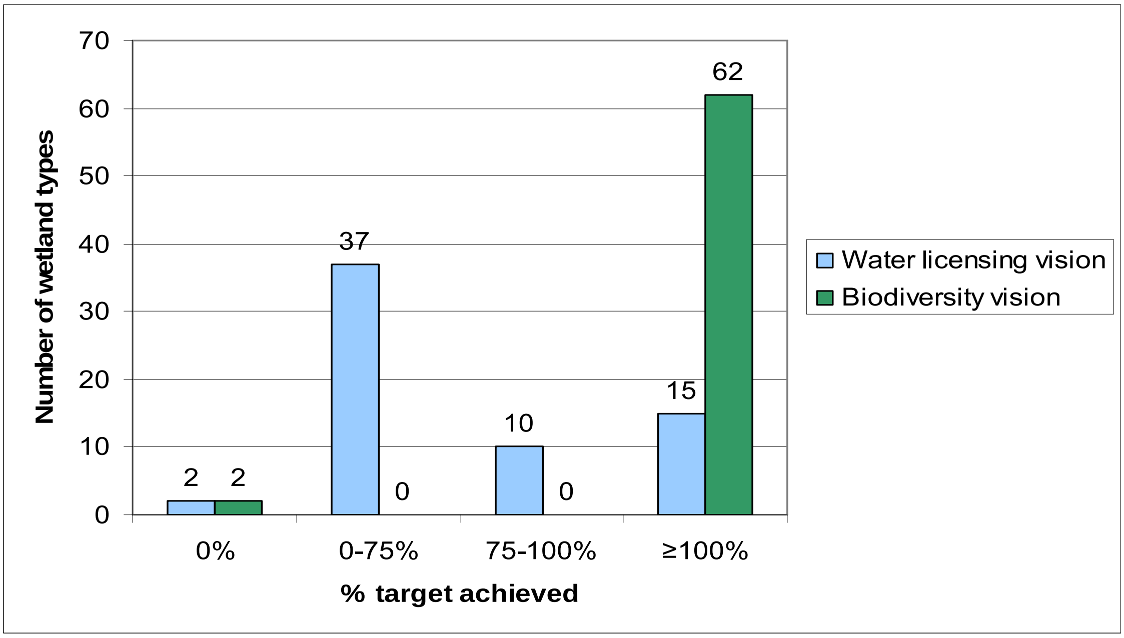

Figure 15. Target achievement for the 64 wetland types in the freshwater biodiversity and water licensing visions.

Limitation: *The wetlands layer was used as a contextual layer for additional special aquatic features and for the purposes of this project, targets were only set for the representation of wetlands. However, all wetlands have an important function to play within the ecosystem and therefore 100% target should be used to preserve wetland function.*

4.2.3 The need for rehabilitation

It is clear from the figures above that in both visions there are rivers and wetlands whose targets cannot currently be achieved. This is due to the fact that those rivers and wetland types have been severely impacted by human land use activities and do not have enough length or area in an intact state to meet their targets. In these cases the rivers and wetlands would have to be rehabilitated in order to ensure that the minimum target can be met. This is particularly the case for rivers in this study. There are 95 river types in the Olifants, Inkomati and Usutu-Mhlathuze Water Management Areas that cannot fully achieve their conservation target length in remaining intact (A or B) rivers. 41 of these river types can achieve their target using rivers in a C class, a further 2 of these river types can meet at least 75% of their target using C class rivers. This leaves 52 river types which can't achieve their targets in an A, B or C state river. This would be concern for river types endemic to the region (those that have more than 80% of their national range within the Olifants, Inkomati and Usutu-Mhlathuze Water Management Area) as their conservation relies on management in these water management areas. It is however not possible to assess the endemicity of Level 3 river types as they have not been mapped outside of the region. However, based on an assessment of Level 2 river types there is a high level of endemicity in the study area (see Section 3.2.2) and thus, rehabilitation should be given serious consideration.

Similar concerns exist for the 8 wetland types for which conservation targets either cannot be met or are significantly reduced due to a lack of remaining natural area in the study region. *Figure 16* displays the sub-catchments containing these river and wetland types. As the water licensing process progresses in this region, it would be necessary to investigate the feasibility of rehabilitating some of these sub catchments in order to conserve the river types and wetland types that are not meeting targets. This would be especially important for types endemic to the study area which cannot be conserved elsewhere in the country. *Figure 16* provides useful guidance highlighting potential areas from which sub catchments can be selected for rehabilitation.

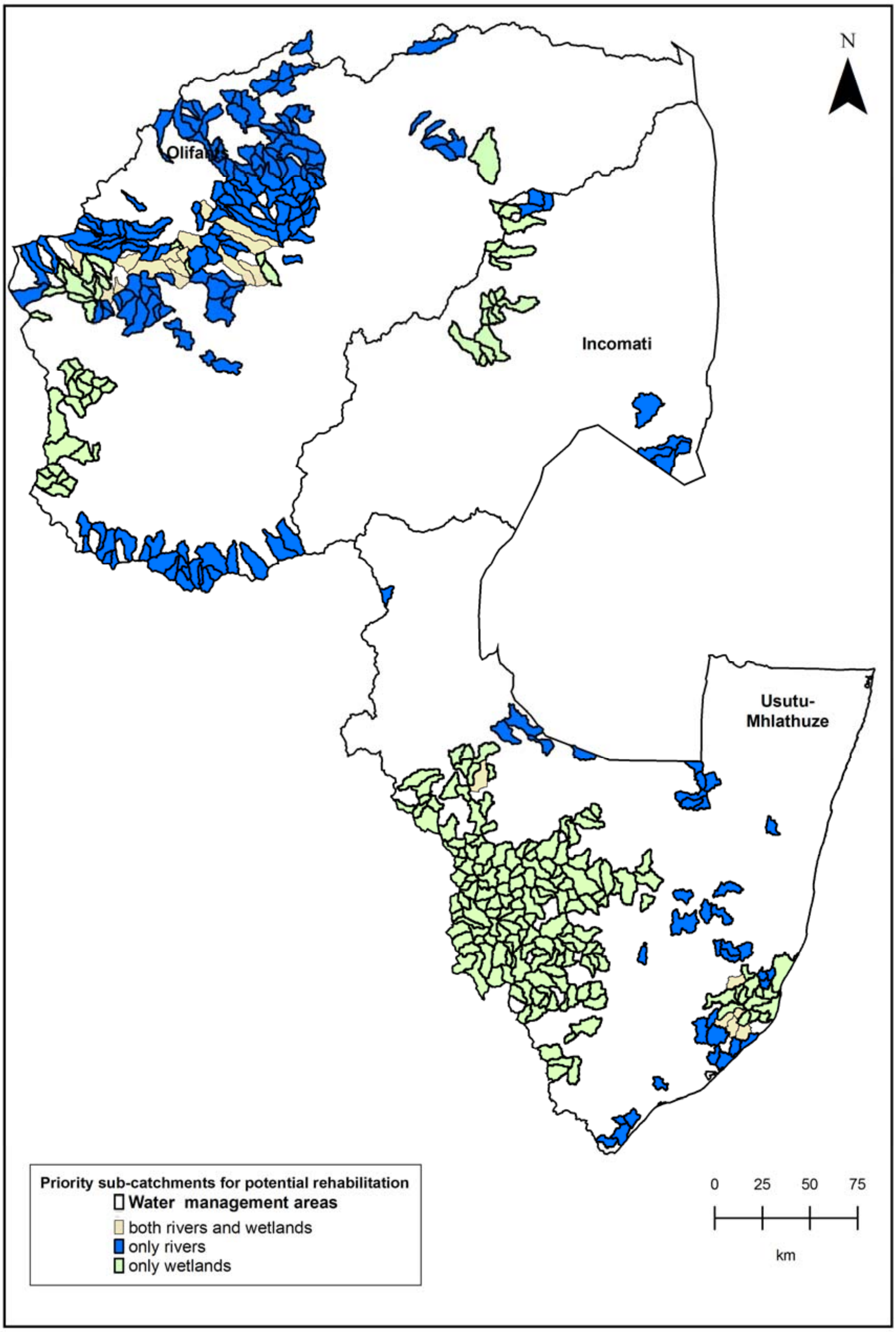

Figure 16. Sub-catchments containing wetlands and river types that should be investigated for rehabilitation.

5. CONCLUSIONS

Decisions made about how natural resources are used are complex and require evaluation of the inherent trade offs. This is particularly the case for water use, not only are many sectors dependent on water, but the human and ecological reserve must be kept in mind when balancing the competing demands. It is thus essential in any decision making process, like the water licensing program, that all trade offs are made explicit and that information on these trade offs and their long term implications for the environment and society is available. This in turn requires information on the needs of all sectors, the environment and the human population. This study demonstrates how this information can be made available for freshwater biodiversity, highlighting areas critical to the conservation of freshwater biodiversity and particularly those areas where no options remain for the conservation of a particular river or wetland type. This information allows decisions made about water use to take freshwater biodiversity needs into account and thus brings the ecological need into the decision making process where it can be compared with societal needs in an effort to find equitable solutions.

This report has highlighted the limitations of the approach used, some of which are not insignificant and require attention and finer scale data before the conservation visions identified in the report are used to inform on the ground decisions. It is essential to highlight that the outputs of this study be reviewed and refined at a finer scale before any decisions are made. The freshwater biodiversity conservation vision demonstrates the large amount of land and river length required to achieve minimum biodiversity pattern targets (this is before any consideration is given to the river and wetland types which have been degraded to such an extent that they cannot achieve their targets). This need for rehabilitation of some areas and the additional area requirements when one considers ecological processes, highlight the challenges for water managers in the region. The management of these areas is essential if freshwater biodiversity is to persist, but also if the long term supply of ecosystem services dependent on biodiversity is to be guaranteed in the area.

Although the water licensing conservation vision only focuses on river biodiversity and results in the exclusion of much wetland biodiversity, as well as estuarine and pan biodiversity, it also requires large tracts of land and rivers.

This report presents 2 conservation visions; however this is only a static example of the outputs of the selection process. The selection process was driven with only biodiversity considerations in mind. The software used are amenable to more than a single consideration and can be used in an interactive decision making process involving several sectors identifying solutions which satisfy multiple demands. For example if an area if already earmarked for a development with a particular water need this can be used in the decision support software. The consequences of this decision for other sectors, the environment and the human reserve can be investigated as well as alternatives.

In conclusion this report recommends that the conservation visions presented herein be used as an example of how biodiversity can be included into the water licensing process in a spatially explicit manner, rather than as static and inflexible visions. Future work could include the use of the decision support software used here or other alternatives to drive a dynamic and iterative process which attempts to meet the multiple demands of the various sectors concerned with water use.

6. REFERENCES

Amis, M.A., Rouget, M. Balmford, A., Thuiller, W., Kleynhans, C.J., Day, J. and Nel, J.L. In press. Predicting freshwater habitat integrity using land use surrogates. *Water S.A*.

Ball, I. and Possingham, H. 2000. *Marxan (v1.8.2): Marine Reserve Design using Spatially Explicit Annealing*. Manual prepared for The Great Barrier Reef Marine Park Authority, Australia.

Balmford A, Bruner A, Cooper P, Costanza R, Farber S, Green RE, Jenkins M, Jefferiss P, Jessamy V, Madden J, Munro K, Myers N, Naeem S, Paavola J, Rayment M. Rosendo S, Roughgarden J, Trumper K, Turner RK (2002). Economic reasons for conserving wild nature. Science 297 (5583), 950-953.

Bills, R. and Skelton, P.H. 2001. The state of South Africa's freshwater fishes. In: Verdoon, G. and Le Roux, J. (eds). Proceedings of the State of South Africa's Species. Endangered Wildlife Trust, Johannesburg, South Africa., pp 140-157.

Braune, E. (1985) Aridity and hydrological characteristics: chairman's summary. In: Developments in hydrobiology, 28. (ed by B.R. Davies and R.D. Walmsley), pp 131-136. Dr W Junk, The Hague.

Brown, C.A., Dollar, E., Harding, W.R., Pemberton, C., Taljaard, S. and van Niekerk, L. 2004. Olifants Doring Catchment Ecological Water Requirements Study: Delineation Report. Southern Waters' Consultancy Report to DWAF: RDM Directorate. Report No. RDM/E00/DR/01/CON/0504. 83 pp.

Colvin, C, Le Maitre, D & Hughes, S 2003. Assessing Terrestrial Groundwater Dependent Ecosystems in South Africa. Report No. 1090-2/2/03, Water Research Commission, Pretoria.

Colvin, C., Le Maitre, D., Saayman, I., Soltau, L., Maherry, A. and Hughes, S. 2006. Aquifer dependent ecosystems in key hydrogeological typesettings in South Africa. CSIR report, Stellenbosch.

Conrad, J. and Münch, Z. 2006. Groundwater assessment of the north-west Sandveld and Saldanha Peninsula as an integral component of the C.A.P.E. fine-scale biodiversity planning project. GEOSS Report Number: G2006/ 09-01, GEOSS, Stellenbosch, South Africa, 36pp.

Daily GC (ed.) (1997). Nature's Services: Societal Dependence on Natural Ecosystems. Island Press: Washington, DC.

Davis, T.J. 1994. The Ramsar Convention Manual: A Guide to the Convention on Wetlands of International Importance especially as Waterfowl Habitat. Ramsar Convention Bureau, Gland, Switzerland. 207pp.

Dini JA and Cowan GI (2000). Classification System for the South African Wetland Inventory. Second Draft, June 2000. South African Wetlands Conservation Programme, Department of Environmental Affairs and Tourism, Pretoria.

Dollar, L.H., Dollar, E.S.J. and Moolman, J. Submitted. Development of an automated desktop procedure for defining macro-reaches for river longitudinal profiles. *Water SA*.

Driver, A., Maze, K., Rouget, M., Lombard, A.T., Nel, J.L., Turpie, J.K., Cowling, R.M., Desmet, P., Goodman, P., Harris, J., Jonas, Z., Reyers, B., Sink, K. and Strauss, T. 2005. National spatial biodiversity assessment 2004: priorities for biodiversity conservation in South Africa. *Strelitzia*, **17**. 45 pp.

Dudgeon, D. Arthington, A.H., Gessner, M.O., Kawabata, Z., Knowler, D.J., Lévêque, C., Naiman, R.J., Prieur-Richard, A., Soto, D., Stiassny, M.L.J and Sullivan, C.A. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biological review, 81:163.182.

Duraiappah, A., Naeem, S., Agardy, T., Cooper, D., Diaz, S., Mace, G., McNeely, J., Pereira, H., Polasky, S., Prip, C., Samper, C., Schei, P.J. & van Jaarsveld, A. 2005. Biodiversity Synthesis Report of the Millennium Ecosystem Assessment. Island Press: Washington DC.

DWAF 2004a. Olifants Water Management Area: Internal Strategic Perspective. Prepared by GMKS in association with Tlou and Matji, Wates, Meiring and Barnard on behalf of the Directorate: National Water Resource Planning. DWAF Report No P WMA 04/000/00/0304.

DWAF 2004b. Inkomati Water Management Area: Internal Strategic Perspective. Prepared by Thlou and Matji Engineering and management Services in association with Charles Sellick and Asscoiates cc on behalf of the Directorate: National Water Resource Planning. DWAF Report No P WMA 05/000/00/0303.

DWAF 2004c. Usutu-Mhlathuze Water Management Area: Internal Strategic Perspective. Prepared by Tlou and Matji (Pty) ltd in association with WRP (Pty) ltd, CPH_2O and Dirk Versveld cc on behalf of the Directorate: National Water Resource Planning. DWAF Report No P WMA 04/000/00/0304.

DWAF 2004d. *South African 1:500 000 river coverage*. Resource Quality Services directorate, Department of Water Affairs and Forestry, Pretoria.

DWAF 2005c. Proposal for the establishment of the Olifants-Doorn Catchment Management Agency. Developed in terms of Section 77 of the National Water Act, 1998 (Act No. 36 of 1998) for submission to the Minister of Water Affairs and Forestry. DWAF, Belville, Cape Town.

DWAF 2006. Class definitions for gazetting: Draft discussion document. Resource Directed Measures directorate, Department of Water Affairs and Forestry, Pretoria, 16pp.

ESRI. 1997. *Arc, Grid and Arcview Command References*. Environmental Systems Research Institute, Redlands, California, USA.

Ewart-Smith, J., Ollis, D., Day, J. and Malan, H. 2006. National wetlands inventory: development of a wetland classification system for South Africa. WRC Report K8/652, Water Research Commission, Pretoria.

Farinha JC, Araújo PR, Silva EP, Carvalho S, Fonseca E and Lavinas C (2005). MedWet Habitat Description System (Version 2005). Instituto da Conservação da Natureza (ICN) / Centro de Zonas Húmidas.

Finlayson CM, Begg GW, Howes J, Davies J, Tagi K and Lowry J (2002). A Manual for an Inventory of Asian Wetlands: Version 1.0. Wetlands International Global Series 10, Kuala Lumpur, Malaysia.

Groves, C.R. 2003. *Drafting a Conservation Blueprint: A Practitioner's Guide to Planning for Biodiversity*. Island Press, Washington, DC.

Hannart, P. and Hughes, D.A. 2003. A desktop model used to provide an initial estimate of the ecological in-stream flow requirements of rivers in South Africa. *Journal of Hydrology*, **270**:167-81.

Hatton, T and Evans, R 1998. Dependence of ecosystems on groundwater and its significance to Australia. Occasional Paper No 12/98, Land and Water Resources Research and Development Corporation, CSIRO Australia.

Holmlund CM, and Hammer M (1999). Ecosystem services generated by fish populations. Ecological Economics, 29: 253-268.

IUCN. 1989. *Caring for the Earth: a Strategy for Sustainable Living*. IUCN, UNEP and WWF. Gland, Switzerland.

Jenkins, M. 2003. Prospects for biodiversity. Science 302:1175-1177.

Jones MGW and Day JA (2003). A Field Classification System for the Wetlands of the Western Cape. Freshwater Research Unit, University of Cape Town.

Kleynhans, C.J. 2000. *Desktop estimates of the ecological importance and sensitivity categories (EISC), default ecological management classes (DEMC), present ecological status categories (PESC), present attainable ecological management classes (present AEMC), and best attainable ecological management class (best AEMC) for quaternary catchments in South Africa*. DWAF report, Institute for Water Quality Studies, Pretoria, South Africa.

Kleynhans, C.J., Thirion, C. and Moolman, J. 2004. *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.

Knight, A.T., Cowling, R.M. and Campbell, B.M. 2006. An Operational Model for Implementing Conservation Action. Conservation Biology, 20(2): 408–419.

Kotzé, D.C., Marneweck, G.C., Batchelor, A.L., Lindley, D.S. and Collins, N.B. 2005. WET-EcoServices. A rapid assessment procedure for describing wetland benefits. Mondi Wetlands Project.

Lerner, D.N., Issar, A.S. and Simmers, I. 1990. Groundwater recharge. A guide to understanding and estimating natural recharge. Heinz Heise, International Contributions to Hydrogeology, 8.

Lotter, M.C., and Ferrar, A.A. 2006. Mpumalanga Biodiversity Conservation Plan CD-ROM: Mpumalanga Parks Board, Nelspruit.

Millennium Assessment. 2003. *Ecosystems and Human Well-being: A Framework for Assessment*. A report of the Conceptual Framework Working group of the Millennium Ecosystem Assessment. Island Press, Washington, USA.

Moyle, P.B. and Leidy, R.A. 1992. Loss of biodiversity in aquatic ecosystems: evidence from fish fauna. In: Fielder, P. L. and Jain, S.K. (eds). Conservation biology: the theory and practice of nature, conservation, preservation and management, pp128-169. New York , NY: Chapman and Hall.

Mucina, L. and Rutherford, M. 2004. Vegetation map of South Africa, Lesotho and Swaziland: shapefiles of basic mapping units. National Botanical Institute, Cape Town, South Africa.

Nel, J.L., Roux, D.J., Maree, G., Kleynhans, C.J., Moolman, J., Reyers, B., Rouget, M. and Cowling, R.M. In press. A systematic conservation assessment of the ecosystem status and protection levels of main rivers in South Africa. *Diversity and Distributions*.

Nel, J.L., Smith-Adao, L., Roux, D.J., Adams, J., Cambray, J.A., de Moor, F.C., Kleynhans, C.J., Kotzé, I., Maree, G., Moolman, J., Schonegevel, L.Y., Smith, R.J., Thirion, C. 2006. Conservation Planning for River and Estuarine Biodiversity in the Fish-to-Tsitsikamma Water

Management Area. Water Research Commission Report K5/1486, Water Research Commission, Pretoria, South Africa.

J.L. Nel, A. Belcher, N.D. Impson, I.M. Kotzé, B. Paxton, L.Y. Schonegevel and L.B. Smith-Adao. 2006. Conservation assessment of freshwater biodiversity in the Olifants/Doorn Water Management Area: Final report. *CSIR Report Number CSIR/NRE/ECO/ER/2006/0182/C*, CSIR, Stellenbosch.

O'Keeffe, J.H. (1989) Conserving rivers in southern Africa. Biological Conservation, 49, 255-274.

Revenga, C., Campbell, I., Abell, R., De Villiers, P. and Bryer,M. 2005. Prospects for monitoring freshwater ecosystems towards the 2010 targets. Philosophical Transactions of the Royal Society, B 360: 397-413.RHP 2006

Ricciardi, A., and J. B. Rasmussen. 1999. Extinction rates of North American freshwater fauna. Conservation Biology 13:1220-1222.

Richter, B.D. and Richter, H.E. 2000. Prescribing flood regimes to sustain riparian ecosystems along meandering rivers. Conservation Biology, 14(5): 1467-1478.

Richter, B.D, Mathews, R., Harrison, D.L and Wigington, R. 2003. Ecologically sustainable water management: managing river flows for ecological integrity. Ecological Applications, 13 (1): 206-224.

Roux, D.J. 1999. Design of a national programme for monitoring and assessing the health of aquatic ecosystems, with specific reference to the South African River Health Programme. In: Gerhardt, A. (Ed.) *Biomonitoring of Polluted Water*. Environmental Research Forum Vol. 9, pp. 13-32, Trans Tech Publications, Switzerland.

Roux, D.J. 2001. Strategies used to guide the design and implementation of a national river monitoring programme in South Africa. *Environmental Monitoring and Assessment*, **69**:131-158.

Roux, D.J., Barber-James, H., Cambray, J.A. and de Moor, F.C. 2002. Use of landscape-level river signatures in conservation planning: a South African case study. *Conservation Ecology*, **6**(2): 6. [online] URL. http://www.consecol.org/vol6/iss2/art6.

Roux, D.J. 2004. From monitoring design to operational program: facilitating the transition under resource-limited conditions. In: G.B. Wiersma (Ed). *Environmental Monitoring*, CRC Press LLC.

Roux, D.J., Nel, J.L. and MacKay, H.M. and Ashton, P.J. 2006. Discussion Paper on Cross-Sector Policy Objectives for Conservation of South Africa's Inland Water Biodiversity. Water Research Commission Project K8/642, Water Research Commission, Pretoria, South Africa.

Rowntree K.M. and Wadeson R.A. 1999. *A Hierarchical Geomorphological Model for the Classification of Selected South African Rivers*. Water Research Commission Report No 497/1/99, Water Research Commission, Pretoria.

Sala, O. E., Chapin, F. S., Armesto, J. J., Berlow, R., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L. F., Jackson, R. B., Kinzig, A., Leemans, R., Lodge, D., Mooney, H. A., Oesterheld, M., Poff, N. L., Sykes, M. T., Walker, B. H., Walker, M. and Wall, D. H. 2000. Global biodiversity scenarios for the year 2100. Science, 287: 1770-1774.

Scholes, R.J. and Biggs, R. (eds). 2004. Ecosystem services in southern Africa: a regional assessment. Council for Scientific and Industrial Research, Pretoria, South Africa.

Shaw, K. A. and de Villiers, R. 2001. Sensitive Wetlands GIS coverage. 1:50 000 scale. CapeNature, Jonkershoek, Western Cape.

Skelton PH, Cambray JA, Lombard A and Benn GA (1995). Patterns of distribution and conservation status of freshwater fishes in southern Africa. South African Journal of Zoology, 30(3): 71-81.

Smith, R.J. 2005. *CLUZ Handbook Version 1.2.* Available online at http://www.kent.ac.uk/anthropology/dice/cluz/.

Thompson M, Marneweck G, Bell S, Kotze D, Muller J, Cox D and Clark R (2002). A Methodology Proposed for a South African National Wetland Inventory. Report prepared for South African Wetlands Conservation Programme, Department of Environmental Affairs and Tourism, Pretoria.

Turpie, J.K. 2004. Improving the Biodiversity Importance Rating of Estuaries. Water Research Commission Report, Water Research Commission, Pretoria, South Africa.

Van Niewenhuizen, G.D.P. & Day, J.A. (1999) Cape Action Plan for the Environment: The conservation of freshwater ecosystems in the Cape Floral Kingdom. Freshwater Research Unit Report, University of Cape Town, Cape Town.

Vegter, JR 1995. An Explanation of a Set of National Groundwater Maps. Report No. TT 74/95, Water Research Commission, Pretoria.

Worsley, K.J. 1979. On the likelihood ratio test for a shift in location of normal populations. *Journal of the American Statistical Association*, **74**(366): 365-367.

WWF 2004. *Living Planet Report*. Gland, Switzerland: World Wide Fund for Nature.

WWF. 2006. Free-flowing Rivers: Economic Luxury or Ecological Necessity? WWF Global Freshwater Programme, Zeist, Netherlands.