National Biodiversity Assessment 2018

TECHNICAL REPORT

Volume 2b:

Inland Aquatic (Freshwater) Realm

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This report uses the names of the government departments confirmed in June 2019. Please refer to www.gov.za to see all the changes in government departments and ministries.

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SYNTHESIS REPORT

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Volume 3: Estuarine

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A number of experts actively participated, guided, and reviewed work related to the inland aquatic realm of the National Biodiversity Assessment for 2018 (NBA 2018) through workshops organised for the reference committee and co-author related to the Inland Aquatic Component (Appendix A). A wider range of expertise further contributed to the process at provincial level, from the private sector, as well as universities, facilitated through the Wetland and River Ecosystem Classification Committee (WECC, RECC) meetings. Members of the inland aquatic team frequently presented progress on the National Biodiversity Assessment for 2018 (NBA 2018) at the Biodiversity Planning Forum (BPF), Freshwater Ecosystems Network (FEN) meetings, the Inland Interdepartmental Inland Water Ecosystem Liaison Committee which is facilitated by the Department of Water and Sanitation (DWS), and the National Wetlands Indabas between 2015 and 2018. These platforms of interaction have allowed many freshwater practitioners, scientists and managers to contribute their insights, time and data to the South African Inventory of Inland Aquatic Ecosystems (SAIIAE) and Assessment reports, to which we are tremendously grateful.

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Interaction with the NBA project leaders and component leads further developed stimulus, impetus and coherence within the Inland Aquatic Component and between all the components. The Core Reference Group members are duly acknowledged:

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Amphibian Specialist Group (ASG)
Agricultural Research Council (ARC)
Bayworld Museum
Birdlife South Africa
Botanical Society
CapeNature
Council for Scientific and Industrial Research (CSIR)
Department of Agriculture, Forestry and Fisheries (DAFF)
Department of Economic, Small business development, Tourism and Environmental Affairs (DESTEA) of the Free State Province
Department of Environmental Affairs (DEA), including the Working for Wetlands Programme
Department of Science and Technology (DST)
Department of Water and Sanitation (DWS)
De Beers
Dragonfly Specialist Group (DSG)
ESKOM
Endangered Wildlife Trust (EWT)
Ezemvelo KwaZulu-Natal Wildlife (EKZNW)
Freshwater Consulting Group (FCG)
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Overview of the report structure:

Chapter / Appendix	Topics addressed
Chapter 1	This Chapter discusses what the National Biodiversity Assessment is, and how this link to South Africa's international obligations for reporting. An overview of the inland aquatic ecosystems is also provided, detailling the ecosystem types for rivers and inland wetlands.
Chapter 2	This Chapter provides an overview of the **benefits** of the inland aquatic ecosystems.
Chapter 3	Chapter 3 gives an overview of the **impacts of climate change** on rivers and inland wetlands, according to the Essential Biodiversity Variables (EBVs).
Chapter 4	This chapter lists the **key pressures** on inland aquatic ecosystems and reviews the known impacts as well as available data to represent the extent and severity of the pressures or their impacts.
Chapter 5	Chapter 5 presents an overview of the **methods** and data used for the assessment of inland aquatic ecosystems.
Chapter 6	Chapter 6 provides the **results** of the ecosystem threat status (ETS) and ecosystem protection level (EPL) **(ecosystem) assessments** of the river and inland wetland ecosystem types.
Chapter 7	Chapter 7 provides the results of the **indigenous freshwater species assessment.**
Chapter 8	This chapter discusses the **genetic assessment** of freshwater species.
Chapter 9	Chapter 9 discuss the **responses** to pressures on rivers and inland wetlands.
Chapter 10	Chapter 10 summarises the results of the report and **provides priority gaps, actions and research** to be taken forward.
Appendix A	Lists the **meetings** held during the course of the project and key decisions made.
Appendix B	Lists the **number of freshwater species in South Africa**.
Appendix C	Provides information on the **pressures on peat wetlands in South Africa**.
Appendix D	Discusses **pressures on the Maputaland Coastal Plain** in more detail.
Appendix E	Lists the **invasive species assocaited with inland aquatic ecosystems in South Africa**.
Appendix F	Provides an overview of the IUCN Red List Catergories and Criteria.

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LIST OF ACRONYMS, ABBREVIATIONS, INITIALISMS AND SYMBOLS

ADE	Aquifer Dependent Ecosystem
AIP	Alien Invasive Plant
ARC	Agricultural Research Council
ARC-ISCW	Agricultural Research Council: Institute for Soil, Climate and Water
BMP	Biodiversity Management Plans
BSP	Biodiversity Sector Plan
C.A.P.E.	Cape Action for the Protection of the Environment
CBA	Critical Biodiversity Area
CER	Centre for Environmental Rights
CFAR	Cape Fold Aquatic Ecoregion
CFR	Cape Floristic Region
CMA	Catchment Management Agency
COP	Conference of the Parties
CR	Critically Endangered
CSIR	Council for Scientific and Industrial Research
DAFF	Department of Agriculture, Forestry and Fisheries (former government department)
DALRRD	Department of Agriculture, Land Reform and Rural Development (formed by merging DAFF and Department of Rural Development and Land Reform in June 2019)
DD	Data Deficient
DDT	Dichloro Diphenyl Trichloroethane
DEA	Department of Environmental Affairs (former government department)
DEFF	Department of Environment, Forestry and Fisheries (formed by merging DAFF and DEA in June 2019)
DEAT	(Former National) Department of Environmental Affairs and Tourism
DEFF	Department of Environment, Forestry and Fisheries (formed by merging DAFF and DEA in June 2019)
DEM	Digital Elevation Model
DLA:CDSM	Department of Land Affairs: Chief Directorate Surveys and Mapping
DMR	Department of Minerals and Resources
DRDLR:NGI	Department of Rural Development and Land Reform: Directorate National Geo-spatial Information
DSI	Department of Science and Innovation (new departmental name in June 2019)
DST	Department of Science and Technology (former government department)
DWAF	(Former National) Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EbA	Ecosystem-based climate Adaption Area
EBVs	Essential Biodiversity Variables
ECC	Ecosystem Classification Committee
EC DEDEA	Eastern Cape Department of Economic Development and Environmental Affairs
EDC	Endocrine Disrupting Compounds
EFTEON	Expanded Freshwater and Terrestrial Environmental Observation Network
EFZ	Estuarine Functional Zone
EIA	Environmental Impact Assessment
EICAT	Environmental Impact Classification for Alien Taxa
EKZNW	Ezemvelo KwaZulu-Natal Wildlife
EMF	Environmental Management Framework
EMP	Environmental Management Plan
EN	Endangered
EPL	Ecosystem Protection Level
ESA	Ecological Support Area
ESRI	Environmental Systems Research Institute
ETS	Ecosystem Threat Status
EWR	Ecological Water Requirements
EWT	Endangered Wildlife Trust
FBIS	Freshwater Biodiversity Information System
FCG	Freshwater Consulting Group

FEN	Freshwater Ecosystem Network
FS DESTEA	Free State Department of Economic, Small Business Development, Tourism and Environmental Affairs
GBIF	Global Biodiversity Information Facility
GDARD	Gauteng Department of Agricultural & Rural Development
GDE	Groundwater Dependent Ecosystems
GDM	Generalised Dissimilarity Modelling
GEF	Global Environment Facility
GIS	Geographical Information System
GISc	Geo-Information Science
GPS	Global Positioning System
GTI	GeoTerra Image Pty Ltd
HGM	Hydrogeomorphic (wetland type)
IAP	Invasive Alien Plant
ICLEI	International Council for Local Environmental Initiatives (ICLEI) – Local Governments for Sustainability
IFA	Important Fish Area
IUCMA	Inkomati Usuthu Catchment Management Agency
IUCN	International Union for Conservation of Nature
KBA	Key Biodiversity Area
LDEDET	Limpopo Department of Economic Development, Environment & Tourism
LC	Least Concern
m amsl	metres above mean sea level
MP	Moderately Protected
MTPA	Mpumalanga Tourism & Parks Agency
NBA	National Biodiversity Assessment
NBF	National Biodiversity Framework
NC DENC	Northern Cape Department of Environment and Nature Conservation
NCA	Natural Capital Accounting
NECC	National Ecosystem Classification Committee
NEMBA	National Environmental Management: Biodiversity Act
NEMP	National Eutrophication Monitoring Programme
NFEPA	National Freshwater Ecosystems Priority Area
NGO	Non-governmental Organisation
NIAPS	National Invasive Alien Plants Survey
NLC	National Land Cover
NMMP	National Microbial Monitoring Programme
NP	Not protected
NRF	National Research Foundation
NSR	National Species Regulations
NT	Near Threatened
NW DEDECT	North West Department of Economic Development, Environment, Conservation and Tourism
NWA	National Water Act
NWCS	National Wetland Classification System
NWI	National Wetland Indaba
NWM	National Wetland Map
NWMP	National Wetland Monitoring Programme
NWRS	Natural Water Resource Strategy
NWVD	National Wetland Vegetation Database
PACA	Protected Areas and Conservation Areas
PAES	Protected Areas Expansion Strategy
PES / EI / ES	Present Ecological State / Ecological Importance / Ecological Sensitivity
PP	Poorly Protected
QDGC	Quarter Degree Grid Cells
RECC	River Ecosystem Classification Committee
REMP	River Eco-status Monitoring Programme
RoD	Records of Decision

RLI	Red List Index
RQOs	Resource Quality Objectives
SABIF	South African Biodiversity Information Facility
SAEON	South African Environmental Observation Network
SAHRC	South African Human Rights Commission
SAIAB	South African Institute for Aquatic Biodiversity
SAIIAE	South African Inventory of Inland Aquatic Ecosystems
SANBI	South African National Biodiversity Institute
SANParks	South African National Parks
SAPAD	South African Protected Areas Database
SASDI	South African Spatial Data Infrastructure
SDF	Spatial Development Framework
SEA	Strategic Environmental Assessment
SEICAT	Socio-Economic Impact Classification of Alien Taxa
SGD	Shale Gas Development
SKA	Square Kilometre Array
SPL	Species Protection Level
SPOT	*Satellite Pour l'Observation de la Terre*
SQ4	Sub-quaternary catchment
SRTM	Shuttle Radar Topography Mission
STS	Species Threat Status
SWSA	Strategic Water Source Areas
ToCC	Taxa of Conservation Concern
UNEP	United Nations Environment Programme
UFS	University of the Free State
UKZN	University of KwaZulu-Natal
UNIVEN	University of Venda
USAID	United States Agency for International Development
UWC	University of the Western Cape
VU	Vulnerable
WCS	Wetland Consulting Services Pty Ltd
WECC	Wetland Ecosystem Classification Committee
WGS84	World Geodetic System of 1984 (spheroid and datum)
WMA	Water Management Area
WP	Well Protected
WRC	Water Research Commission
WRCS	Water Resource Classification System
WTW	Water Treatment Works
WUL	Water Use License
WWTW	Wastewater Treatment Works
YBP	years before present

LIST OF ACRONYMS USED FOR PROVINCES

EC	Eastern Cape
FS	Free State
GT	Gauteng
KZN	KwaZulu-Natal
LP	Limpopo
MP	Mpumalanga
NC	Northern Cape
NW	North West
WC	Western Cape

GLOSSARY OF TERMS

Allelic diversity (N_A): The presence and number of different alleles at a gene locus.

Alien species: 'a species that is present in a region outside its natural range as a result of human action that has enabled it to overcome biogeographic barriers … .' (Van Wilgen & Wilson 2018:xiii).

Alien invasive species: Invasive species are alien species that sustain self-replacing populations over several life cycles, produce reproductive offspring, often in very large numbers at considerable distances from the parent and/or site of introduction, and have the potential to spread over long distances (Richardson *et al*. 2011; Wilson *et al*. 2017).

Artificial water bodies / artificial wetlands: include terrestrial and aquatic ecosystems which have been modified by humans to varying degrees either within or in the vicinity of aquatic ecosystems. Such datasets may include point or polygon data on the extent and distribution of for example artificial wetlands, aquaculture facilities, bridges, canals, excavations, railways, reservoirs, roads, salt works, sand mining, treatment works and weirs.

Aquifer Dependent Ecosystems: 'ecosystems which depend on groundwater in, or discharging from, an aquifer' (Colvin *et al*. 2007:3).

Aquatic ecosystems: 'an ecosystem that is permanently or periodically inundated by flowing or standing water, or which has soils that are permanently or periodically saturated within 0.5 m of the soil surface' (Ollis *et al*. 2013:94).

Biodiversity: 'The diversity of genes, species and ecosystems on Earth, and the ecological and evolutionary processes that maintains this diversity' (SANBI 2016:5).

Biodiversity target: can be set for both ecosystems and species. 'For ecosystems: The minimum proportion of each ecosystem type that needs to be kept in a good ecological condition in the long term in order to maintain viable representative samples of all ecosystem types and the majority of species associated with them. Expressed as a percentage of the historical extent of an ecosystem type (measured as area, length or volume). For species: The minimum number of occurrences or populations that need to be kept extant (ideally with some form of protection) in order to ensure the persistence of the species, or the minimum amount of suitable habitat that needs to be kept in good ecological condition in order to ensure the persistence of a minimum viable population of the species' (SANBI 2016:45).

Biomonitoring: The act of observing and assessing the state and ongoing changes in ecosystems, components of biodiversity and landscape, including the types of natural habitats, populations and species.

Climate change: refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.' The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes (IPCC 2014).

Commission error: for the purpose of this report, terrestrial areas mapped as wetlands.

Coordinate system used for data: is the South African Albers Equal Area conical projection with the central meridian at 25°E, parallels at 24°S and 33°S and the spheroid and datum the World Geodetic System of 1984 (WGS84).

Deoxyribonucleic acid (DNA): hereditary material in almost all living organisms.

EcoClassification: (or the Ecological Classification process) refers to the determination and categorisation of the Present Ecological State (PES; health or integrity) of various physical attributes of rivers relative to the natural

reference condition. A range of models are used during EcoClassification, each of which relate to the indicators assessed (DWS 2018).

Ecoregional classification: or typing is a hierarchical procedure that involves the delineation of ecoregions with a progressive increase in detail at each higher level of the hierarchy. Ecological regions are, then, regions within which there is relative similarity in the mosaic of ecosystems and ecosystem components (biotic and abiotic, aquatic and terrestrial) (Kleynhans *et al*. 2005).

Ecological condition: 'An assessment of the extent to which the composition, structure and function of an area or biodiversity feature has been modified from a reference condition of natural' (SANBI 2016:19).

Ecological resilience: 'the capacity of a system to absorb disturbance and reorganize while ndergoing change so as to still retain essentially the same function, structure, identity, and feedbacks' (Walker *et al*. 2004:2).

Ecosystem services: 'the aspects of ecosystems utilized (actively or passively) to produce human well-being. The key points are that (1) services must be ecological phenomena and (2) that they do not have to be directly utilized. Defined this way, ecosystem services include ecosystem organization or structure as well as process and/or functions if they are consumed or utilized by humanity either directly or indirectly' (Fisher *et al*. 2009:645).

Flagship and free-flowing rivers: 'A free-flowing river is a long stretch of river that has not been dammed, flowing undisturbed from its source to the confluence with another large river or to the sea' (SANBI 2016:43).

Floodout: 'Lobate/fan-shaped sediment body that radiates downstream from an intersection point of a discontinuous channel. Typically comprise sandy materials immediately downstream of the intersection point, but may terminate in swamps or marshes as fine-grained sediment accumulates downstream.' (Brierley & Fryirs 2005:113).

Genetic diversity: The number of different alleles or haplotypes for a population or species. High genetic diversity means the sample of individuals from a population or species have many different versions (alleles or haplotypes) of the gene that was quantified.

Global change: the effects of significant influence by human activities on the biological, living processes that make up the Earth's environment, modifying environmental processes on a planet-wide scale to affect human well-being. (Robinson 2018, derived from MEA 2005).

Groundwater: 'subsurface water in the saturated zone below the water table' (DWAF 2008:9).

Habitat loss: 'Conversion of natural habitat in an ecosystem to a land use or land cover class that results in irreversible changes in the composition, structure and functional characteristics of the ecosystem concerned' (SANBI 2016:27).

Heterozygosity: The condition when an individual has two different alleles for one gene.

Inland Aquatic Ecosystems: 'an ecosystem that is permanently or periodically inundated by flowing or standing water, or which has soils that are permanently or periodically saturated within 0.5 m of the soil surface' (Ollis et al. 2013) and which occurs Inland and is not estuarine or marine in nature.

Interflow: 'refers to the (rapid) lateral movement of subsurface water from rainfall through the soil layers above the water table to a stream or other point where it reaches the surface (McGraw-Hill, 1978); generally synonymous with subsurface stormflow … interflow is considered as temporarily saturated lateral flow in the unsaturated (vadose) zone.' (Colvin *et al*. 2007:63).

Invasive species: 'Alien species that sustain self-replacing populations over several life cycles, produce reproductive offspring, often in very large numbers at considerable distances from the parent and/or site of introduction, and have the potential to spread over long distances … .' (Van Wilgen and Wilson, 2018:xiv).

Lacustrine: (non-vegetated wetlands) 'Relating to a system of inland deep-water and wetland habitats associated with lakes and reservoirs and characterized by the absence of trees, shrubs, or emergent vegetation.' (Collins 2014).

Lakes: 'are depressions in the valley bottoms which may be temporarily, seasonally or permanently inundated. Unlike pans, they are not deflationary erosional features, but instead they have, or would have had, an outlet at the downstream end of the valley (a low point); which has been variously blocked or otherwise restricted by dune deposits; terminal moraines (e.g. Lake District; U.K.), landslides or other depositional features across the valley bottom. Their shape is therefore determined by the surrounding slopes/higher ground (in contrast to the deflational processes creating the typical circular or oval depressional pan shapes)' (DWAF 2008:20).

Limnetic: '(*cf*. littoral) inundated to a maximum depth of 2 m or more at the average annual low-water level of an open waterbody' (Ollis *et al*. 2013).

Littoral: '(*cf*. limnetic) inundated to a maximum depth of less than 2 m at the average annual low-water level of an open waterbody' (Ollis *et al*. 2013).

National Freshwater Ecosystems Priority Area (NFEPA): 'A biodiversity planning project that identified a set of freshwater ecosystem priorities for meeting biodiversity targets for rivers, wetlands and freshwater fish species of special concern.' (SANBI 2016).

Omission error: for the purpose of this report, wetland areas not mapped in a NWM.

Palustrine: (vegetated wetlands) 'Relating to a system of inland freshwater wetlands, such as marshes, swamps, and lake shores, characterized by the presence of trees, shrubs, and emergent vegetation.' (Collins 2014).

Present Ecological State (PES): The current state or condition of a water resource in terms of its biophysical components (drivers) such as hydrology, geomorphology and water quality and biological responses viz. fish, invertebrates, riparian vegetation). It indicates the degree to which ecological conditions of an area have been modified from natural (reference) conditions.

Resource Quality Objectives (RQOs): are numeric or descriptive goals that can be monitored for compliance to the Water Resource Class, for each part of each water resource (DWS 2018).

Riparian habitat: 'includes the physical structure and associated vegetation of the areas associated with a watercourse which are commonly characterised by alluvial soils, and which are inundated or flooded to an extent and with a frequency sufficient to support vegetation of species with a composition and physical structure distinct from those of adjacent land areas' (RSA 1998:9).

Rivers: a linear inland aquatic ecosystem with clearly discernible bed and banks, which permanently or periodically carries a concentrated flow of water. A river is taken to include both the active channel and the riparian zone as a unit (Adapted from Ollis *et al*. 2013:100).

Soil water – or soil moisture: '…water held in the pores (gaps between the particles) in the soil and in the soil itself, in both liquid and vapour phases (McGraw-Hill 1978). Includes saturated and unsaturated states. Measured as a percentage of the soil dry weight (% by weight) but sometimes as the volume of water as a percentage of the soil volume (% by volume) or as the depth of water per metre depth of soil (m/m)' (Colvin *et al*. 2007:69).

Strategic Water Source Areas: 'Strategic Water Source Areas (SWSAs) are defined as areas of land that either: (a) supply a disproportionate quantity of mean annual surface water runoff in relation to their size and are considered nationally important; or (b) have high groundwater recharge and where the groundwater forms a nationally important resource; or (c) areas that meet both criteria (a) and (b)' (Le Maitre *et al*. 2018:1).

Sub-quaternary catchments (SQ4s): A fifth level of catchment division which has been derived in South Africa from a 50 m spatial resolution Digital Elevation Model (DEM) for the National Freshwater Ecosystems Priority Areas (NFEPA) project (Nel *et al*. 2011). The Department of Water and Sanitation (DWS) uses this dataset for their Present Ecological State (PES) assessments issued in 2011. See also Quinary.

Typing of Inland Aquatic Ecosystems: refer to the categorisation of ecosystems according to the *Classification System for Wetlands and other Aquatic Ecosystems in South Africa* in South Africa (Ollis *et al.* 2013).

Quinary: A fifth level of catchment division which has been derived in South Africa from the 90 m spatial resolution DEM which was hydrologically corrected from the original Shuttle Radar Topography Mission (SRTM) DEM. A similar procedure to the SQ4s were used, however the boundaries of the updated quaternary catchments from WRC Report No. 1908/1/11 (Weepener *et al*. 2012) were used to constrain the calculation (Maherry *et al*. 2013). WRC Report No. 2020/1/12). See also Sub-quaternary catchments (SQ4s).

Washes: a term used in the arid and semi-arid regions which refers to the broad, gravelly, normally dry bed of an intermittent stream (Derived from Bates & Jackson 1987:730, Glossary of Geology). A wash is a type of floodout.

Water Resource Classification System is a defined set of guidelines and procedures for determining the different classes of water resources (South African National Water Act (Act 36 of 1998) Chapter 3, Part 1, Section 2(a)). The outcome of the Classification Process will be the setting of the class, Reserve and Resource Quality Objectives by the Minister or delegated authority for every significant water resource (river, estuary, wetland and aquifer) under consideration. This class, which will range from Minimally used to Heavily used, essentially describes the desired condition of the resource, and concomitantly, the degree to which it can be utilised (DWS 2018).

Watercourses: 'Watercourses' includes both the channel and banks of all rivers, springs, natural channels 'in which water flows regularly or intermittently' (RSA 1998:9).

Wetlands: 'means land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil' (RSA 1998:9).

Wetland delineation: 'the determination and marking of the boundary of a wetland. … marking the outer edge of the temporary zone of wetness' (Adapted from DWAF 2008:11). In this document the term is used to refer to both in field and desktop delineation.

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EXECUTIVE SUMMARY

Introduction

The National Biodiversity Assessments provide a high-level summary of the state of South Africa's biodiversity. It uses the Ecosystem Threat Status (ETS) and Ecosystem Protection Level (EPL) as headline indicators for ecosystems, and the Species Threat Status (STS) and Species Protection Levels (SPL) for species. These are aligned with the principles, methods and categories used by the International Union for Conservation of Nature (IUCN). The ETS and STS inform us on the threat status of ecosystem types and species whereas the EPL and SPL indicate how protected the ecosystem types and species are. Both indicators are dependent on spatial datasets of ecosystem types and condition, as well as species records of occurrence and breeding sites. Similarly, all indigenous species in South Africa are assessed using the IUCN Redlist of species conservation status, assessment of trends in species conservation status and how well species are protected in South Africa, making use of the Protection level assessment. These assessments were disaggregated from all species groups, to include only species dependent on, or strongly associated with, inland aquatic systems. Information on the spatial extent and severity of pressures, and the impacts of these on ecosystems and species are crucial for informing the condition realms.

The assessment report of inland aquatic ecosystems, which forms part of the National Biodiversity Assessment 2018 (NBA 2018), follows on from two previous assessments. These were undertaken for mainstem rivers and previously assessed in the National Spatial Biodiversity Assessment 2004 (NSBA 2004) and for mainstem and tributary rivers, and inland wetlands, previously assessed in the National Biodiversity Assessment 2011 (NBA 2011). The current report builds on the previous datasets, reports and findings, as well as that of the National Freshwater Ecosystems Priority Areas (NFEPAs) project of 2011.

Benefits

Inland aquatic ecosystems in a good ecological condition offer a range of benefits to both humans as well as other environments. Ecosystems in a good ecological condition can sustain life and offer provisioning, regulating and cultural services. Many of the services are supporting and / or synergistic. Ecosystem services are essential, particularly in the face of climate change. We focused primarily on the ecosystem services of wetlands in this report, and hence further work is required to address those of river ecosystems too.

Main pressures and impacts on ecosystems and species

The degree and magnitude of pressures on inland aquatic ecosystems are poorly understood and not well monitored. Five key pressures have been considered in this NBA 2018, namely (i) modifications to the natural variation of the hydrological regime, (ii) to modifications in water quality, (iii) loss of natural habitat, habitat degradation and fragmentation (iv) the spread of invasive species and (v) the over-exploitation of species. Changes in climate, particularly rise in temperature and changes to the amount and intensity of precipitation, as well as seasonal timing and peak therefore, are expected to exacerbate the impacts of current pressures on inland aquatic ecosystems. Ecosystem resilience should be built through stabilisation or reduction of pressures and rehabilitation to minimise the impacts of climate change and secure our natural capital / ecological infrastructure and ecosystem services. Socio-economic factors impact human are interaction with the environment and should be considered in planning and intervention.

Thresholds used for headline indicators Ecosystem Threat Status (ETS) and Ecosystem Protection Level (EPL)

Owing to insufficient available data for determining ecologically differentiated targets, a wide range of stakeholders from related sectors agreed to a biodiversity target of 20% for inland aquatic ecosystems at a workshop held in 2006 (Roux *et al*. 2006; Nel *et al*. 2011). Ecosystems with < 20% of their spatial extent in a natural or near-natural ecological condition (where the Present Ecological State or PES = A and B for rivers or A/B for inland wetlands), was considered Critically Endangered. Thresholds of 35% and 60% were used for Endangered (EN) and Vulnerable (VU) categories, respectively, whereas ecosystems with > 60% in a natural or near-natural ecological condition, was considered of Least Concern (LC). These thresholds were applied to the river ecosystem types as well as inland wetland ecosystem types. The threshold of freshwater lakes, or limnetic wetlands, of which only eight exist in South Africa to our knowledge, were set at 100% of the biodiversity target, as agreed to in a reference committee meeting for the inland aquatic ecosystems (Appendix A). The degree of land conversion, as well as the restricted range criterion B of Bland *et al.* (2017), was used to assess the threat status of the eight freshwater lakes.

Key findings

Representation of river and wetland ecosystem types:

- 90% of the length of river ecosystem types have been assessed for present ecological state using expert ratings;
- 10% of the extent of river ecosystem types are poorly understood (ephemeric or episodic systems in arid regions);
- The update of the National Wetland Map version 5 (NWM5) showed that 2.2% of the country has been mapped as inland wetlands, totalling 2,6 million ha;
- NWM5 has significantly improved the representation of inland wetland ecosystem types. The representation of the extent of inland wetlands has improved by 123%, whereas the incorrect representation of terrestrial ecosystems as wetlands has been reduced;
- In spite of these improvements, nearly 70% of the extent of South Africa is still at a low confidence level (Van Deventer *et al.* 2018); &
- Unique ecosystem types with restricted ranges have also been identified for the inland aquatic ecosystems. Eight freshwater lakes (limnetic wetlands) are in the process of being verified while further research is underway for swamp forests.

Ecological condition of ecosystems:

- The majority of rivers (67% of total river length) are degraded. However, tributaries are generally less heavily impacted than mainstem rivers with 38% of tributary length in a natural condition compared to 28% of mainstem rivers
- Rivers are also declining in ecological condition. Nel & Driver (2015) reported an 11% decline in river condition from 1999–2011. This worsening trend for river ecosystem types is of major concern;
- The ecological condition of inland wetlands was modelled from land cover and ancillary data sets at a national scale, and the results showed that 15% of the extent is in a near-natural ecological condition, 18% moderately modified with 67% heavily to severely/critically modified; and
- Freshwater lakes (limnetic wetlands) were largely modified and degraded.

Pressures on rivers and inland wetlands

- Five key pressures have been identified for rivers and inland wetlands during the NFEPA project. These include changes to the hydrological regime (water quantity), water quality pollution, loss of natural habitat, invasive alien species and the over-exploitation of species;
- Climate change is considered a key driver of evolutionary change and will exacerbate existing pressures. South Africa is very likely to experience an increase in temperature, which will likely result in changes of the evapotranspiration and other parts of the hydrological cycle;
- Internationally, inland aquatic ecosystems are considered the most vulnerable ecosystem type to climate change with the status of aquatic species deteriorating faster than other ecosystem types. South Africa, with its mean annual precipitation below the international average, has been identified as a water-related vulnerable 'hotspot'. Evidence of warming and subsequent increasing in air temperature, number of hot days and duration of warm spells is very likely to increase evapotranspiration and impact the hydrological regime of inland aquatic ecosystems. In addition, increases in the variability of water temperature within some of Africa's large water bodies and rivers have been observed;
- The geographic extent, duration and impacts of pressures on inland aquatic ecosystems in South Africa are poorly understood; and
- A total of 191 alien species are associated with rivers and inland wetlands, and of these, 65 are considered invasive.

Increasing and Emerging pressures

- **Increasing water abstraction** with a growing demand for water and food, as well as intensifying droughts under climate change, an increasing abstraction of water from surface and groundwater systems is of major concern;
- **Water pollution is an increasing concern.** In 2013, 7.3% of SA's 859 WWTW received Green Drop certification, while 30% (248 WWTW) received purple status. According to DWS (2018a), 56% of the > 1 150 WWTWs are in a poor or critical condition, while 11% are dysfunctional. By the 1st January 2019, the former minister of the Department of Water and Sanitation (News24 2019) has declared 46 WWTW under critical review. In 2018 only 33% of surface and 7% of groundwater monitoring points have been analysed, with a general decline observed over the past three years (DWS 2018b);
- **Fracking of the Karoo aquifer is an emerging pressure.** The proposed exploration and exploitation of shale gas fields in the Karoo and elsewhere in South Africa are emerging pressures on inland aquatic ecosystems. The expected impacts range through pollution of groundwater, release of methane, drawdown of groundwater impacting on ephemeral aquatic ecosystems, seismic activity during exploration, large-scale removal of indigenous biota, and the cumulative impacts relating to infrastructure development;
- **Micro-plastics and pharmaceuticals** are emerging pressures, and uncertainties are associated with levels of toxicity, minimum acceptable standards and ability to remove;
- **Illegal sand mining** is emerging as a pressure on vulnerable seasonal and ephemeral river ecosystems in South Africa. It is an emerging concern particularly because it takes place at a small scale and is difficult to monitor. An evaluation of the cumulative impact of Illegal sand mining should inform permitting decisions; and
- **Aquaculture for economic benefits is an emerging concern.** Growth in particularly Tilapia and Marron crayfish were observed in the past ten years.

Ecosystem Threat Status (ETS) and Ecosystem Protection Level (EPL) results

- This assessment found that respectively 64% and 79% of South Africa's river and wetland ecosystem types are threatened (Critically Endangered, Endangered or Vulnerable);
- Rivers and inland wetlands are Poorly Protected. This assessment found that less than a quarter of the country's river and wetland ecosystem types could be considered Well Protected (13% and 6% respectively);
- Lowland river ecosystem types, as well as valley-bottom and floodplain wetlands, usually coincide with low-lying areas, are predominantly developed and at the receiving end of effluent. This assessment found 67% of the lowland rivers and 93% of the valley-bottom and floodplains wetlands to be Critically Endangered. Most of the inland wetlands were found to be Poorly Protected, mainly because < 5% of the extent of these hydrogeomorphic types was in a near-natural ecological condition;
- Wetland ecosystem types were likely more threatened than their river, coastal, marine, terrestrial and sub-Antarctic counterparts (64%, 60%, 50%, 23% and 18% of river, coastal, marine, terrestrial and sub-Antarctic ecosystem types are threatened respectively). In this assessment, estuarine ecosystem types were found to be more threatened compared to the wetlands, with 86% of the ecosystem types threatened;
- Wetlands are the most threatened of all South Africa's ecosystems, with 62% of wetland ecosystem types Critically Endangered. Wetlands in South Africa's landscape today make up only 2.2% of the country's area, yet wetland ecosystem types are mostly underrepresented in the National Wetland Map;
- About 73% of inland wetlands are threatened and unprotected (Not Protected or Poorly Protected). The shortfall to the biodiversity target is largest for Bushmanland Depression and Mesic Highveld Grassland Valley-bottom wetlands. These systems should be prioritised for in-field integrity assessment following by consideration in an expansion strategy for protection;
- The eight unique freshwater lakes or limnetic wetlands are threatened and Poorly Protected; and
- A total of 14% of the length of rivers and 7.4% of the extent of inland wetlands are located within the proteted area network, which is below the 17% Aichi target 11 for 2020.

Free flowing and flagship rivers

- Nineteen flagship rivers remained in a near-natural ecological condition;
- Fourteen free-flowing rivers have changed in status: four as a result of dams not represented in the layer used for the NFEPA project (6% of the original 62 free-flowing rivers) and ten as a result of deterioration of their ecological condition (16% of the original 62 free-flowing rivers); and
- South Africa has 48 remaining free-flowing rivers.

Results from the indigenous freshwater species assessments

- A total of 658 indigenous freshwater species associated with rivers and inland wetlands have been assessed for this NBA, of which 160 are endemic. Of these endemic species, 61% are Taxa of Conservation Concern (ToCC), leaving South Africa with the sole responsibility to conserve and protect these species;
- South Africa has a total of 112 (17%) threatened species associated with rivers and inland wetlands. In general, most indigenous freshwater species (71%) are assessed as Least Concern. While trends in species status shows, a continued decline in species status with mammals associated with aquatic systems showing a very steep decline, with 20% of specie driving the change, followed by aquatic plants (14%), while all remaining taxonomic groups were driven by between 2% and 7% of taxa driving the change in status;
- Freshwater taxa show a high sensitivity to multiple pressures, the most serious being the loss of natural habitat owing to invasive alien species, pollution of river systems, agricultural and housing developments; and over-abstraction of water;
- Freshwater fish are South Africa's most threatened and least protected taxonomic group. In addition to the freshwater fish, the protection levels of birds, mammals, reptiles and amphibians have been assessed for this NBA. The majority of these species (> 65%) were found to be Well Protected, with the exception of freshwater fish;
- Patterns observed for freshwater fish, is in contrast to other taxononomic groups, as this group mainly use rivers that are not well captured by the current protected are network (only 14% of South African river lengths occur within the protected area network). Furthermore, many species occurring within existing protected areas are threatened and declining as a result of pressures present within or originating outside of protected areas due to the linear nature of river systems, making it difficult for protected areas to mitigate against catchment wide pressures;
- Twenty-seven species are ToCCs and assessed as Not Protected. These species are priority species for inclusion in protected are expansion and other conservation initiatives; and
- Impacts of invasive alien species and water pollution are major drivers of fish extinction risk, impacting 81% (51 taxa) and 70% (44 taxa) of ToCC respectively.

Responses to pressures on rivers and wetlands

- South Africa is successful in a number of response pathways for the protection and management of inland aquatic ecosystems and freshwater species:
  - South Africa is one of only a few countries globally that has succeeded in incorporating ecosystems and species in conservation planning at a national scale through the National Freshwater Ecosystems Priority Areas (NFEPA) Atlas, which is strongly influenced by the principles of systematic conservation planning;
  - South Africa follows an integrated water resource management approach to ensure that water resources are protected for their sustainable utilisation. One of the strategies implemented by the Department of Water and Sanitation (DWS), in support of the National Water Act (NWA, 1998) is Resource Directed Measure which consist of three components: Water Resources Classification, Reserve Determination and Resource Quality Objectives (RQOs). Since the enactment of the Water Resource Classification System (WRCS) in 2010, eight river systems have water resource classes and RQOs determined while a further seven have been gazetted for public comment. This constitutes more than half of the planned drainage 26 regions;

- South African environmental legislation make provision for the use of quite sophisticated tools for the protection, conservation and management of our inland aquatic ecosystems and freshwater species. Several case studies have demonstrated the effectiveness of these tools that have been developed as part of the National Water Act (NWA) and National Environmental Management: Biodiversity Act (NEMBA);
- The 22 Strategic Water Source Areas (SWSAs) for surface water (SWSA-sw) and 37 Strategic Water Source Areas for groundwater (SWSA-gw), covering 8% of SA, have been identified as the top priority areas for mapping, intervention and climate change adaptation strategies in response to pressures on inland aquatic ecosystems and freshwater species. The SWSAs offer a focused approach of intervention to ensure that both humans and ecosystems benefit. There are subsequently multiple and diverse stakeholders that take ownership of and contribute to this initiative;
- The ecological condition of 19 flagship rivers remained ecologically intact as a result of the awareness generated through the NFEPA project, and subsequently the accountability and responsibility taken by managers and land owners to protect these systems;
- The assessment of the ecological condition of rivers is an advanced system which monitors the abillity of these ecosystems to adjust to increasing pressures. Both ecosystem drivers (hydrological, geomorphological, physicochemical) and responses (fish, macroinvertebrates and riparian vegetation) are monitored and assessed. The availability of fairly comprehensive datasets developed by DWS over many years, enabled the assessment of national river accounting, a first example of Natural Capital Accounting, which is also considered the first globally. It is furthermore being used as a template across the world and in other realms too. These ecological condition datasets of DWS are used widely across sectors, from water legislation, to environmental impact assessment and annual reporting;
- Several interventions to control and eradicate invasive plant and animal species have emerged and grown over the past seven years with evidence of the positive effect it has had on inland aquatic ecosystems and freshwater species. Government plays a critical role to coordinate, manage and maintain such efforts across the multiple sectors, and can contribute to evidence-based guidance and trend analysis of these interventions.
- Protected areas form critical cornerstones to invest in better land use management within and outside the reserves, whereas cooperative stewardship programmes have contributed to supportive programmes of protection. Further investment in these multi-level initiatives are critical to curb the negative trajectory of the ecological condition of inland aquatic ecosystems and some freshwater species;
- Species management plans have proven successful for threatened species and should be expanded to curb negative trends evident in freshwater species;

- Despite these achievements, a number of critical issues require immediate attention, which became evident during the assessment period:
  - Monitoring and implementation remains a huge challenge in South Africa, despite excellent legislation, policies and frameworks that support the management and conservation of inland aquatic ecosystems and freshwater species.
  - Immediate and urgent intervention are required to re-operationalise Waste Water Treatment Works (WWTWs) in the country. Of the 859 WWTWs, 56% are in a poor or critical condition, 11% dysfunctional and 46 (5%) under critical review since 2018, and consequently, no green drop status reports are published;

- A serious decline in funding for monitoring water quality and quantity during the second half of 2017 and 2018, resulted in a near-collapse of the river monitoring programme, with < 40% of surface and groundwater monitoring points assessed in the 2018. This has far-reaching implications for current reporting and analysis, compliance monitoring and future trend analysis, is a major concern;
- A critical lack of, and loss, of skilled personnel to monitoring water quality, quantity and associated ecosystems and freshwater species;
- Monitoring needs to be strategically expanded across the country, with improved representation of river ecosystem types, the commencement of the National Wetland Monitoring Programme (NWMP) for the representation of inland wetlands, and sufficient funding, skilled staff and cooperative governance between Interested and Affected Parties. Currently, 33% of the 222 river ecosystem types lack flow monitoring while 26% require water quality; and
- Despite our advances in using technology, associated with the fourth industrial revolution (4IR), to model water demand and use, regulation and enforcement remain problematic. New and alternative 4IR technologies should be investigated for monitoring and passive compliance regulation to enable more efficient intervention.

- The status of responses to the pressures on inland aquatic ecosystems and freshwater species, including successes and challenges, are discussed in detail in Chapter 9 according to seven core areas and include foundational and base data, strategic planning, regulation, protection, rehabilitation, monitoring, sustainable financing and cooperative governance.

This NBA 2018 was the first to attain alignment between inland aquatic ecosystems (including rivers, inland wetlands and estuaries) which highlighted the importance of transition zones and interdependent support functions. Collaborative discussion amongst numerous wetland specialists benefitted the NBA 2018 and cumulative benefits resulted from such collaboration. It is important to note that the majority of the inland aquatic Assessment report for the NBA 2018, results from volunteered contributions from river and wetlands specialists. Their tremendous passion and determination to make things work have been inspirational. The shared goal and work ethics are a key component to this NBA 2018.

Key messages

I. **River and inland wetlands ecosystem types represent inland aquatic ecosystems of South Africa.**

II. **Water security is essential for human wellbeing and livelihoods. Aquatic ecosystems supply the quantity and quality of water required for survival**.

III. **Inland wetlands remained highly threatened and under-protected**.

IV. **River ecosystems are declining in ecological condition. Of the 222 river ecosystem types assessed, 64% were found to be threatened (43% Critically Endangered, 19% Endangered and 2% Vulnerable).**

V. **Flagship rivers have remained intact over the past seven years, and serve as an excellent example of ecosystem types from source to sea**.

VI. **South Africa has eight unique freshwater lakes (totalling roughly 13 300 ha), all of which are Critically Endangered and under-protected.**

VII. **A total of 658 indigenous freshwater taxa associated with rivers and inland wetlands, from seven taxonomic groups, were assessed for this NBA and freshwater fishes are the most threatened (36% of all taxa and 66% of endemic taxa threatened).**

VIII. **The first protection level assessment for species found that the majority of freshwater associated taxa, with the exception of freshwater fishes, are Well Protected: 100% of reptiles, 83% of birds, 65% of mammals and 74% of amphibians.**

IX. **Monitoring is critical to inform baseline information, decision making and improved governance of ecosystems, species and pressures**.

X. **Integrative and collaborative monitoring and management will optimise the protection of rivers and inland wetlands.**

XI. **Genetic diversity brings new value to the inland aquatic ecosystem types.**

Knowledge gaps and Priority Actions

Knowledge gap	Priority Action
National monitoring data for river and inland wetlands are incomplete and are insufficient to show trends in ecological condition. The River EcoStatus Monitoring Programme (the former River Health Programme) is in danger of failure. The National Wetland Monitoring Programme remains to be implemented.	Dedicated funding for regular **monitoring** will strengthen ability to assess ecosystem status and determine trends. The monitoring programmes should aim at a better representation of ecosystem types across the country (spatial aspect), as well as their representation over the diversity of hydrological regimes (temporal aspect).
Water use statistics are estimated which limites our ability to make informed decisions.	Water is a limiting factor for rivers and inland wetlands. South Africa as a semi-arid to arid country needs to manage water stricter as a scarce resource. **Ensure water availability for river and inland wetland ecosystem types**. South Africa has shown success here in targeting resource management within the Strategic Water Source Areas. Additional water saving mechanisms and water pricing are critical mechanisms to secure water across board.
Representation of river and inland wetland extent and ecosystem types show spatial inaccuracies and inland wetlands are particularly underrepresented in the National Wetland Maps. In particular, inland aquatic ecosystems in arid regions needs better indicators for defining and identifying and characterising these systems.	Invest in **improved representation and verification of these systems** through a combination of citizen science, expert mapping, integration in GIS and remote sensing methods. In particular, river ecosystem types need to be refined to include riparian vegetation because these not represented and could potentially be highly threatened. Develop indices for the identification of inland aquatic ecosystems in arid regions.
Freshwater fish and aquatic plants show declining trends according to the Red List Index assessments. Insufficient representation of exclusively aquatic invertebrates hampers understanding of the impact of changing ecological condition on aquatic species. Most of the groups on the RLI currently (birds, amphibians, mammals and dragonflies) are able to disperse and potentially escape pressures, and therefore the RLI result are likely to underestimate overall threat levels and rates of decline in the inland aquatic realm.	**Additional inland aquatic invertebrate groups must be assessed** and monitored for inclusion in the next NBA, with a specific focus on endemic groups. A comprehensive database of macro invertebrates to support assessments and planning should be prioritised and budget allocated to its ongoing maintenance. Important fish areas should be included in provincial biodiversity plans. The successful interventions of Cape Nature to curb invasive fish should be rolled out to other parts of the country.
The National Freshwater Ecosystem Priority Areas (NFEPA) product nears a decade and requires an update, particularly following the assessment of freshwater species done for this report, the critical state of freshwater fish and the need for updated Important Fish Areas, as well as the update done for the inland wetland ecosystem types.	**Update the Important Fish Areas and wetland FEPAs in NFEPA II** to inform planning within the next decade, while more accurate baseline information is collected in the next decade for improved decision making and planning.
The impact of climate change on inland aquatic ecosystems and freshwater species is largely unknown.	**Fund research to provide evidence of the impact of climate change** on inland aquatic ecosystems and freshwater species, to enable better planning for shifts in ranges and extinctions. Priority areas which could serve as refugea during drought or long-term ecosystem base adaptation should be developed and incorporated in conservation plans.

Research gaps

In addition to the knowledge gaps listed above, several research gaps have also been identified:

- Update and refine flow categories for river ecosystem types;
- Criteria for the identification and characterisation of inland aquatic ecosystems in arid regions;
- Collating data for the distribution of macro-invertebrate data of rivers and inland wetlands and determine their sensitivity and resilience to multiple pressures;
- Improve understanding of ecosystem types in relation to freshwater species;
- Test criteria for categorising ecological condition of rivers and inland wetlands;
- The impact of climate change on inland aquatic ecosystems and freshwater species; and
- Localities of key ecosystem services of inland aquatic ecosystems.

1. INTRODUCTION AND APPROACH

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1.1 What is the National Biodiversity Assessment?

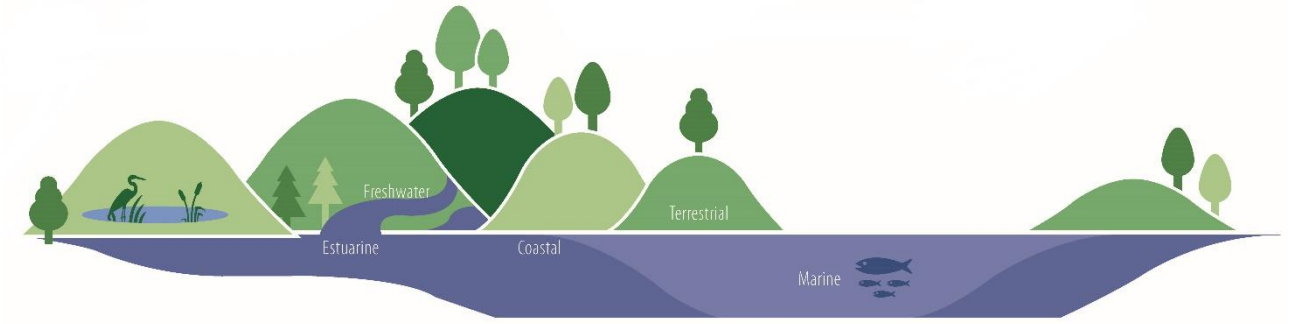
This technical report focusses on state of inland aquatic biodiversity in South Africa and forms part of the National Biodiversity Assessment (NBA) 2018, which is a collaborative effort to synthesise the best available science on South Africa's biodiversity. The overarching aim of the NBA is to inform policy and decision-making in a range of sectors, and contribute to national development priorities. The NBA seeks to answer the following high-level, policy-relevant questions:

- **Status**: How is South Africa's biodiversity doing at the ecosystem, species and genetic level?
- **Trends**: Are ecosystems, species and genetic diversity doing better or worse?
- Are we **responding** effectively to the challenge of managing and conserving biodiversity?
- How is society **benefiting** from biodiversity?

What is Biodiversity?

According to the Convention on Biological Diversity (CBD), biodiversity is defined as the 'variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems'. Ecosystems are defined as a 'dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit'.

Biodiversity incorporates diversity at the genetic level, species level and ecosystem level; which together form the foundation of ecosystem services. Biological diversity is about more than plants, animals and micro-organisms and their ecosystems – it is about human well-being and our dependence on ecosystem services.



1.1.1. What is the NBA used for?

The NBA is used to inform policy in the biodiversity sector, such as the National Biodiversity Framework and the National Protected Area Expansion Strategy (PAES), as well as informing policies and strategies of a range of other sectors that rely on, or impact on natural resources, such as the water, agriculture and mining sectors (Nel *et al*. 2016; Figure 1.1; Table 1.1). The NBA provides information to help prioritise the often limited resources for managing and conserving biodiversity — actions can focus on preventing further loss and degradation of ecosystems and ecological infrastructure, on consolidating and expanding the protected area network, and on interventions required to restore areas not in a natural or near-natural ecological condition so that they become healthy, functioning systems of benefit to people. The NBA provides context and information that feeds into strategic planning processes such as strategic environmental assessments and bioregional plans (these are built from systematic biodiversity plans and biodiversity sector plans). Figure 1.1 illustrates the links between the NBA and a range of national and international level monitoring, reporting and assessment processes. The NBA ensures that the Department of Environment, Forestry and Fisheries (DEFF) can produce the national Environment Outlook Report and that DEFF has the necessary biodiversity information to meet South Africa's international reporting commitments to the United Nations Convention on Biological Diversity (CBD)[1] and national and regional reporting linked to the Sustainable Development Goals (SDG)[2] and the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES)[3]. For example, the spatial extent of inland aquatic ecosystems and their associated cover has been used by the Department of Water and Sanitation (DWS) for the reporting to the United Nations Environment Programme (UNEP) on SDG indicator 6.6 related to water.

The NBA is also a key reference and educational product relevant to scientists, students, consultants and decision makers, and acts as a national level platform for collaboration, information sharing and capacity building in the biodiversity sector in South Africa.

1.1.2. SANBI's mandate

The NBA is the overarching tool for monitoring and reporting on biodiversity in South Africa and provides focus and impetus for measuring several indicators and synthesising them periodically at the national scale. There are several additional reports that provide more detail on certain aspects, including status reports for invasive alien species, reports on impacts of genetically modified organisms and reports linked to the trade of threatened or protected species. All of these form part of SANBI's mandate to monitor and report regularly on the status of South Africa's biodiversity, in terms of the National Environmental Management:

[1] The Convention on Biological Diversity (CBD) has 3 main objectives: i) the conservation of biological diversity; ii) the sustainable use of the components of biological diversity; and iii) the fair and equitable sharing of the benefits arising out of the utilization of genetic resources. South Africa is a signatory to the convention and fulfils its obligations by developing and updating the National Biodiversity Strategy and Action Plan (NBSAP) and producing National Reports biennially. The most recent NBSAP (2015) drew heavily on the NBA 2011.

[2] The United National Development Programme (UNDP) Sustainable Development Goals (SDGs) came into effect in 2016 and guide UNDP policy and funding until 2030; they include goals focused on water, climate action, life below water and life on land.

[3] The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) is an independent intergovernmental body open to all member countries of the United Nations. IPBES aims to provide a mechanism recognised by both the scientific and policy communities to synthesise, review, assess and critically evaluate relevant biodiversity and ecosystem service information. IPBES also aims to strengthen capacity for the effective use of science in decision making at all levels by providing tools and training for regional, sub-regional and national level assessments (www.ipbes.net).

Biodiversity Act (Act 10 of 2004; RSA 2004)[4]. The NBA has an especially important role to play in supporting the development and implementation of biodiversity policy and legislation in South Africa.

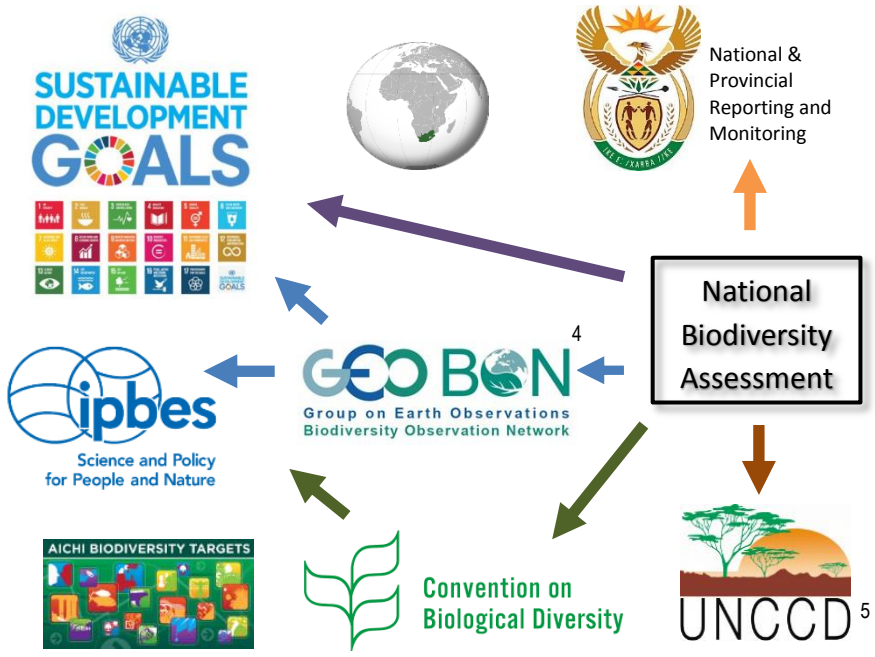


Figure 1.1. Illustration of national and international reporting processes and channels into which the NBA is a key informant. Including international conventions signed by the South African Government [5,6] and voluntary processes.

1.1.3. Navigating the NBA

The NBA 2018 is the third national assessment for South Africa - following the National Spatial Biodiversity Assessment (NSBA 2004; Driver *et al*. 2005) and the National Biodiversity Assessment (NBA 2011). The NSBA 2004 was the first comprehensive national spatial assessment of the state of biodiversity, covering terrestrial, inland aquatic (or freshwater), estuarine, coastal and marine environments. It introduced two new headline indicators for assessing the state of South Africa's biodiversity: Ecosystem threat status (ETS), and Ecosystem Protection Level (EPL). Each iteration of the national assessment has seen advances in information and analyses undertaken.

[4] Hereafter referred to as the 'Biodiversity Act'.

[5] The Group on Earth Observations Biodiversity Observation Network (GEOBON) seeks to 'Improve the acquisition, coordination and delivery of biodiversity observations and related services to users including decision makers and the scientific community' through the identification and operationalization of Essential Biodiversity Variables (EBVs).

[6] The United Nations Convention to Combat Desertification (UNCCD) links the environment and development to sustainable land management in arid and semi-arid regions in particular.

Table 1.1. Processes utilising the NBA findings, messages and datasets (see also Nel *et al*. 2016).

Processes	Examples	Finding & Messages	Datasets
National & provincial reporting	National and provincial Environmental Outlook reports (EO) (also known as state of environment reporting) are key national reporting channels that rely on the NBA	✓	✓
National strategies	The national development indicators linked to the National Development Plan of the Presidency (NDP) National Development Plan, National Biodiversity Framework, National Protected Areas Expansion Strategy (PAES) are all built partly on the findings of the NBA	✓	
Sector strategies	The NBA informs sector specific strategies for sustainable development including the Mining and Biodiversity Guidelines; ecosystem management guidelines per biome (Fynbos, Grasslands, Thicket and Savanna) and many others.	✓	
International reporting	CBD Country Reports and the National Biodiversity Strategy and Action Plans (NBSAP) rely on the NBA as do the IPBES – Regional Assessments and global Assessments; the UNCCD Land Degradation Neutrality Reports; and the UN SDGs – national reporting processes	✓	
Biodiversity planning	Bioregional planning and biodiversity sector planning at provincial and municipal scales rely on the NBA for regional context and for updated national scale datasets on ecosystem and species status	✓	✓
Regional planning	Spatial Development Frameworks (SDF) and Environmental Management Frameworks (EMFs) at local government level	✓	✓
Protected area planning	PAES at national and provincial scales		✓
Strategic Environmental Assessments (SEA)	SEA for large infrastructure programmes such as Square Kilometre Array, national electricity grid, renewable energy infrastructure, shale gas exploration, national gas pipelines	✓	✓
Environmental Impact Assessments (EIA)	Ecosystem and species status and distribution data; ecosystem condition data; and protection data are used extensively in EIAs both at site level and for regional context. The overall findings provide mostly contextual information for the EIA.	✓	✓
Research	Researchers use both the findings and messaging for context in conservation and biodiversity research, and the datasets are extensively used in ecological research, biogeography, environmental research etc.	✓	✓
Education	The NBA and the technical reports that underpin it are realm specific summaries of biodiversity status that are widely used in tertiary education in biological and environmental sciences in particular.	✓	✓

The NBA is structured as follows: **technical reports** were produced for each **realm** (terrestrial, inland aquatic, estuarine and marine), for the coastal zone, for the Prince Edward Island group and the surrounding seas, and for the genetic component of biodiversity. These are presented as separate technical volumes of the NBA 2018. The overall results were summarised and are presented in the **synthesis report**. Additional technical reports on specific aspects of the NBA, such as the South African Inventory of Inland Aquatic Ecosystems (SAIIAE) or in short the South African Inventory for Inland Aquatic Ecosystems (SAIIAE)

(Van Deventer *et al*. 2018), the benefits of biodiversity compendium (SANBI 2019), and the technical report on land cover change are available online (Skowno *et al*. 2019).

SANBI draws substantially on contributions of time and other in-kind resources from a wide range of partners over the course of the NBA. This is important not only for completing the work, but also for the collective ownership of the NBA by the biodiversity science community in South Africa. The NBA is a multi-author and multi-institution effort, and the authors of each section and subsection are clearly indicated and acknowledged in all the various volumes of the NBA 2018. In addition to authorship, a large number of individuals and institutions have made their information available to this national assessment; wherever possible the source of the information used in the NBA is clearly attributed. The co-production of knowledge for the NBA also assists scientists, practitioners and decision makers to work towards a common vision for action following the assessment.

Various governance structures were put in place in 2015 to guide the approach taken in the NBA 2018, and ensure that a wide range of experts in each specific biodiversity sector were included in the process:

1. Reference groups were set up for each realm consisting of key technical and scientific experts.
2. Ecosystem Classification Committees have been permanently set up for each realm consisting of ecosystem classification and mapping experts – these will continue to be facilitated by SANBI and are not specifically linked to the NBA cycle of reporting.
3. A Core Reference Group made up of the leaders of the realms and themes as well as key technical and policy experts.
4. An internal SANBI Steering Committee to engage with senior management from the various Divisions and Directorates.
5. A Strategic Advisory Committee consisting of senior officials from various government departments, non-governmental organisations and research institutes, which provide guidance on key messages that should be highlighted in the NBA synthesis report.

The NBA 2018, like the NSBA 2004 and NBA 2011, was led by the South African National Biodiversity Institute (SANBI), whose mandate includes reporting on the state of biodiversity in South Africa, in partnership with a range of organisations and experts. The NBA 2018 covers terrestrial, inland aquatic, estuarine, coastal and marine environments, and discusses various themes across these environments — including pressures on biodiversity, ecosystem classification, the status of ecosystems, the status of indigenous species, and protection level of ecosystems and species. As there are now more than two national assessments, NBA 2018 also shows trends for several of these themes in selected cases. In addition, NBA 2018 includes several new themes — notably an examination of potential ways to assess genetic diversity.

Technical Reports were produced for each environment, and the overall results were summarised in the Synthesis Report. References for the set of reports produced for the NBA 2018 are shown at the beginning of this report.

The NBA 2018 worked in an integrated and aligned way across aquatic and terrestrial realms. Historically, previous assessments have developed these separately, with separate sets of terminology, methods and approaches. Insisting on compatible approaches can be seen as a constraint on conventional approaches. Regardless of the challenges, however, the benefits are numerous, including enabling comparisons, shared

learning and innovations across different realms. Cross-pollination between the aquatic realms were crucial to ensure not only spatial alignment, but that pressures and impacts are recognised across the fuzzy boundaries and grading ecotones of these systems. Inland aquatic ecosystems, for example, include rivers, inland wetlands and estuaries (Ollis *et al*. 2013), and boundaries of these connected systems grade from one into another. This report focuses on the rivers and inland wetlands whereas the estuarine ecosystems are reported in a separate technical report by Van Niekerk *et al*. (2019).

1.2. Indicators

1.2.1. Headline indicators: threat status and protection level for species and ecosystems

Biodiversity indicators have received renewed attention recently amid calls to slow global losses of biodiversity (Nicholson *et al*. 2012; Tittensor *et al*. 2014; Geijzendorffer *et al*. 2015). Indicators in general, are a tool to i) improve general awareness and gain public attention for biodiversity; ii) meet international reporting requirements; monitor conservation actions; and iii) inform policy and decision making by governments *(Nicholson et al. 2012, 2015; Keith et al. 2013, 2015; Geijzendorffer et al. 2015; Tanentzap et al*. 2017).

The NBA relies on two **headline indicators** that can be applied to both ecosystems and species; **threat status and protection level**. The first indicator (threat status) is based on the International Union for Conservation of Nature (IUCN) risk assessment framework for species (Red List of Species) (IUCN 2012) and ecosystems (Red List of Ecosystems) (Bland *et al*. 2017). The IUCN Red List of Species is well established globally and in South Africa and has formed a part of the NBA reporting since 2005 (Driver *et al.* 2005). The IUCN Red List of Ecosystems (RLE) is relatively new (v1.0 released in 2016) and prior to its development South Africa developed its own ecosystem threat status assessment framework between 2004 and 2008 (RSA 2011). The second indicator, protection level, was developed in South Africa for national reporting purposes (Driver *et al.* 2004) and addresses the extent to which ecosystems and species are protected. In the 2004 and 2011 national assessments protection level was only applied to ecosystems, but over the last two years SANBI's Threatened Species Unit has applied the indicator to species and it will be reported on for the first time in the NBA 2018. These headline indicators provide a way of comparing results meaningfully across the different realms, and also provides a standardised framework that links with policy and legislation in South Africa, thus facilitating the interface between science and policy. There is growing recognition within government and other institutions of this framework and the need to respond to these headline indicators in planning and decision making.

Ecosystem indicators

Ecosystem Threat Status (ETS) tells us about the degree to which ecosystems are still intact or alternatively losing vital aspects of their structure, function and composition, on which their ability to provide ecosystem services ultimately depends (Figure 1.2). The conceptual 'end point' of decline for an ecosystem is termed collapse and is equivalent to extinction in the species red listing framework. Ecosystem types are categorised as Critically Endangered (CR), Endangered (EN), Vulnerable (VU) or Least Concern (LC), based on the proportion of each ecosystem type that remains in a natural or near-natural ecological condition relative to a series of thresholds. For the NBA 2018 the IUCN Red List of Ecosystems was used as the risk assessment framework for inland aquatic ecosystems (Bland *et al*. 2017). The previous national

assessments (2004 and 2011) pre-dated the development of the IUCN RLE and the South African Threatened Ecosystem Framework was used (Driver *et al.* 2004, 2012; RSA 2011); making South Africa one of the pioneers globally of this approach to assessment.

Ecosystem Protection Level (EPL) tells us whether ecosystems are adequately protected or under-protected. Ecosystem types are categorised as Not Protected, Poorly Protected, Moderately Protected or Well Protected, based on the proportion of each ecosystem type that occurs within a protected area recognised in the National Environmental Management: Protected Areas Act (Act 57 of 2003; RSA 2003)[7].

The ability to map and classify ecosystems into different ecosystem types is essential in order to assess threat status and protection levels and track trends over time. South Africa has an emerging national ecosystem classification system, including vegetation types, river ecosystem types, wetland ecosystem types, estuary ecosystem types, and marine and coastal ecosystem types, which provides an essential scientific basis for ecosystem-level monitoring, assessment and planning.

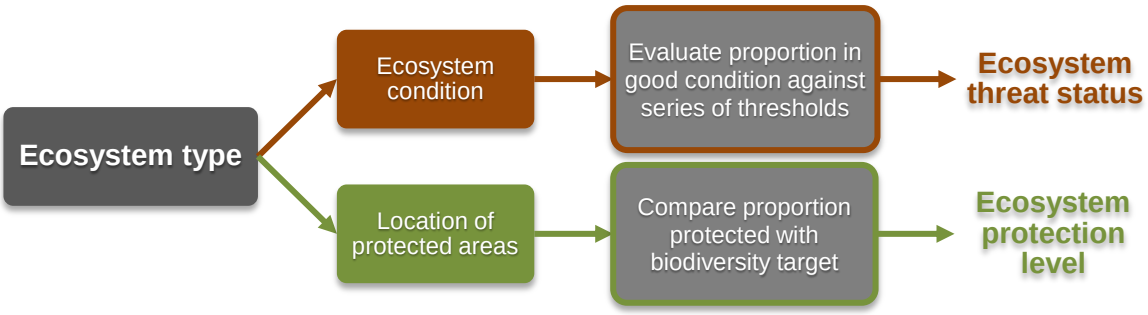


Figure 1.2. Steps in assessing Ecosystem Threat Status (ETS) and Ecosystem Protection Level (EPL). Note the link between ecosystem condition and protection level – only natural habitat contributes to protection level targets (e.g. the airport within a large protected area would not contribute to protection targets as the natural habitat has been lost).

Species indicators

Threat status of species tells us which species in South Africa are at risk of extinction. Threatened species are those with high risk of extinction and are classified in three categories of increasing risk of extinction Vulnerable (VU), Endangered (EN) and Critically Endangered (CR). Levels of threat are determined against quantitative threshold-based criteria. South Africa uses the latest version of the IUCN Red List Categories and Criteria, version 3.1. (IUCN 2012).

Protection level of species is presented for the first time in this NBA and has no global equivalent indicator. Protection level measures progress towards effective protection of a habitat or population conservation target for each species. The indicator consists of two components. The first measures how well represented each species is within the protected area network, based on the conservation target for the species. This component allows the identification of which species require further protection, where species not represented or poorly represented within protected area network are prioritised for inclusion in spatial planning for protected area expansion. Component two includes a measure of management effectiveness within each protected area and when combined with protected area representation provides an overall (effective) protection level measure for each species.

[7] Hereafter referred to as the 'Protected Areas Act'.

Both the threat status and protection status indicators for species allow South Africa to report against Aichi Target 12.

Indices of change

The headline indicators of the NBA can form the basis for an index that tracks change over time. One such index, developed by the IUCN, is the Red List Index (RLI) for species (Butchart *et al.* 2007). The RLI tracks genuine changes in extinction risk across entire species groups (i.e. it is based on only changes in extinction risk between Red List assessments due to actual improvements or deteriorations in extinction risk). It is used to generate 15 of the indicators used to track progress towards the Aichi Targets (UNEP/CBD/SBSTTA/20), mobilised through the Biodiversity Indicators Partnership as well as serving as the official UN Indicator 15.5.1 for SDG 15.5 (Brooks *et al.* 2015).

1.2.2. Other indicators

Indicators for biological invasions

Recent work by Wilson *et al*. (2018) developed a theoretical framework for reporting on biological invasions at a national level. The framework explicitly considers biological invasions in terms of pathways, species (taxa), sites and interventions (separated into inputs, outputs and outcomes). Indicators for pathways describe the opportunities available for introduction to and dispersal within South Africa, as well as the degree to which alien species are being introduced along these pathways. Indicators for species include the number and status of alien species in the country, the extent and abundance of these alien species, and the impacts caused. Indicators for invaded areas include the number of alien species in different areas, the alien species richness relative to indigenous species richness, the abundance of invasive species relative to the abundance of indigenous species, and the impact of invasions on particular areas. Indicators for the interventions include an assessment of key inputs (the regulatory framework, the money spent and the planning coverage), outputs (the degree and quality of treatments applied to pathways, species and areas) and outcomes (the effectiveness of treatments of pathways, species and areas, as well as returns on investment). The framework aggregates the 20 indicators into four high-level indicators that align with the pressure, state and response framework (Table 1.2): a) rate of introduction of unregulated species (pressure); b) number of invasive species that have major impacts (state); c) extent of area that suffers major impacts (state) and d) level of success in managing invasions (response).

Table 1.2. Proposed high-level indicators for monitoring the status of biological invasions at a country level (based on Wilson *et al.* 2018).

Indicator	Type	Description
Rate of introduction of new unregulated species (**pathways**)	Indicator of **risk (pressure)** of biological invasions	This provides an indication of potential future biological invasions (i.e. species-based invasion debt). Species which have been introduced following a proper detailed and independently assessed risk analysis are not included.
Number of invasive species that have major impacts (**species**)	Indicator of **status** of biological invasions & an indicator of pressure on biodiversity	The total number of alien species that have been reported to have a Major (MR) or Massive (MV) impact under either the Environmental Impact Classification for Alien Taxa (EICAT*) or Socio-Economic Impact Classification of Alien Taxa (SEICAT**) schemes provides an indicator of the current size and complexity of the problem. A growth in the number of species would indicate an increase in consequences and management complexity.
Extent of area that suffers major impacts from invasions (**areas**)	Indicator of **status** of biological invasions & an indicator of pressure on biodiversity	The extent of invaded area that suffers major impacts is an indicator of the overall extent of impacts in biological invasions. Invaded areas are expected to deliver fewer or diminished ecosystem services, and/or to support lower levels of biodiversity.
Level of success in managing invasions (**interventions**)	Indicator of **response** to biological invasions	The degree of success achieved by control measures will vary from place, and this indicator is intended to provide an assessment of overall control effectiveness across all projects. High levels of effectiveness would indicate that control measures are appropriate and that the goals of management are realistic and achievable. Low levels of effectiveness would indicate inefficiencies in management, or unrealistic expectations and goals, or both. It should trigger a thorough examination of the component projects with a view to re-allocating national-level resources to projects where the goals are more likely to be achieved, or to re-defining more-realistic goals.

** Blackburn et al. 2014; Hawkins et al. 2015*
*** Bacher et al. 2018*

Global biodiversity indicators

The Aichi Biodiversity Targets were structured around the CBDs 2011–2020 Strategic Plan for Biodiversity. Strategic Goals B (*Reduce the direct pressures on biodiversity and promote sustainable* use; Aichi targets 5–10) and Goal C (*Improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity; Aichi targets 11–13*) are the most closely linked to the NBA 2018. Table 1.3 shows the links between the NBA headline indicators and the indicators for the Aichi Targets and SDGs. Ecosystem Threat Status, in particular, is not well captured in the Aichi Targets or SDGs. The SDGs linked to biodiversity propose Key Biodiversity Areas (KBAs) as a possible focal 'unit of assessment' for various indicators and it is likely that assessing the status of KBAs will become a global indicator of biodiversity that can be added to the NBA headline indicators. To facilitate this, SANBI has initiated a project in partnership with BirdLife South Africa and co-funded by the World Wide Fund for Nature South Africa (WWF-SA) Nedbank Green Trust to identify and delineate preliminary KBA network for the South Africa based on existing KBAs (identified through previous processes) and on the species and ecosystem information gathered in the NBA.

Table 1.3. Links between the National Biodiversity Assesment (NBA) headline indicators and Aichi Targets and the Sustainable Development Goals (SDGs).

NBA indicator	Aichi target	Sustainable Development Goals (SDGs)	Comment
Ecosystem Threat Status (ETS)	5	15.1	This powerful indicator of threat to ecosystems is not adequately captured in Aichi and SDG related indicators.
Ecosystem Protection Level (EPL)	11	15.1	A version of protection level is used in SDG 15.1 reporting.
Species Threat Status (STS)	12	15.5	Good links between national indicators and the Aichi and SDG indicators.
Species Protection Level (SPL)	12	15.1	Not captured in the Aichi and SDG indicators.
Ecosystem extent / habitat loss	5	-	Not captured in Aichi and SDG indicators.
Biological Invasion Indicators (species, Areas and Pathways)	9	15.8	Reasonable links between national indicators and Aichi and SDG indicators.

Essential Biodiversity Variables

Internationally, the Group on Earth Observation: Biodiversity Observation Network (GEOBON) has developed the Essential Biodiversity Variables (EBVs) to track the status of biodiversity at regional to global scales (Pereira *et al*. 2013). Six EBV classes have been developed with 21 candidates that all realms can report changes in biodiversity (Table 1.4).

Several global indices are in development that would facilitate the reporting the status of EBVs to the CBD strategic plan and some of the Aichi Targets. Examples include the Species Habitat Indices, the Biodiversity Habitat Index, Species Protection Index, Protected Area Representativeness and connectedness index, the Local Biodiversity Intactness Index, Global Ecosystem Restoration Index and Species Status Information Index (https://geobon.org/ebvs/indicators/). Remote sensing is a valuable tool to assist in the reporting of some EBVs at regional to global scales (Skidmore *et al*. 2015) while others indices require in-field observations for reporting (Turak *et al.* 2017). To date, much of the GEOBON work has focussed on terrestrial and marine EBVs. However, the Freshwater Biodiversity Observation Network (FW BON) was established in 2017, to create a network of people and institutions that have the capacity to realise a comprehensive assessment of the status of freshwater biodiversity across the world by 2020. An assessment of the EBV framework for the freshwater realm revealed that it would be possible by 2020 to assess the EBV classes in Table 1.4 for ecosystem structure, species populations and community composition in the freshwater realm, but the remaining EBV classes would require longer term investment (Turak *et al*. 2017). Several priorities to advance the reporting of EBVs in the freshwater realm by 2020 were identified including: developing a globally systematic approach to collecting and assessing freshwater species data, collating existing and new data within shared global platforms, coordinating efforts for mapping inland water ecosystems extent at high spatial resolution, linking *in situ* data to modelling across regions, and mobilising citizen science for the collection and verification of data. These priorities have been incorporated into the activities that currently guide the implementation of FW BON, which include connecting and mobilising people and resources towards comprehensive global freshwater biodiversity assessment by 2020; developing fish and invertebrate sampling guidelines; inventorying global freshwater biodiversity for Freshwater Information Platform (FIP); and mapping and classifying freshwater

ecosystems and assessing their associate services. Please visit https://geobon.org/bons/thematic-bon/freshwater-bon/ for further information on FW BON and how to get involved in this global community of practice.

Table 1.4. Essential biodiversity variables or EBVs (adapted from https://geobon.org/ebvs/what-are-ebvs/, Pereira *et al*. 2013; Skidmore *et al*. 2015; Turak *et al*. 2017).

EBV class	EBV candidate	Indices remote sensing can monitor	Examples of Inland aquatic indices
Ecosystem structure	Habitat structure, ecosystem extent and fragmentation, ecosystem composition by functional type.	Ecosystem distribution, fragmentation and heterogeneity, land cover, vegetation height.	Free-flowing rivers.
Ecosystem function	Net primary productivity, secondary productivity, nutrient retention, disturbance regime.	Fire occurrence, vegetation phenology, primarily productivity and leaf area, inundation, soil moisture.	Rates of organic matter, nutrient dynamics, primary production, rates of ecosystem metabolism, water colour/transparency, fisheries production, biodiversity, biomass.
Community composition	Taxonomic diversity, species interactions.		Species-area relationships (SAR) coefficients.
Species traits	Phenology, morphology, reproduction, physiology, movement.	Leaf Area and leaf nitrogen content.	Functional traits, community composition metrics, biotic indices.
Species populations	Species distribution, population abundance, population structure by age/size class.	Species occurrence.	Species Threat Status (STS), Red List Index (RLI).
Genetic composition	Co-ancestry, allelic diversity, population genetic differentiation, breed and variety diversity.	N.A.	Allelic diversity, environmental DNA (eDNA).

EBV indicators related to species populations concur with the Species Threat Status and Red List Index headline indicators of the NBA. The headline indicators of the NBA (see Table 1.3), however, the availability of EBV indicators can inform the Ecosystem Threat Status. The headline indicators of the NBA (see Table 1.3) are more in line with the EBV indicators related to ecosystem structure, since they focus on the condition and extent of habitat. NBA headline indicators also describe changes in connectivity as provided for by the EBV indicators on ecosystem structure. This is because changes to river flow and water quality, which can constitute major barriers to freshwater species are included in the assessment of ecological condition which feeds into the NBA headline indicators. Extent of free-flowing rivers is an additional indicator used in the NBA, which measures ecosystem structure in relation to connectivity.

Free-flowing rivers

The free-flowing rivers index has been developed in the National Freshwater Ecosystems Priority Areas (NFEPA) project and finalised through extensive workshops with stakeholders across the country. A free-flowing river had to meet four criteria (Nel *et al*. 2011):

- Permanent or seasonally flowing rivers. Rivers that do not flow every year (ephemeral rivers) were not considered;
- At least 50 km, or the majority of the river, should be in a natural or near-natural ecological condition (PES = A or B ecological category); and
- At least 50 km of the river should have no dam in the channel throughout its length. No minimum distance threshold has been set for coastal rivers. The original assessment used the 1:50 000 farm dams issued by the former Department of Land Affairs: Chief Directorate Surveys and Mapping (DLA:CDSM) between 2005 and 2007. Data constraints prevented consideration of farm dams built after 2005, as well as weirs. The Upper Vaal and Upper Marico rivers were special cases where the long stretch of river flowing freely from source to dam was considered free flowing.

Three rivers, however, were included on the list of free-flowing rivers, based on recommendations of experts during the workshops. The Kobonqaba, Groot Marico and the Mutale Rivers were listed as free-flowing rivers, regardless of them not meeting the ecological condition criterion. Of the 62 free-flowing rivers, 19 rivers were then selected as flagship rivers, where ideally no large dams should be developed. The flagship rivers serve as examples of river ecosystem types which are intact from source to mouth (estuary) along the variation of its geomorphological zones and which demonstrate their significance for ecosystem processes and biodiversity value.

Changes in free-flowing rivers can be tracked in two ways: i) assessment of whether the river has lost its status as a free-flowing river since the development of a large dam occurred in between NBAs; and ii) whether any change in ecological condition have taken place between NBAs that have caused the free-flowing river to lose its status.

1.3. The biodiversity of inland aquatic ecosystems

Inland aquatic ecosystem biodiversity consists of river and inland wetland ecosystem types as well as their associated species. The rivers of South Africa straddle our international borders, consist of 856 mainstem rivers that drains the 22 primary catchments of South Africa (Figure 1.3). Mainstems typically pass through a quaternary catchment into a neighbouring quaternary catchment (Nel *et al*. 2011). The quaternary catchment is used as the basic unit for national water resource management (mean size 650 km^2), and each contains hydrological data (gauged or simulated) that is updated occasionally. Mainstem rivers were considered as rivers that pass through a quaternary catchment into a neighbouring quaternary catchment (Nel *et al*. 2007). These mainstem rivers have been historically identified using the South African quaternarcy catchments, as drawn up by the former National Department of Water Affairs and Forestry in 1994 (Midgley *et al*. 1994; Nel *et al*. 2007).

The *Classification System for Wetlands and other Aquatic Ecosystems in South Africa* serves as a framework for the tiered classification of inland aquatic ecosystems and associated attributes (Ollis *et al*. 2013). Rivers and inland wetlands are identified as the two primary sub-categories of inland aquatic ecosystems and are

distinguished from estuarine and marine ecosystems (Ollis *et al*. 2013; Van Deventer *et al*. 2018). The river channel and riparian vegetation at Level 4C make up what is broadly referred to as 'rivers' at Level 4 of the *Classification System for Wetlands and other Aquatic Ecosystems in South Africa*. Although river ecosystem types were classified in the NFEPA project to Level 4B and to some extent to Level 4C for the active channel, riparian zones were not represented as knowledge on them are still scant.

River ecosystem types of South Africa are characterised at three levels, including (i) a broad ecological context representative of, for example, regions where the topography, rainfall, geology and natural vegetation are relatively similar; (ii) the flow variability of the rivers, ranging from permanent to not permanent (seasonal or intermittent); and (iii) geomorphic zones or also slope categories (Figure 1.4). Four geomorphic zones are represented: mountain stream, upper foothill, lower foothill and lowland rivers (Figure 1.5).

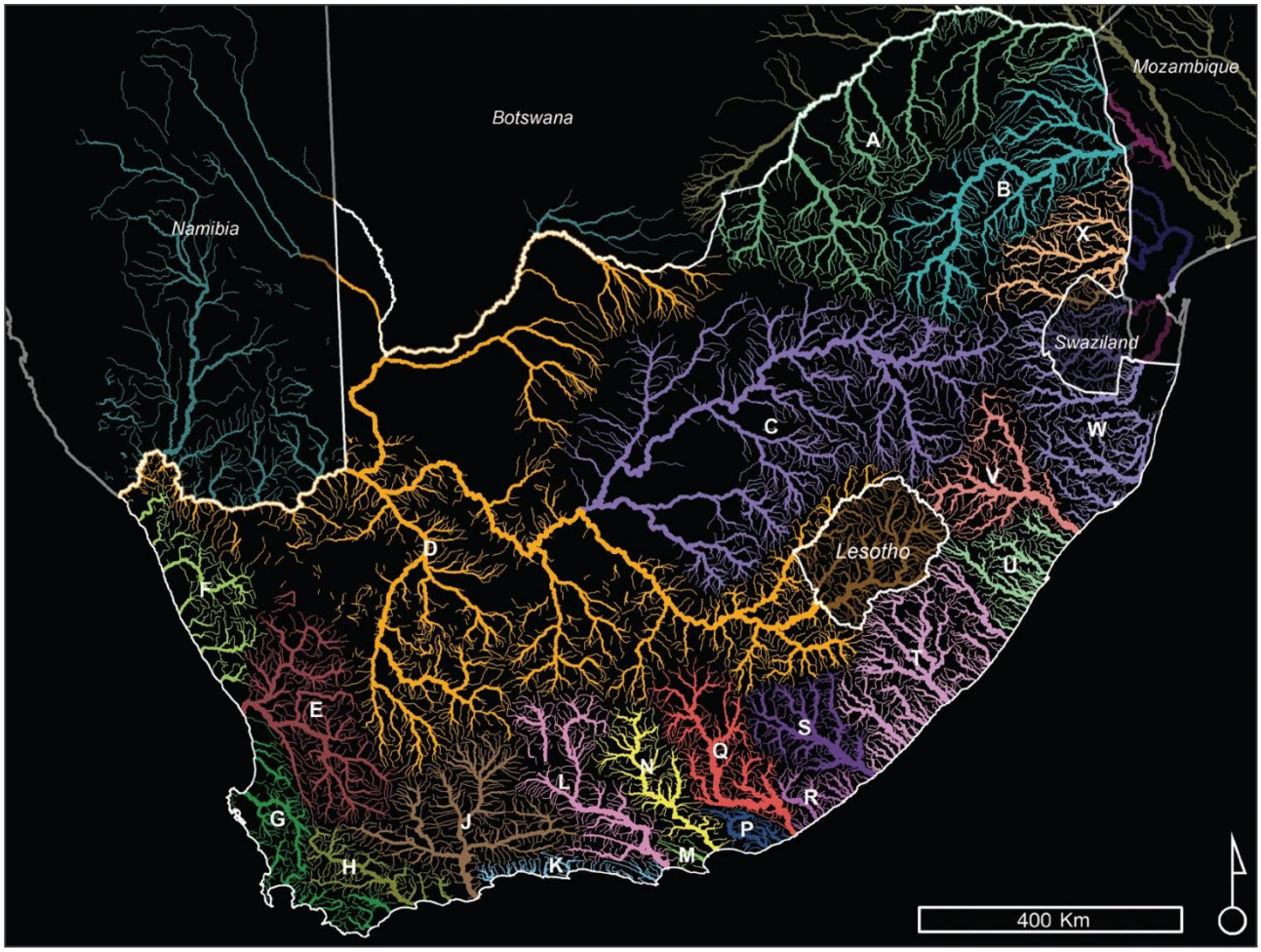


Figure 1.3. Primary catchments of South Africa showing the major river network. The largest catchment in the country is linked to the Orange River (D), which together with the Vaal River (C), Limpopo (A) and Olifants (B) dominate the interior. The coastal areas below the escarpment have smaller catchments. Map inspired by the work of Sukhmani Mantel, Rhodes University. (Map produced by L. Smith-Adao and A. Skowno).

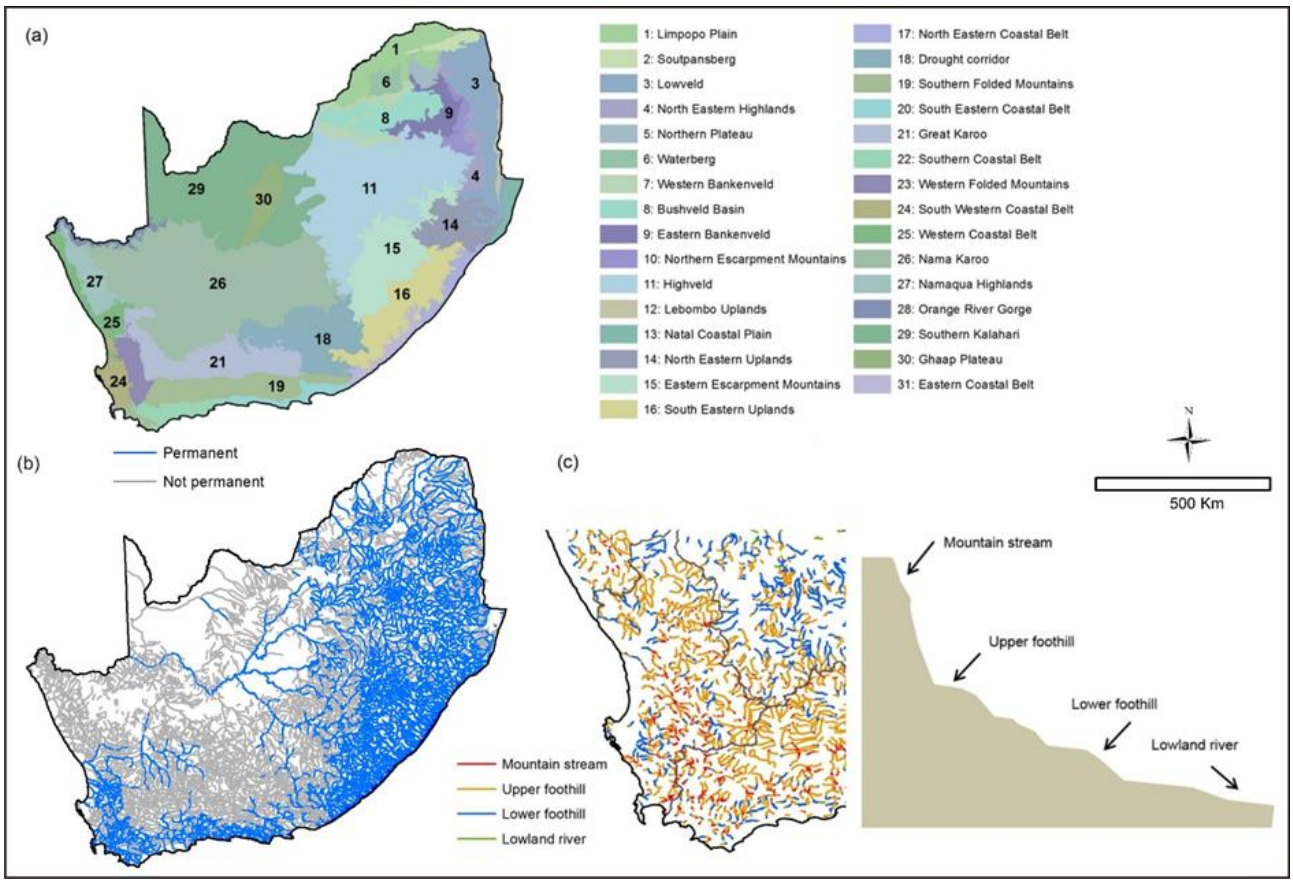


Figure 1.4. Typing of river ecosystems includes (a) Level 1 ecoregions (after Kleynhans *et al.* 2005), (b) flow variability (DLA:CDSM 2006), and (c) slope categories (Rowntree & Wadeson 1999; Rowntree *et al*. 2000; Moolman 2008).

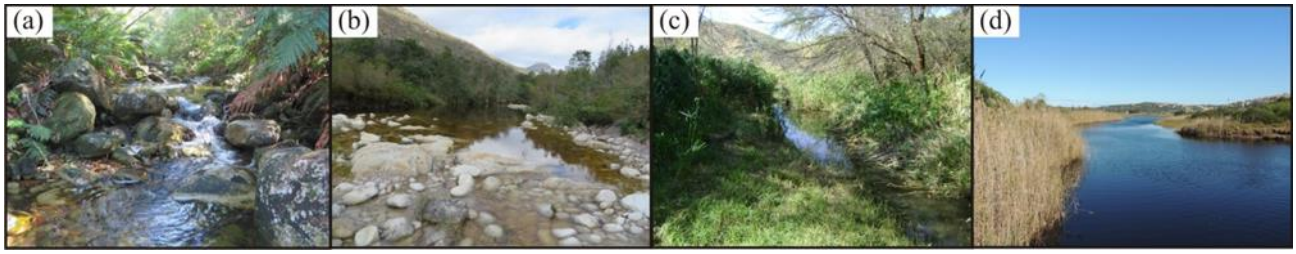


Figure 1.5. Examples of the geomorphic slope categories of river ecosystem types: (a) Mountain stream; (b) Upper foothill; (c) Lower foothill and (d) Lowland river. (Photographs by C. Petersen & L. Smith-Adao).

Waterfalls usually form part of river ecosystems and are key points in the landscape where the river drops over a vertical incline across a geological control. Examples include the Bridal Veil Falls, Augrabies Falls and the Tugela Falls (Figure 1.6). The Tugela Falls is the highest waterfall in Africa (948 m) and the world's second highest. It is a complex of five seasonal waterfalls located in the Drakensberg (Dragon's Mountains) within the Royal Natal National Park in the KwaZulu-Natal Province. These falls are located near the source of the Tugela River (Figure 1.6).

Figure 1.6. Examples of waterfalls from South Africa (Photographs by J. Jay & L. Smith-Adao).

Inland wetland ecosystem types are identified using broad ecological regions (Level 2 of the *Classification System for Wetlands and other Aquatic Ecosystems in South Africa*) and hydrogeomorphic (HGM) units (Level 4A of the *Classification System for Wetlands and other Aquatic Ecosystems in South Africa*). The broader regions are representative of the ecological biodiversity of inland wetlands, and the HGM units of the functional diversity. Both the ecological and functional diversity drives the species diversity associated with these systems. Examples with images of inland wetland ecosystem types are presented in Ollis *et al*. (2013). A number of ecosystem types have been identified to date as being unique and possible restricted in ranges. For example, the Palmiet is an endemic wetland plant with a restricted distribution, with many unchannelled valley-bottom wetlands in the Cape Floristic Region dominated by these plants (Rebelo *et al*. 2017; Box 1.1). While these Palmiet wetlands can easily be mapped, other unique freshwater features, are more difficult to map, as is the case with tufa waterfalls and seeps (Box 1.2), as well as rock sheet aquifers.

Box 1.1. Palmiet wetlands of South Africa.

Alanna Rebelo, Department of Conservation Ecology & Entomology, Stellenbosch University

Palmiet wetlands are predominantly unchannelled valley-bottom wetlands and named after the wetland plant that dominates them: *Prionium serratum* (Palmiet). Palmiet is a unique species, endemic to South Africa, one of only four in its family (Thurniaceae), and considered to be an ecosystem engineer — a species that exerts disproportionate influence on an ecosystem (Rebelo *et al*. 2017). Palmiet wetlands are found in the narrow valleys of the Cape Fold Mountains, with outliers in the Eastern Cape and southern KwaZulu-Natal provinces. Palmiet wetlands are peat-forming systems, and peat has been measured to range from 0.5–10 m deep. The peat of two independent Palmiet wetlands in the Cape Floristic Region has been dated to around 5050–5620 years old. Healthy Palmiet wetlands provide many important ecosystem services to society, including flood attenuation, erosion control, carbon sequestration, water purification, and water regulation. Despite this, Palmiet wetlands are highly threatened, thought to have decreased by on average 31% in area since the 1940/50s. Photo insert: Palmiet (*Prionium serratum*) taken within the Theewaterskloof Palmiet wetland.

Groundwater systems are less well understood and in South Africa they have mostly been studied from a water use point of view as opposed to an ecological and biodiversity point of view. Surface rivers and inland wetlands that are driven by groundwater supply are referred to as aquifer dependent ecosystems (ADE). It is also known that where the groundwater is exposed in the phreatic zone – for instance in caves as so-called 'underground lakes' unique invertebrates such as stygobitic amphipods may be observed (Durand 2008; Durand *et al*. 2012; Milne & Griffiths 2013).

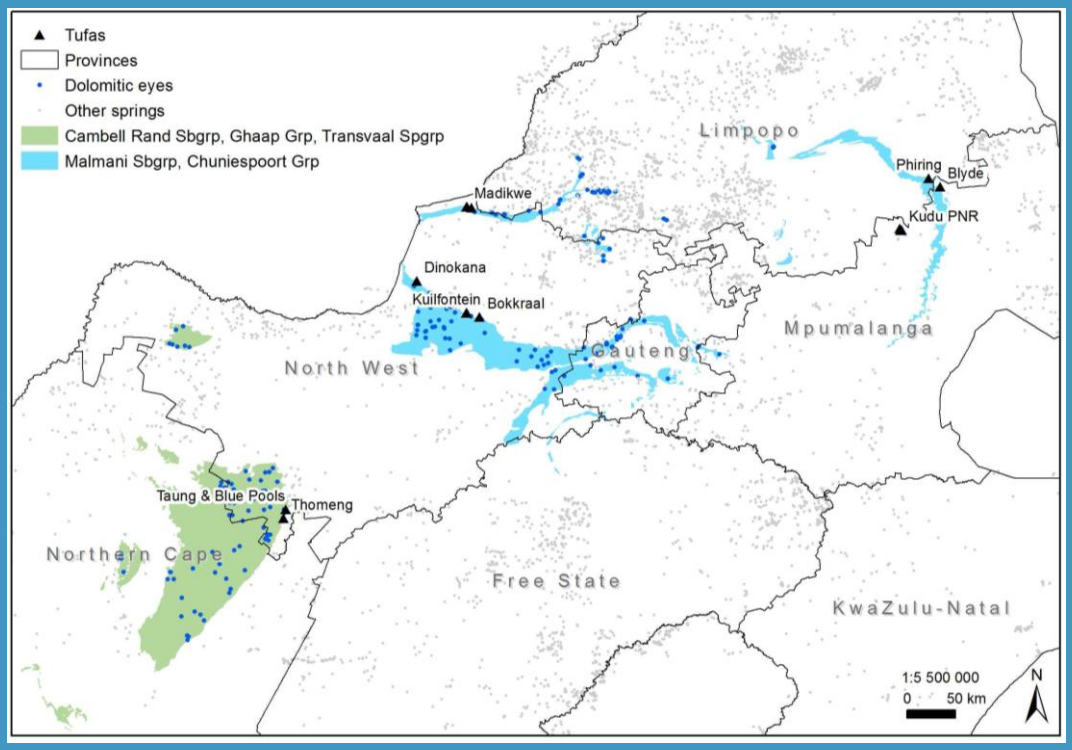
A wide range of species are associated with the rivers and inland wetlands in South Africa (Table 1.5). For a number of taxa, the total amount of species is unknown, providing ample research opportunities for the discovery and monitoring of new species to fully describe the biodiversity of South Africa's inland aquatic ecosystem.

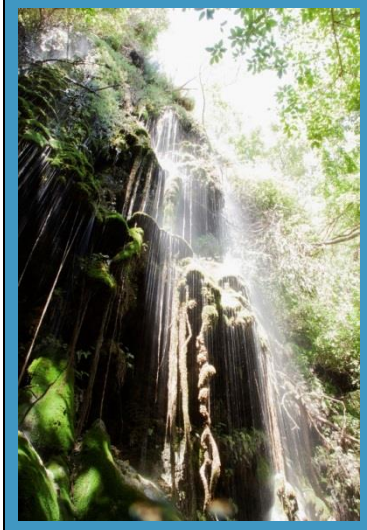
Owing to the complexity of species associated with inland wetlands, ecosystem types are often used as a surrogate for representing the habitats on which the associated species depend (Groves 2003; Ridrigues & Brooks 2007). The relationship between ecosystem types and species for inland aquatic ecosystems is, however, not well described in South Africa. Several challenges in the associated between ecosystem types and species hinders full understanding in South Africa (Nel *et al*. 2009). In addition, the representivity of the ecosystem type categories remains to be ascertained through strategic ground-truthing and investment in ongoing research to improve accuracy and reduce uncertainty in these national assessments. The NBA 2018 builds on the previous NSBA 2004 (Driver *et al*. 2005) and NBA 2011 (Nel & Driver 2012), as well as the National Freshwater Ecosystems Priority Areas (NFEPA) project. These projects had more information on ecosystem types than species. The NBA 2018 includes not only an improved mapping of the ecosystem types (Chapter 5) and assessment thereof (Chapter 6), but also the assessment of species related to inland aquatic ecosystems (Chapter 7).

Box 1.2. Why are Tufa waterfalls in South Africa so special?

Hermien Roux, Freshwater lecturer, University of Venda

Tufa is a porous, sedimentary rock which forms along the headwater rapids, cascades and waterfalls situated in dolomitic karst regions of South Africa. Tufa is the limestone precipitate that form as a result of the bubbling water gassing out carbon dioxide from the calcium carbonate (limestone, or CaCO3) rock, as well as biological processes by algae, bacteria and mosses. These range-restricted habitats host a unique set of riverine species which are poorly understood. Over abstraction and pollution of karst aquifers, as well as mining of limestone, threaten these vulnerable features in river ecosystems. Since these tufa features are quite small in extent—ranging from 200 m to 5 km—they are particularly vulnerable to pressures. Protection for these systems should include Integrated Water Resource Management actions and declaration of formal protected areas.





Tufa waterfall near Lydenburg (Photo by Anton Linström)

Bokkraal se loop (Photo by Norbert Hahn)

Seasonal tufa at Upper Marico tributary (Photo by Hermien Roux)

Table 1.5. Number of species associated with inland aquatic ecosystems for southern Africa given per class (Text in bold indicate taxa assessed in this report; see Chapter 7 for more information and Appendix B for full list and related references as well as the complete list of species on the SANBI NBA website).

Kingdom	Phylum or Class	Number of SA species associated with Freshwater
Bacteria		Unknown
Fungi		Unknown
Algae*		Unknown
Plants	Bryophytes (mosses),	50
	Marchantiophytes (liverworts)	40
	Angiosperms (flowering plants)	337**
Total plants		427
Animals (vertebrates)	**Mammals**	20
	Birds	141
	Reptiles	15
	Amphibians	102
	Fish	118
Animals (invertebrates)	Sponges	11
	Cnidarians (jellyfish, hydrozoans)	4***
	Platyhelminthes (flatworms)	13
	Nematodes (round worms)	286
	Annelids (segmented worms, including leeches)	67
	Arachnida (spiders, mites)	120
	Insects (including beetles, bugs, **dragonflies**, mayflies, stoneflies, flies)	3 058****
	Crustaceans (including crabs, shrimps, copepods, branchiopods, seed shrimps)	340
	Molluscs (snails, mussels)	33
	Rotifers (wheel animals)	34
	Tardigrades (water bears)	37
Total animals		4 003
Total		*4 430*

**Algae is a term referring to a wide range of photosynthetic organisms which do not form a recognised Kingdom or phylum*
*** Aquatic plants according to the definition of Cook (2004). A sample of 100 of the aquatic plant species in the Angiosperma were assessed*
**** These four species may be introduced but more research is required to verify this*
***** Only the dragonflies (162 species) were assessed*

1.3.1. Headline indicators of the inland aquatic ecosystems

The headlines indicators of the inland aquatic realm are done separately for ecosystems and species. For the inland aquatic ecosystems, the ETS and EPL were calculated for the river ecosystem types and inland wetland ecosystem types, while the changes to the free-flowing rivers and their ecological condition were assessed. The ecosystems assessment is dependent on (i) mapping and classifying ecosystem types across the country; and (ii) mapping ecosystem condition across the country (Nel & Driver 2012). The extent of river and inland wetland ecosystem types were mapped for South Africa and documented in the South African Inventory of Inland Aquatic Ecosystems (SAIIAE; Van Deventer *et al*. 2018). Subsequently the ecological condition categories were added (Figure 1.7): for the rivers based on the six ecological categories assigned by the DWS, whereas the ecological condition for wetlands is not being recorded through any official process, and therefore the six categories had to be modelled. The DWS A–F categorisation system for rivers (Kleynhans 2000; Table 1.6) is based on a process called EcoClassification to define the EcoStatus of a river. EcoClassification refers to the determination and categorisation of the Present Ecological State (PES; health or integrity) of various driver and biotic response attributes of rivers relative to the natural reference condition. These categories have been translated to five main ecological categories for rivers and three for wetlands (Table 1.6), with more information on the steps taken in Chapter 5.

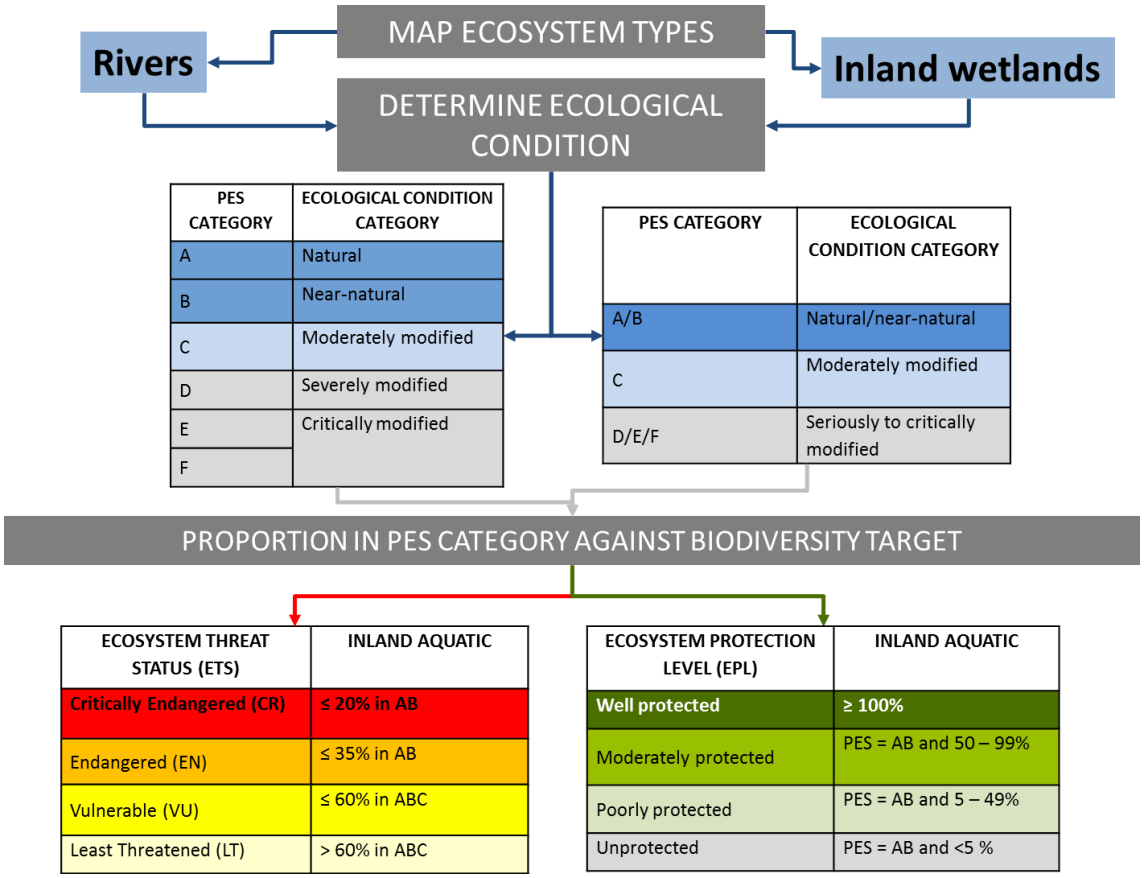


Figure 1.7. Steps in assessing the headline indicators of Ecosystem Threat Status (ETS) and Ecosystem Protection Level (EPL) categories for inland aquatic ecosystems in relation to a set of thresholds.

Table 1.6. Translation of the ecological categories used by the Department of Water and Sanitation (DWS) to describe the condition of aquatic ecosystems in South Africa, to the ecological condition categories used in this assessment (adopted from Kleynhans 2000). *For this assessment, rivers in an A and B ecological category were regarded as being in 'a natural or near-natural ecological condition', with the ability to contribute towards biodiversity targets. Rivers in a C ecological category were considered to be moderately-modified.*

DWS ecological category	Description of the DWS ecological category	NBA 2018 Ecological condition category
A	Unmodified, natural.	Natural
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.	Near-natural
C	Moderately-modified. A loss and change of natural habitat and biota have occurred but the basic ecosystem functions are still predominantly unchanged.	Moderately modified
D	Largely-modified. A large loss of natural habitat, biota and basic ecosystem functions have occurred.	Heavily modified
E	Seriously-modified. The loss of natural habitat, biota and basic ecosystem functions are extensive.	Severely modified
F	Critically or Extremely-modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.	Critically modified

For rivers and inland wetlands, the IUCN Criterion C (*a relative index of environmental degradation*) (Figure 1.8) was used to estimate the ecological condition (see Chapter 5). A high level of uncertainty prevails in determining the ecological condition inland wetlands though, since a limited amount of information was available for assessing the ecological condition. Methods used in the NBA 2011 and NBA 2018 also differed, making historic trend analysis, as required for Criterion C, impossible.

Ecological condition is estimated using a range of different approaches across the realms, but essentially depends on the ability to spatially represent the various pressures exerted on biodiversity. Condition in the terrestrial realm relies primarily on land cover change data; cumulative pressure mapping is used in the marine realm; and a multi criteria ecological condition framework is used in the estuarine and inland aquatic realms. The different systems were aligned as far as possible in the NBA to allow for cross realm comparisons and unified terminology (Table 1.7).

Table 1.7. The ecological condition categories used in the National Biodiversity Assessment (NBA), showing the original Department of Water and Sanitation (DWS) framework (Present Ecological State [PES] categories using the letters A to F) applied to rivers, inland wetlands and estuaries and the International Union for Conservation of Nature (IUCN) Red List of Ecosystems approach of percentage degradation of ecosystems or percentage disruption of biotic processes.

Department of Water and Sanitation (DWS) ecological condition	A	B	C	D	E	F
	Natural	Largely natural	Moderately modified	Largely modified	Highly degraded	Extremely degraded
IUCN RLE ecosystem degradation categories	Natural or near-natural (<50% degr.)		Moderately degraded (50–70% degr.)	Severely degraded (70–90% degr.)		Very severely degraded (>90% degr.)
NBA ecological condition categories	Natural	Near-natural	Moderately modified	Heavily modified	Severely modified	Critically modified
	Decreasing ecosystem function & increasing ecosystem restoration cost					

The latest IUCN guidelines make provision for unique ecosystems with restricted extent under Criterion B (*Restricted distribution*). During the update of the National Wetland Map version 5 (NWM5), eight unique freshwater lakes (limnetic wetlands) were identified from a combination of peer-reviewed and grey literature which qualify under the restricted range criterion (B) of Bland *et al*. (2017) (see also Van Deventer *et al*. 2018). In-field verification of the bathymetry of these systems should be done to confirm whether they are truly limnetic. For these eight freshwater lakes the reference committee of the Inland Aquatic Ecosystems have recommended the use of a 100% biodiversity target in the NBA 2018. For the freshwater lakes, Criterion B (*Restricted distribution*) and Criterion C (*Environmental degradation*) have been combined to determine their ETS.

Criterion	A	B	C	D	E
	Reduction in distribution	Restricted distribution	Environmental degradation	Disruption of biotic processes	Quantitative analysis
Data gathering and analysis	- Gather and process spatial data. - Classify, validate and create time-series of maps.		- Select abiotic variables and collapse thresholds. - Estimate relative severity and extent of degradation.	- Select biotic variables and collapse thresholds. - Estimate relative severity and extent of disruption.	- Select abiotic and biotic variables, and collapse thresholds. - Implement appropriate ecosystem model.
Application	Extent over time: A1. Past 50 years. A2a. Next 50 years. A2b. Any 50 year period. A3. Since 1750.	Current extent: B1. EOO B2. AOO B3. Number of locations.	Relative severity and extent: C1. Past 50 years. C2a. Next 50 years. C2b. Any 50 year period. C3. Since 1750.	Relative severity and extent: D1. Past 50 years. D2a. Next 50 years. D2b. Any 50 year period. D3. Since 1750.	Probability of collapse: CR. ≥ 50% within 50 years. EN. ≥ 20% within 50 years. VU. ≥ 10% within 100 years.

Figure 1.8. Criteria used by the IUCN for the assessment of threat status and red listing of ecosystems (Bland *et al*. 2017:26).

In determining the ETS for inland aquatic ecosystems, the proportion of each ecosystem type in a natural or near-natural condition is assessed against a series of thresholds (Figure 1.7; Table 1.8). Owing to insufficient data in determining ecologically differentiated targets, a wide range of stakeholders from related sectors

(water, environment and agriculture) agreed to a biodiversity target of 20% for inland aquatic ecosystems at a cross-sectoral policy process held in 2006 (Roux *et al*. 2006; Nel & Driver 2012). This target means that at least 20% of each ecosystem types should remain in a natural or near-natural ecological condition, defined as the A or B ecological category used by the DWS (Roux *et al*. 2006; Kleynhans & Louw 2007; Nel & Driver 2012). Similar to the NSBA 2004 (Driver *et al*. 2005) and NBA 2011 (Nel & Driver 2012), rivers and inland wetlands have been evaluated against the 20% biodiversity target and set of additional thresholds (Table 1.8). The NBA 2011 recommended the revision of the biodiversity target with each update (Nel & Driver 2012). No information was available in the NBA 2018 to justify a change in approach, and therefore the biodiversity targets have been kept, regardless of the fact that the NBA 2018 uses the most recent IUCN guidelines (Bland *et al.* 2017).

Table 1.8. Thresholds used in determining the Ecosystem Threat Status (ETS) and Ecosystem Protection Levels (EPL) of rivers and inland wetlands.

	CR	EN	VU
Thresholds applied to river ecosystems	Where the length of river ecosystem type in a natural or near-natural ecological condition (PES = A or B) is ≤ 20% of the total length for that ecosystem type.	Where the length of river ecosystem type in a natural or near-natural ecological condition (PES = A or B) is ≤ 35% of the total length for that ecosystem type.	Where the length of river ecosystem type in a natural or near-natural ecological condition (PES = A or B) is ≤ 60% of the total length for that ecosystem type.
Thresholds applied to inland wetland ecosystems	Where the extent (area) of each inland wetland modelled in a natural or near-natural ecological condition is ≤ 20% of the total extent for that ecosystem type.	Where the extent (area) of each inland wetland modelled in a natural or near-natural ecological condition is ≤ 35% of the total extent for that ecosystem type.	Where the extent (area) of each inland wetland modelled in a natural or near-natural ecological condition is ≤ 60% of the total extent for that ecosystem type.

The EPL is used as an indicator of how well- or under-protected South Africa's ecosystems or habitats are (Nel & Driver 2012). Categories range from Well Protected to Moderately, Poorly and Not Protected. Aquatic ecosystems are, however, dynamic systems which are dependent on the quality and quantity of the inflow, interflow and groundwater that supplies water to the ecosystems. The supply therefore be impacted from outside of the two-dimensional boundary of a protected area or reserve (Mancini *et al*. 2005). Excessive water abstraction in a catchment may, for example, negatively impact the ecological condition of an aquifer-dependent ecosystem, even though the ecosystem may be formally protected. The ecological condition of a river within a protected area may also be negatively impacted through water abstraction and water pollution or invasive fish species, resulting in Poorly Protected ecosystem and species within a protected area. Connectivity of river ecosystems outside protected areas to those inside protected areas, on the other hand, may 'be a powerful strategy to catalyse conservation activities in the surrounding catchments and provide stimulus for the implementation of effective integrated catchment management' (Nel & Driver 2012:vii). The protected area may also enable the improvement of the ecological condition of aquatic ecosystems downstream of the protected area, demonstrating the 'positive impact that good land management can have on river condition and the important role of land-based protected areas in protecting rivers' (Nel & Driver 2012:vii).

Combining the two headline indicators, ETS and EPL, can provide an idea of which ecosystem types are at risk of collapse (see Bland *et al*. 2017 for the definition and description of collapse). Ecosystem types which

are threatened and also classified as not protected or Poorly Protected, have been identified as **highly threatened and unprotected**. A cost-benefit analysis should be done on these systems to evaluate their potential for inclusion in biodiversity stewardship programmes, conservation plans, management plans and the PAES.

In addition to the two headline indicators, the river ecosystem types have also assessed with respect to the extent of fragmentation, giving rise to the 62 free-flowing rivers and 19 flagship rivers identified in the NFEPA and NBA 2011 projects. We also report the change in river condition as was assessed within the River Ecosystem Accounting Project (Nel & Driver 2015).

1.3.2. Headline indicators for freshwater species

Species threat status and protection levels have been calculated for taxa which are associated and dependent on river and/or wetland habitats. A trend assessment of how species status has changed since the last assessment was included for the first time. These indicators highlight the major pressures facing species in these aquatic environments and showcase the importance of prioritising conservation efforts in the inland aquatic realm to conserves species as well as their environment. Chapter 7 provides a full overview of the assessment of freshwater taxa done for the NBA 2018.

In additional to the indicators used in this NBA 2018, several themes related to the inland aquatic ecosystems have been addressed across several chapters of the report, as laid out in the next subsection.

1.4. Structure of this document

While the NBA 2018 Synthesis Report is intended for a wide audience, this technical report is intended for a more specialist audience interested in the scientific analyses underpinning the results of the NBA 2018. It is structured as follows:

Chapter 2 – details the benefits and ecosystem services of inland aquatic ecosystems;

Chapter 3 – provides an overview of observed and predicted changes associated with inland aquatic ecosystems in the face of climatic changes;

Chapter 4 – details the different types of pressures on inland aquatic ecosystems, uncertainties of the geographic extent and magnitude of these pressures. We further indicate whether indices are available to monitor both the pressure and impact on inland aquatic ecosystems;

Chapter 5 – gives details on the spatial data used to depict and assess the river and inland wetland ecosystem types and their associated ecological condition used in the ETS calculation. Information on the protected areas layer used for the EPL is also described;

Chapter 6 – documents the results of the ETS and EPL headline indicators as well as the results of the free-flowing river index and indices related to the ecosystem which are highly threatened and Poorly Protected;

Chapter 7 – details the results of the indigenous freshwater species assessment indicators;

Chapter 8 – provides information on the genetic assessment of a small number of inland aquatic species. This is really an emerging theme in South Africa, with benefits in understanding;

Chapter 9 – considers current and future responses to identified pressures on inland aquatic ecosystem types and species; and

Chapter 10 – concludes the report with key findings, messages and recommendations.

Box 1.3. Artesian springs of South Africa.

Dr Piet-Louis Grundling, Department of Environment, Forestry and Fisheries (DEFF)

Globally, mires that are fed by warm water are rare (Grootjans *et al*. 2010). However, according to Scott and Vogel (1983) 50 thermal springs occur in South Africa of which some with organic deposits such as Wonderkrater and Aliwal North. The Wonderkrater thermal spring has a mound of ambient temperature that is 3.5 m high above surface, with 8 m deep peat and is 35 000 years old (McCarthy *et al*. 2010).

Thermal springs form when heated groundwater in an aquifer encounters a fractured zone which allows it to rise to the surface (Olivier *et al*. 2008) forming artesian springs due to a positive pressure head. Groundwater becomes heated when it percolates downwards into permeable rocks or joints and becomes heated at an increased temperature rate of 2–3°C per 100 m due to the geothermal gradient (Press & Siever 1986). Convection currents are created in the groundwater as the heated water expands and rises.

Artesian springs are mostly impacted by hydrological changes due to extracting water from these springs for domestic or irrigation use. Acid mine drainage (AMD) often impact water quality of artesian springs as is evident in the figure below where iron deposition on the peat dome is evident. Thermal springs are mostly impacted by dredging of peat dome to form hot water spas such as Goudini, Bela-Bela and Tshipise.

This artesian peat dome close to a coal mine in Carolina is clad in an AMD induced iron layer

The warm artesian mires of Kruger National Park

Two warm artesian (spring) mire complexes occur in the northern region of Kruger National Park that are fed by thermal water with a temperature of 37–42 °C. These mires at Malahlapanga and Mfayeni are small ranging from 1 to 20 m in diameter. The peat depth ranges from 1 to 2.5 m, of which 1–1.5 m are elevated above the surface. Some of these domes have dried out severely due to erosion and trampling by large animals (Grootjans *et al*. 2010)

Malahlapanga

Malahlapanga wetland is about 9 ha in extent and consist of a seepage area on the banks of the tributary of the Mphongolo River containing, several thermal springs and spring mires. Four small (ca. 200–500 m^2) peat domes rise 1–2 m above their surroundings. Smaller seepage patches (1–10 m^2) were present between the larger mires. These were sparsely vegetated and damaged by animals such as elephant and buffalo that had trampled the peat in order to get to the water; also possibly going after the mineral salts contained in the peat. This has resulted in erosion within the wetland.

The upper surface of the two largest domes are dried out and lacked wetland vegetation, which was present only at the bases of these domes. Markers monitoring the height of these domes clearly indicate a lowering of the domes as water drain from the peat and peat pores collapse. Two smaller and wetter domes occurring between the two dried-out domes had many wetland plant species across their entire surfaces. However, the rims of the four domes were breached by trampling and subsequent erosion; therefore, resulting in the draining of these small mires.

Erosion of the peat domes as a result of channel incision and trampling threatens the integrity of the wetland and its ability to maintain biodiversity and various ecosystem services such as water and carbon storage, baseflow maintenance and others. The existing overgrazing and pressure of large mammals on the system, will in the long term, result in the deterioration of the hydrological functioning of the system. In order to achieve the broader rehabilitation objectives defined for the Malahlapanga wetland, several interventions are proposed such as closure of access roads, stormwater control from roads, bush packing and revegetation. However, it is crucial that the rims of the basins are restored to a level where the basins are inundated, peat formation processes restored, trampling limited and wet period flow facilitated.

The Malahlapanga hot spring mire complex

The Southern peat copula before (top and middle) and after rehabilitation (bottom). Note the larger inundated area in the photo below.

Photo credits: Piet-Louis Grundling, Althea Grundling, and family Tererai

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2. THE ECOSYSTEM SERVICES PROVIDED BY THE INLAND AQUATIC REALM IN SOUTH AFRICA

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2.1 Introduction

Ecosystems which are not degraded provide a wide range of services to people, including provisioning services such as livestock grazing, regulating services, flood attenuation, and cultural services through the environments they provide for relaxation and spiritual upliftment (Millennium Ecosystem Assessment (MEA) 2003, 2005; Turpie *et al*. 2010c). Wetlands in a natural or near-natural ecological condition are well known globally for their particularly high level of ecosystem services supply (Russi 2013), and this is likely to apply to South Africa, where the specific contribution of wetlands is fairly well recognized through programmes such as Working for Wetlands. Rivers are also well recognized for the many services which they provide to society (Russi 2013). Despite this high level of ecosystem supply, wetlands and rivers remain under high pressure and continue to be degraded, resulting in a loss of ecosystem services which they can provide (Turpie *et al*. 2010c).

South Africa is a very diverse country in terms of climate, physiography and biota, which is reflected in a considerable diversity of wetland and river types (Ollis *et al*. 2013). This diversity, in turn, is reflected in a diversity of ecosystem processes and structure, which ultimately determine the supply of ecosystem services. For example, while all wetlands are characterized by prolonged flooding and / or saturation and the resulting anaerobic conditions, the frequency and duration of these conditions varies considerably. In high rainfall areas wetlands are generally characterized by extensive permanently saturated areas, whereas in low rainfall areas saturation and / or flooding is usually temporary, and several years may pass between saturation and /or flooding events (Breen 1991).

South Africa is also very diverse and dynamic in terms of the socio-economic and land use factors which influence both the supply and, in particular, the demand for the specific ecosystem services. Although representing a declining proportion of South Africa's population, communal rural areas under the governance and management of Traditional Authorities are characterized by households which are still strongly dependent on the provisioning services supplied by ecosystems, implying that the the demand for provisioning services is high. In contrast, there is an ongoing increase in the extent of urban and industrial areas, which are characterized by low direct dependence on ecosystems but the demand for regulating services provided by natural and near-natural ecosystems is very high.

In South Africa there has been an interest in assessing the ecosystem services supplied by wetlands. The WET-EcoServices method (e.g. Kotze *et al*. 2008) was developed and is currently being refined and updated through a Water Research Commission Project (K5/2737). In addition, several individual case assessments (e.g. Turpie *et al*. 2010a; Kleynhans *et al*. 2010; Rebelo 2017) have been undertaken. However, attempts to provide a national overview of wetland ecosystem services have been somewhat lacking.

Thus, the chapter seeks to address four key questions.

- What services do South African wetlands and rivers provide and what evidence exists for this supply?
- How does the supply of these services vary across different ecosystem types and climatic settings?
- How is the supply of services influenced by the ecological condition (integrity) of the ecosystem?
- How does the supply and demand for these respective services vary according to the broad land use contexts encountered in South Africa?

Before addressing these questions, the concept of 'ecosystem services' will be defined. The Millennium Ecosystem Assessment (MEA 2003) defines ecosystem services as the benefits people obtain from ecosystems. Closely aligned with this definition, The Economics of Ecosystems and Biodiversity (TEEB), an international initiative to draw attention to the benefits of biodiversity, defines ecosystem services as the benefits that people, society and the economy receive from nature (TEEB 2010; Russi *et al*. 2013). Fisher *et al.* (2009:645) define ecosystem services somewhat more specifically as 'the aspects of ecosystems utilized (actively or passively) to produce human well-being. The key points are that (1) the services must be ecological phenomena and (2) that they do not have to be directly utilized. Defined this way, ecosystem services include ecosystem organization or structure as well as process and/or functions if they are consumed or utilized by humanity either directly or indirectly.' For the purposes of this chapter, the definition of Fisher *et al*. (2009) will be used.

Allied with the concept of ecosystem services is the concept of ecological infrastructure, which refers to naturally functioning ecosystems that deliver such services to people (SANBI 2013; 2017). Ecological infrastructure is conceptualized as the nature-based equivalent of built infrastructure, and underpins socio-economic development (SANBI 2013). Investment in ecological infrastructure can lengthen the life of existing built infrastructure and reduce the need for additional built infrastructure, thereby saving costs (SANBI 2013). For example, investment in wetland rehabilitation and improved management of grasslands in a dam's catchment is anticipated to increase a dam's lifespan by reducing sediment supplied from the catchment (SANBI 2013).

This chapter deals specifically with the provision of ecosystem services by wetland and river ecosystems. The benefits from these ecosystems may accrue across a multitude of scales, including locations which are spatially far removed from the ecosystem generating the service, and freshwater flows act as a key connector for (often remote) upstream source areas with multiple downstream ecosystems and human beneficiaries (De Vos *et al*. 2017).

It is acknowledged that while Diaz *et al*. (2018) have recommended a shift in terminology from 'services' to 'contributions', this shift has yet to be widely taken up in South Africa and the chapter will remain with using the terminology 'services'. It is also important to note upfront that while this chapter encompasses wetlands, rivers and riparian areas, its focus and the examples from which it draws are primarily wetlands.

2.2 What services do South African inland aquatic ecosystems provide and what evidence exists of their supply?

2.2.1 An overview of the services supplied by South African inland aquatic ecosystems

A wide range of ecosystem services are potentially supplied by South African inland aquatic ecosystems. McInnes & Everard (2017) list 36 ecosystem services potentially supplied by wetlands globally (Figure 2.1) and most of these services are likely to apply to South African wetlands to some degree. Nonetheless, it was considered valuable to undergo a screening process to identify the most important and widely supplied for the South African context (Table 2.1).

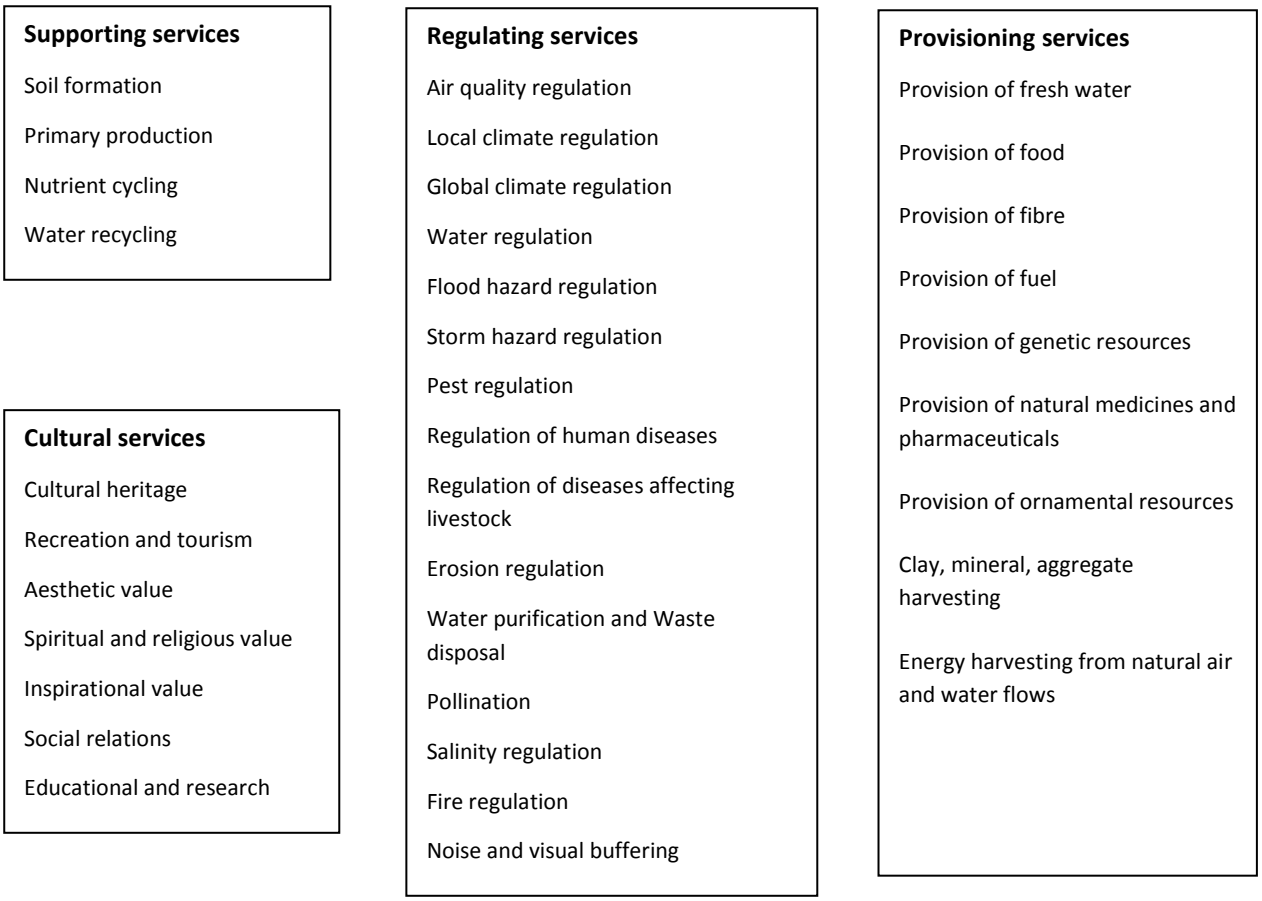


Figure 2.1. Ecosystem services included in the Rapid Assessment of Wetland Ecosystem Services (RAWES) method of McInnes & Everard (2017).

Table 2.1. Key ecosystem services supplied by South African wetlands and rivers (adapted from Kotze *et al.* 2008)[1].

Regulating services	Flood attenuation
	Sediment trapping
	Erosion control
	Streamflow regulation
	Water quality regulation
	Carbon storage
Provisioning services	Provision of water
	Grazing for livestock and game
	Plants for crafts and construction
	Indigenous/wild foods and medicines
	Cultivated foods
Cultural services	Cultural and spiritual experience
	Tourism and recreation
	Education and research

[1]*Supporting services (e.g. nutrient cycling) and maintenance of biodiversity itself (including refugia during droughts and contribution to connectivity on the overall landscape) are omitted from the table, but are acknowledged to underpin most of the other services.*

It is important to emphasize that the above list is by no means exhaustive. Some wetlands may be very important in supplying other services, including sodium chloride salt for human consumption, clay for making ceramic items such as pots and sculptures, and flowers such as Arum Lilies (*Zatedeschia aethiopica*) which are harvested as cut flowers.

2.3 Existing evidence from South Africa of the supply of the respective services

2.3.1 Flood attenuation

The contribution that wetlands make to flood attenuation has been well demonstrated globally and in South Africa. For the Kromme River wetland, Rebelo *et al*. (2015) used historical data going back to the 1950s of extent of intact valley bottom wetland together with rainfall and flow record data. This showed with declining extent of wetland down to approximately 1/3 of the 1950s extent there was a corresponding declining contribution to flood attenuation by approximately 1/3 of its original extent. For the Nylsvley wetland Kleynhans *et al*. (2010) used hydraulic modelling and mapping of inundation areas. This showed significant attenuation of floods flowing through the wetland, as expected for a large floodplain wetland. Generally, wetlands located low in the catchment, particularly floodplain wetlands, have a greater potential to reduce floods than headwater wetlands (Acreman & Holden 2013).

2.3.2 Sediment trapping

The contribution of intact wetlands and riparian areas to trapping sediment is well known. For example, Turpie *et al*. (2014) calculated that maintenance of riparian buffers contributed to up to 36% reduction in sediment loads into Durban Harbour.

Species such as *Phragmites mauritianus* are well adapted to promoting sediment retention, through their dense tall stems which increase hydraulic roughness and promote deposition of suspended sediment and their deep and complex network of rhizomes, including vertical rhizomes can quickly grow up into newly deposited overlying sediment (Kotschy & Rogers, 2008).

Over many millennia of sediment accumulation, a considerable depth of valley fill may be reached, with one of the deepest recorded being that of ~35 m for the Nyl floodplain wetland (McCarthy *et al*. 2011). In other major wetlands it may be much shallower, e.g. <4 m in the Klip River floodplain, Memel (Tooth & McCarthy 2007). The capacity of wetlands to trap sediment depends strongly on wetland type and climatic setting. This is demonstrated by the valley bottom wetlands examined by Grenfell *et al*. (2014) which are under comparable geology and catchment position but under contrasting climate. In the Seekoei River floodplain in the semi-arid Karoo, flows are likely to be episodic and characterized by floodouts and avulsing distributaries, and net retention of sediment is greater than in the sub-humid Nsonge River Floodplain in the KwaZulu-Natal Province, where flows are much more sustained and in a continuous meandering channel, and sediment depth is limited.

In addition to sediment trapping, i.e. clastic sedimentation, wetlands may also accumulate sediment through chemical sedimentation, which occurs primarily in semi-arid landscapes and is driven by the high levels of evapotranspiration in these wetlands. The selective removal of water by transpiring wetland vegetation causes solutes to concentrate in the soil water, precipitating as $CaCO_3$, amorphous silica, and Fe-smectite (Humphries *et al*. 2011).

2.3.3 Erosion control

The contribution of wetlands to controlling erosion is widely recognized. A key factor contributing to this service is the dense natural vegetation typically associated with wetlands (see Sediment trapping). This contribution is most evident where this vegetation is removed, typically for cultivation purposes, and severe erosion results thereafter. A striking example of this is documented for the clearing of valley bottom wetlands dominated by Palmiet (*Prionum serratum*) (Rebelo *et al*. 2015). The draining effect of severe erosion diminishes the storage of water and nutrients in the wetland, which in turn may greatly impact on other ecosystem services, including regulating services such as water purification and provisioning services such as grazing which are sustained by the stored water and nutrients. Ultimately, the long-term agricultural production potential is diminished.

It is important, however, to recognize that some wetlands naturally pass through cycles of erosion or incision and deposition, for which erosion of the wetland would therefore sometimes be part of the natural geomorphological dynamics of the wetland (Grenfell *et al*. 2009).

2.3.4 Streamflow regulation

Although Bullock & Acreman (2003) present evidence to show that wetlands generally do not sustain streamflows in the dry season, some wetlands have been shown to provide this service. For example, Smakhtin & Batchelor (2005) showed that the Rustenburg Nature Reserve (now called the Kgaswane Nature Reserve, North West Province) wetland performs a flow regulating function by reducing daily flows in the high-flow end (at exceedance levels smaller than 10–20%) and displaying increased flows through the rest of the flow range. In contrast, Kleynhans *et al*. (2010) in quantifying the flow regulation services provided by Nylsvley wetland, showed that although contributing significantly to flood attenuation, the high evapotranspiration losses from for this large wetland low in the catchment reduced low-flows at the wetland outflow point.

Two key factors in particular influence whether or not a wetland potentially enhances streamflows. The first factor is the hydrogeological setting of a wetland and the influence that this has on links between groundwater and the wetland. Wetlands which, by virtue of their hydrogeological setting, have strong links with groundwater are generally best 'positioned' to contribute to sustaining streamflows. For these wetlands it is important to emphasize that it is the hydrogeological and/or hydropedological processes in the wetland's catchment rather than ecological processes in the wetland which are primarily responsible for the wetland's contribution. Secondly, the evapotranspiration from a wetland constitutes a potentially major limitation over the contribution a wetland might make to sustaining streamflows. However, in wetlands which have both a relatively low leaf area, e.g. short sedge or grass wet meadow and which become dormant in the dry season (Dye & Jarmain 2004) this limitation is much less than wetlands with a relatively high leaf area remaining active over the dry season, as is typical of indigenous swamp forest (Clulow *et al*. 2012) and wetlands dominated by invasive alien trees such as black wattle (Dye & Jarmain 2004).

2.3.5 Water quality regulation

The contribution of wetlands to regulating water quality at a catchment scale has been demonstrated for catchments assessed in the Western Cape by Turpie *et al*. (2010a) who analysed the measured loads of nitrogen, dissolved phosphorous and suspended solids at the outflow points of 100 sub-catchments in respect of spatial data on land cover and wetland area. Wetlands were found to play a significant role in the reduction of nitrates, nitrites and ammonium, but not dissolved phosphorous or suspended solids. Estimated removal rates ranged from 307 to 9 505 kg N/ha/yr, with an average of 1 594 ± 1 375 kg N/ha/yr. Based on the real costs of water purification, the average value of the water treatment service provided by wetlands in the study area was about R14 350 ± 12 385/ha/yr Turpie *et al*. (2010a).

The considerable contribution of wetlands to water quality regulation has been well demonstrated for a few individual wetlands, notably the Klip River wetland in Gauteng (McCarthy & Venter 2006) and the Zaalklapspruit wetland in Mpumalanga province (Maila *et al*. 2017). Based on the total loads in the Klip River wetland measured by McCarthy & Venter (2006) of several contaminants (including Cadmium, Mercury, Lead, Uranium and others) which had accumulated over many decades, Mulders *et al*. (2017) estimated that in the absence of this assimilative store for the contaminants the costs of remediating the downstream would be from R143 billion to R179 billion. Based on water quality monitoring data of inflows and outflows of the Zaalklapspruit wetland, Maila *et al*. (2017) estimated that the water quality regulation value of the Zaalklapspruit wetland, which is located downstream of acid mine drainage, ranged between R20 000–R85 000/ha/yr or R2.6-R11.4 million per year.

Box 2.1. The self-purifying capacity of streams (Compiled by Bettina Genthe, CSIR)

Water quality regulation is not confined to wetlands, and provided that a stream is not overwhelmed by excessive nutrients, streams possess a self-purifying capacity to reduce nutrient loads within a relatively short distance, thereby aiding in nutrient assimilation (Elósegui *et al*. 1995). This self-purifying capacity may vary greatly from one stream to the next and is influenced by several physical, chemical and biological processes within streams which influence the transport, transformation and retention of nutrients during downstream transport (Oberholster *et al*. 2013) and generally, first to third order streams are most efficient at nutrient retention (Peterson *et al*. 2001).

Oberholster *et al*. (2013) demonstrate in the highly polluted Olifants River catchment how an understanding of some of the above factors influencing the self-purifying capacity of a stream can contribute to identifying the most sensitive rivers, and thereby assist in managing eutrophication in the catchment.

2.3.6 Carbon storage

The contribution of wetlands to carbon sequestration is highlighted by the fact that although wetlands occupy only 4–5% of the land area of the globe, they hold approximately 30% of the carbon in the terrestrial biosphere (Roulet 2000; Joosten & Clark 2002). Peatlands have particularly high levels of organic matter, and therefore they are particularly important for the storage of carbon. The global extent of peatlands is estimated at 4 000 000 km^2. Owing in particular to the dry climate over much of South Africa, peatlands are very limited in extent, and the total extent of peatlands in South Africa is estimated at 400 km^2 (P-L Grundling, *pers. comm*., 2018) therefore representing a tiny fraction of the global extent.

Peat depth has been determined for several of South Africa's peatlands, and for some of these, age has also been measured, from which carbon sequestration rates can be inferred. Peatland formation developed with climatic changes and three peaks in the frequency of peatland commencement are evident: one after the Last Glacial Maximum (LGM) and two during the Mid- to Late Holocene (Elshehawi *et al*. 2019). Two distinct peat age trends are present in the peatlands of South Africa. Most of the peatlands are younger than 7 000 years and are distributed across the coast, whilst the peatland on the Highveld are in general 13 000 years and younger with an average accumulation rate of 0.5 mm/year (Grundling & Grobler 2005). The Maputaland peatlands are in general younger than 700 years with an average accumulation rate of 1 mm/year (Grundling *et al*. 2000). Rebelo (2017) determined that two Palmiet wetlands in the coastal regions of the southern Cape, the Goukou with peat at 4 m deep and an age of 5050±30 years (Job 2014) and the Kromme, with peat at 4.05 m depth and 5620±70 years (Nsor 2007) have peat accumulation rates of between 0.79 and 0.72 mm/a respectively. An anomaly in the South African peatlands exists in two of the Maputaland peatlands (Mfabeni and Mhlanga) which are of Pleistocene age. Mfabeni is most probably one of the oldest active peat accumulating wetlands in the world. It was dated at 43 000 + 4 900–3 000 BP at a peat depth of 9.9 m. During the period 43 000–11 000 YBP (the late Pleistocene), peat accumulated at 0.23 mm/year, while during the period 11 000 YBP to present (Holocene), the peat accumulated at 0.43 mm/year (5.290±70 YBP at a depth of 2.5 m) (Grundling *et al.* 2000).

Peatlands do not only accumulate thick layers of organic material over time such as pollen acting as archives of the past they also act as carbon and water stores with positive feedback loops in regional groundwater storage. Furthermore, the biota and habitat diversity culminate in a rich and unique biodiversity value in the drier South African region with important benefits such as flood mitigation and baseflow maintenance. Erosion, draining and excessive water abstraction result in losses, risk of burn and increase of GHGs. Management costs, especially restoration costs escalate as these systems slips into worsening levels of degradation. Prevention is therefore better and more cost effective than cure and

restoration should be prioritised in systems where degradation is in an early stage. Contribution of inland wetlands, although small, remains significant for South Africa in terms of ecosystem services.

2.3.7 Livestock grazing

The high value of wetlands for livestock grazing has been demonstrate in a diversity of contexts, including private commercial farms (Oellerman 1994; Palmer *et al*. 2002), communal small-scale rural areas (Kotze 1999; Pollard *et al*. 2009; Kotze *et al*. 2010) as well as in communally used urban areas (Lannas & Turpie 2009). Wetlands are key grazing resources, particularly in the context of a semi-arid climate (Fynn *et al*. 2015). Wetlands are especially valuable in dry years and at the end of the dry season in most years, owing to their residual moisture. Thus, wetlands are often critical forage sources over the dry season for both wild and domestic grazers (Fynn *et al*. 2015).

2.3.8 Cultivation

Although excessive wetness and the risk of flooding may make wetlands difficult and hazardous areas to cultivate, the residual moisture and generally high fertility of many wetland areas makes them attractive areas for cultivation. Extensive areas of wetland have historically been converted to commercial cultivated lands, particularly in the Western Cape and KwaZulu-Natal provinces. While some of these areas have subsequently been abandoned, most continue to be actively cultivated today. In addition, small-scale or subsistence cultivation is widespread in wetlands in the eastern parts of South Africa.

One of the principle crops grown under wetland subsistence cultivation is taro (*Colocasia esculenta*), also known as madumbes, which offers an important source of dietary fibre, calcium (Ca), magnesium (Mg) and potassium (K), and additionally its moderately low glycemic index (GI) may be important for conditions such as diabetes. Taro's reported antioxidant and anti-inflammatory properties will probably provide some measure of protection against non-infectious diseases (Pollard *et al*. 2009).

It is important, however, to emphasize that the considerable alteration of wetland structure and functioning is typically associated with cultivation, and this, in turn, is generally at considerable expense to the multiple other services supplied by a wetland.

2.3.9 Plants for crafts and construction

One of the key resources harvested from wetlands (and the riparian zone of rivers) are plants used for craft production. In South Africa, and KwaZulu–Natal in particular, there is an extremely rich tradition of utilization of wetland plants for weaving of crafts (Cunningham 1987; Kepe 2003; Traynor 2008; Kotze & Traynor 2011). Traditional knowledge, skills and practices involving the giving of sleeping mats at weddings for example are sustained through craft production (Hennessy & Koopman 2000) and crafting provides a means of keeping culture alive and vibrant (Marcus 2000). The contribution of crafting as a livelihood strategy compares favorably with income that most rural women can generate in formal employment in the existing labor market (Marcus 2000). In Kwa-Zulu–Natal, approximately 60 000 harvesters and weavers of indigenous fiber derive their livelihoods from trading in fiber products (Mander & McKenzie 2005) and a major supply of raw materials for woven–craft production is from wetland plants (Kotze & Traynor 2011). Wetland plants harvested for crafts are generally very resilient to harvesting (Traynor *et al*. 2010). The

harvesting of wetland plants generally has minimal impact on wetland structure and functioning and the multiple other services provided by a wetland.

Harvesting of *Phragmites australis* and *P. mauritianus* reeds is undertaken widely across South Africa, mainly for reed screens and thatching. Hardbiesie (*Scirpus inanus*) is traditionally used by the Nama people in the western parts of South Africa for weaving large mats which are used to cover portable, beehive-shaped mat-houses (matjieshuise) (Van Wyk & Gericke 2000).

2.3.10 Indigenous and /or wild foods

The most important indigenous and / or wild foods supplied by South African wetlands and rivers are fish and the floating aquatic plant waterblommetjies (*Aponogeton distachyos*). Fruits such as those of the swamp forest tree (*Voacanga thourasii*) and waterberry (*Syzigium cordatum*), herbaceous plants used as leafy vegetables, the underground storage organs of water lilies (*Nymphaea* sp.), the bullfrog (*Pyxicephalus edulis*), mammals, birds and insects, notably grasshoppers, are also used.

Fish are obtained widely across South Africa, particularly from river systems, especially in high order perennial rivers and dams (Box 7.1). South African wetlands generally do not support abundant fish stocks, but there are exceptions, of note the Pongolo floodplain wetland. Heeg & Breen (1982) estimated that local people catch about 400 tonnes of fish annually. Although this amount may have declined owing to factors such as reduced flooding, agricultural encroachment and overfishing. Fish continue to be a key source of protein for communities bordering the floodplain (Coetzee *et al*. 2015) and fishing in the floodplain constitutes an important subsistence and commercial activity for local people (DWS 2014).

Waterblommetjies occur extensively in the wetlands and slow flowing streams of the Western Cape, and their flowers are widely harvested as a vegetable used in bredies and stews (Van Wyk & Gericke 2000). Once a favoured food amongst Khoi and San, they soon became a popular traditional Cape food and today are even available commercially as a canned product (Van Wyk & Gericke 2000).

2.3.11 Tourism and recreation

The key role played by wetlands and rivers for tourism and recreation is widely recognized. One of the major attractions of wetlands is for bird watching. The Nylsvley wetland and surrounding habitats attract 10 000 visitors annually, mainly for bird watching. Based on the average on-site expenditure and off-site travel expenditure attributed to visiting the site, the tourism value of the Nylsvley wetland was estimated to be at least R9–10 million per annum (Scovronick & Turpie 2010).

Rivers have a particularly high recreational value for a variety of activities, including fishing and canoeing. Recreational fishing is a massive industry in South Africa, with an estimated 1.5 million freshwater bait anglers, with the sector contributing about R1.5 billion to the economy (Leiboldt & Van Zyl 2018) through the sales of fishing and associated equipment (boats) and through transport and accommodation costs (fishing trips). Much activity is focused on invasive fish species such as carp, trout and bass, but recreational fishing on indigenous fishes is also substantial, with Brand *et al.* (2009) valuing yellowfish (*Labeobarbus*) angling on the Vaal River in the region of R133 million per season. Subsistence fishing is also a major activity, generating food and income for impoverished rural communities across South Africa. Most of the recreational and subsistence fishing is focused on public dams, with subsistence fishing activity recorded on 77% of dams, recreational fishing on 69% and artisanal and / or small-scale commercial fishing on 40%

(Britz *et al*. 2015). Some of South Africa's rivers attract many canoeists. For example, the Dusi Canoe Marathon is a canoe race between Pietermaritzburg and Durban on the Msunduzi and Mgeni Rivers, with annual participation numbers of approximately 2 000 paddlers. Rivers also add greatly to the scenic value of a landscape, and river features, notably waterfalls are often key tourism attractions in themselves. One of these is the Augrabies Falls on the Orange River.

2.3.12 Cultural and spiritual experience

Rivers and wetlands make a potentially very important contribution to an area's sense of place. This has a spiritual dimension and refers to the meanings and values that people attach to places, and which arises out of the interaction between people and the environment (Barendse *et al*. 2016). At a sensory level, what people do (e.g. fish from the bank of a river), feel (e.g. the cool water of a mountain stream), hear (e.g. the rustling of reeds in the wind) and see (e.g. a river plunging over a waterfall) will contribute to their experiences in relation to a place (Barendse *et al*. 2016). Such experiences are likely to change over time (e.g. different seasons) and space (e.g. vantage points) and to be mediated by memory of previous such experiences (Barendse *et al*. 2016).

In South Africa there is a strong association between traditional healers and wetlands and rivers, much of this relating to the spiritual connection that these areas have with the ancestors (Tham 2002; Bernard 2000). The African Indigenous Churches (e.g. the Shembe Church the Zion Christian Church [ZCC], one of the largest churches in South Africa) also have a close relationship with rivers, which are used for baptism ceremonies. With increasing westernization, some of the traditional beliefs linked with rivers are declining, but religious beliefs and practices surrounding river baptisms continues to remain strong (Tham 2002).

2.3.13 Education and research

Intact ecosystems offer high opportunity value for intellectual interactions (e.g. research, education or historic records) between people and nature, including opportunities for scientific research and education (Smit *et al*. 2017). Wetlands and rivers specifically are important places for research and education, serving as useful outdoor classrooms with many resources and tools are available to assist with research and education activities on wetlands and rivers. The most widely applied of these is miniSASS, a simple tool which can be used by non-specialist, including school learners to monitor the health of a river by collecting a small sample of macroinvertebrates from the water, and depending on which macroinvertebrate groups are found, obtaining a measure of the general river health and water quality in that river.

The organic sediments accumulated in wetlands provide archives of environmental change. For example, the Mfabeni wetland to the east of Lake St Lucia has a 10.8 m thick peat sediment sequence which provides a continuous sedimentation record spanning from about 45 to 47 thousand years ago to the present (Grundling *et al*. 1998; Baker *et al*. 2014). Seeds, pollen and other identifiable fragments of plant matter preserved throughout the sediment sequence allow for the plants to be identified which were growing at the time when the sediment was formed. This allows for determining how the vegetation has changed over the period represented by the sediment sequence (Baker *et al.* 2014; Mulders *et al*. 2017).

2.4 How does the supply of these services vary across different wetland types and climatic settings?

As indicated in the introduction, South Africa has a great diversity of wetland types and climatic contexts, and an attempt is made in Table 2.2 to represent how some of this diversity influences the supply of range of different ecosystem services.

Table 2.2. Preliminary rating[1] of the ecosystem services potentially supplied by a wetland based upon its hydrogeomorphic (HGM) wetland type, and climatic setting (humid to sub-humid and semi-arid) (modified from Kotze *et al.* 2008; Kotze 2014).

Ecosystem services: / HGM types	Flood attenuation	Sediment trapping	Erosion control	Streamflow regulation	Water quality regulation	Carbon storage	Water provision	Grazing	Plants for crafts & construction	Medicinal plants	Indigenous/ wild foods	Cultivated foods	Tourism & recreation
Floodplain wetland[2]	3.5	3	3	1	3	2.5	3	4	3	3	3	4	4
	4	3.5	3	0.5	2.5	1.5	2	4	2	2.5	3	4	4
Valley-bottom wetland, channelled	2	3	3	2	3.5	2.5	3	3	3	4	2	3	3
	3	3	3	1.5	3	1.5	2	3	2.5	3	2	3	2.5
Valley-bottom wetland, unchannelled	2.5	4	4	1.5	4	4	3	3	4	3	2	3	3
	3.5	4	4	1	3.5	2	2	3.5	3.5	2.5	2	3	2.5
Seep with channelled outflow[3]	1.5	1	3	3	2	3	4	3	3	4	2	3	2
	2	1	3	3	1.5	2	3	3	2.5	3.5	2	3	2
Seep without channelled outflow	1.5	1	2	1	1.5	2.5	1.5	3	2	3	1	3	2
	2	1	2	0.5	1	1	0.5	2	1.5	2	1	2	1.5
Depression, exorheic[4]	2	1	1	1	2	3	3	3	2	1	3	2	3
	2.5	1	1	0.5	1.5	1.5	1	1.5	1.5	1	3	2	2
Depression, endorheic	2	1	1	0	1	2	1	2	1	1	3	1	3
	2.5	1	1	0	0.5	1	0	1	0.5	0.5	2	0	2
River channel	2	2	3	2	2.5	1	4	2	2	2	3	1	4
	2.5	2	3	2	2	0.5	2.5	2	2	2	3	1	3

[1] *The same range in scores from 0 to 4 is used as is applied by WET-EcoServices (Kotze et al. 2008) with 0 indicating a likely absence of the service, 2 an intermediate importance and 4 a very high importance.*

[2] *A floodplain wetland is taken as typically comprising predominantly floodplain flat with floodplain depressions contained within the flat. If a particular floodplain unit is characterized by the very limited extent of depressions then this unit is probably best treated as a channelled valley bottom unless it is particularly wide (i.e. > 500 m).*

[3] *A seep with channelled outflow is assumed to be supplied with a sustained source of sub-surface water, including groundwater and deep interflow.*

[4] *Exorheic depressions generally experience flushing, which prevents the accumulation of solutes. However, under arid conditions this flushing will often be inadequate to prevent such accumulations, and therefore under arid conditions these depressions may need to be treated as endorheic in terms of water provision.*

Rationale underlying Table 2 — Regulatory services

The rationale for the influence of HGM wetland type over regulatory services is largely based on Kotze *et al.* (2008). However, some adjustments have been made, in particular taking into account the catchment interception potential (as elaborated upon by Hansen *et al*. [2018]) of the respective HGM units, which was not accounted for by Kotze *et al*. (2008). Further rationale, mainly concerning the influence of climatic context is given below.

Flood attenuation: If a wetland is already flooded on arrival of a flood event then its capability to attenuate floods is lower than if it was in a dry state on arrival of the flood, and areas which remain flooded for prolonged periods are generally most extensive in wetlands in humid climates and least extensive in wetlands in arid climates, which tend to be ephemerally flooded.

Sediment trapping: This is assumed to be less affected by the climatic context than the HGM type, but as described earlier with reference to Grenfell *et al*. (2014) climate may influence sediment trapping through its influence over how sustained/episodic streams in the wetland are likely to be.

Streamflow regulation: HGM wetland types scored highest in terms of streamflow regulation are those most likely to be sustained most by groundwater or deep interflow, i.e. with sustained water sources. As discussed earlier, a key factor limiting the extent to which a wetland sustains streamflow is evapo-transpirative loss, which is already potentially high in humid climates and increasing progressively with increasing aridity.

Water quality regulation: A variety of processes including chemical precipitation, adsorption and ion exchange contribute to the assimilative capacity of a wetland, and several of these required sustained reducing conditions, which are associated with prolonged saturation. Such conditions are most prevalent in humid climates, and progressively declining in extent and duration with increasing aridity. They are also more prevalent in certain HGM wetland types, notably unchannelled valley bottoms.

Carbon storage: Soil organic matter is promoted under sustained reducing conditions, which are associated with prolonged saturation, which, as indicated above, are most prevalent in humid climates and in certain HGM wetland types.

Rationale underlying Table 2.2 — Provisioning services

Water provision: A hillslope seepage feeding a stream channel is assumed to generally be maintained by a sustained supply of sub-surface water discharging to the ground surface. This type includes areas which would be referred to as springs, and it generally provides a reliable source of clean water, often even in semi-arid conditions. Springs remain a critical source of water for many rural communities without access to reliable piped water. In contrast, seeps without channelled outflow are generally maintained by a less sustained supply of water, rendering these areas less reliable sources of water. The inward-draining character of endorheic depressions generally results in a concentration of solutes through evaporation in the wetland, leading to water which is naturally poor for human consumption.

Besides the lower volumes of water generally stored in wetlands under semi-arid conditions than under humid conditions, the prevalence of salt accumulation is also much more likely under semi-arid conditions than under humid conditions, which impacts negatively on the value of this water for human use.

Grazing: Many floodplains are occupied by a large proportion of seasonally flooded or saturated grasslands of high grazing value, particularly in the flat and shallow depression areas of the floodplain. The other hydro-geomorphic types tend to have a lower proportion of these grasslands, but nonetheless generally provide valuable grazing. In terms of climatic context, under humid conditions, the prolonged flooding of extensive areas of the wetland limits access to some of the potentially grazable and harvestable resources. In semi-arid climates resources are more accessible but tend to be present even in the dry season.

Plants for crafts: Unchannelled valley-bottom wetlands are generally characterized by permanent saturation and deep sediments, and the most prolific growth of fibrous plants that are typically used for crafts. In contrast, endorheic depressions and seeps without channelled outflow generally have the least prolific growth of fibrous plants.

Medicinal plants*:* Wentzel & Van Ginkel (2012) list hydric species used for medicinal purposes according to preferred HGM wetland type, which allows for HGM wetland types to be scored according to their potential supply of medicinal plants. Channelled valley-bottom wetlands are scored the highest given that the greatest number of medicinal hydric species is listed as occurring in this HGM wetland type. In contrast, depressions have the lowest number of listed medicinal hydric species.

Indigenous or wild foods: Rivers provide the most extensive habitat for a variety of indigenous and introduced fish species used for human consumption. In addition, key habitats for fish, floating aquatic plants, frogs and many birds are depressions, including isolated depressions, as well as depressions contained within floodplains which are most important for fish. Mammals and grasshoppers are generally most favoured where grazing is good.

Cultivated foods: In scoring the HGM wetland types according to their potential for the cultivation of food, the types are considered in terms of (a) supply of water and nutrients and (b) limitations in terms of salts or excess wetness. As explained for 'Water provision', endorheic depressions are often characterized by a high concentration of salts, resulting in their generally being unsuitable for cultivation. Exorheic depressions typically do not accumulate solutes to the same degree as endorheic depressions, but deep flooding limits cultivation, at least seasonally. Unchannelled valley-bottom and seeps with channelled outflow are generally characterized by excessive wetness, which can usually be practically overcome, primarily through artificial drainage. However, while this may be relatively easily achieved for seeps, which are generally small, for large un-channelled wetlands with gentle longitudinal slopes, artificial drainage may require a considerable investment and also have potentially considerable environmental impacts.

Tourism and recreation: Two key linked features considered in scoring importance for tourism is the presence of open water and wetland-dependent birds. Open water areas are generally very limited or absent in Hillslope seepages and most extensive in depressions and the depression component of floodplains.

'Education and Research' and 'Cultural experience', both of which are likely to be strongly related to the social context of the wetland, are not included in Table 2.2. It is considered inappropriate to single out specific HGM wetland types for research value given that research is required for all types. It is also difficult to single out specific HGM wetland types which are of particular cultural value. However, wetlands which store water, particularly those which occur in a relatively dry climate, where water is scarce, seem to feature most prominently amongst the wetlands with a high cultural significance. In addition, several of the crafts produced from wetland plants have cultural significance, for example traditional sleeping mats continue to play an important role in the exchange of gifts at many weddings in KwaZulu-Natal (Kotze &

Traynor 2011). Thus, 'water provision' and 'plants for crafts' could potentially be used as surrogates for cultural heritage.

2.5 How is the supply of services influenced by the integrity of the ecosystem?

It is generally held that as the ecological condition or integrity (health) of an ecosystem declines there is a corresponding decline in the provision of ecosystem services (Macfarlane *et al*. 2008). However, the relationship is complex and depends on which ecosystem services are being examined and what are the specific stressors impacting upon the wetland (Ellery *et al*. 2010) and the initial decline from pristine may at first result an increase in ecosystem service provision, thereafter followed by a decline (De Groot *et al*. 2010).

In order to better understand the relationship between ecosystem integrity and ecosystem services provision, it is useful to examine case examples and compare the benefits under different integrity scenarios. One such case is Manalana wetland in the Limpopo Province, which Pollard *et al*. (2008) examined under two scenarios (intact rehabilitated wetland vs deeply-incised degraded wetland) in terms of provisioning services (water, crop production, livestock grazing and craft plant harvesting). The wetland was utilized by 34 households, and it was determined that the overall net benefit of the provisioning services to the livelihoods of the 34 households who used the wetland was R 149,256 and R 38,196 per annum under intact and degraded scenarios respectively.

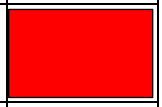
Another case is that of Rebelo (2017) who compared water quality regulation of pristine portions of unchannelled valley bottom wetland dominated by Palmiet (*Prionum serratum*) with comparable portions which have been degraded by deep channel incision. This comparison was undertaken at three different sites, Kromme River, Goukou and Theewaterskloof in the Western Cape Province, using a mass balance approach to estimate changes in water quality (total phosphorus, potassium and Kjeldahl nitrogen) over wetland sections. The study revealed that the pristine sections generally acted as sinks in terms of the examined water quality parameters, while the degraded sections at two of the sites acted as sources for these parameters, i.e. degradation led to a net 'leakage' of nutrients from the wetland.

In addition to addressing this question at the local scale of an individual ecosystem, it can also be addressed at broader spatial scales, which is the focus of the framework developed by Ginsburg *et al*. (2010), which was used to assess two scenarios in the Sand River catchment, the first allocates the water from a new dam to an irrigation scheme with large social benefit, leaving the river in an ecological category C or D, whereas the second allocates less water to the irrigation scheme and more to the river, allowing a B ecological category to be maintained. Without consideration of the value of ecosystem services lost, Scenario 1 is the favoured option. However, after adding the full cost of ecosystem services, Scenario 2 becomes the favoured option (Ginsburg *et al*. 2010).

2.6 How does the supply and demand for these respective services vary according to broad land use contexts?

Table 2.3 is an attempt to summarize how the supply and demand for specific ecosystem services varies depending on the general land use context of a wetland. Supply assumes a mix of HGM wetland types as well as considering the effect of modifications/loss of wetlands characteristic of the land use type. For example, in urban areas and intensive agricultural areas, the extent of wetlands is typically diminished (e.g. through infilling) and water quality in the wetlands is generally compromised. A further modification in urban areas (with their characteristically extensive hardened surfaces) is the greatly increased intensity of storm flows leading to increased peak discharges and channel incision in many of the wetlands.

Table 2.3. Supply and demand for different ecosystem services[1] under three different general land use contexts, with the size of rectangle proportional to magnitude of supply/demand.

Ecosystem service	Urban/industrial areas		Intensive agricultural areas		Extensive natural areas	
	Supply	Demand	Supply	Demand	Supply	Demand
Flood attenuation						
Sediment trapping						
Water quality regulation						
Provision of water for human use						
Provision of livestock/game grazing						
Provision of harvestable resources						
Provision of cultivated foods						
Tourism and recreation						
Education and research						

[1] *Carbon storage was omitted from the table as the primary demand for this service is at a global scale, and the more localized contributions of carbon storage would be reflected in some of the other ecosystem services, in particular water quality regulation.*

Table 2.3 shows how the demand for specific ecosystem services varies considerably depending on the land use context of a wetland. For example, under urban or industrial land use the demand for water quality regulation is particularly high, for water from local sources it is generally low given the ready availability of piped water, for recreational areas is particularly high because of the large human population seeking accessible. In such urban or industrial contexts, the supply is generally limited by the reduced aerial extent of wetlands and for recreation also by the compromised water quality. Even so, several urban wetlands in South Africa, such as the Rondevlei wetlands and Khayelitsha Wetlands Park in Cape Town, provide many urban residents an opportunity for relaxation and education close to where they live. An additional benefit supplied by wetlands for which there is a particular demand in highly urbanized areas is mitigating the urban heat island effect (McInnes & Everard 2017). In the context of extensive natural areas, the demand for water quality regulation is generally given the limited pollutions sources, for water from local sources it is high given that piped water is often not available, for recreational areas it is variable but often low at least locally because of the small local population.

2.7 Limitations of the assessment and recommendations for future research

Much of the work on ecosystem services in South Africa and the specific assessment presented in this chapter are based strongly on the conceptualization of ecosystem services by the MEA. In identifying future research priorities for ecosystem services in South Africa it is therefore considered instructive to take note of some key limitations of the MEA framework. Diaz *et al*. (2018) note that the detailed conceptualization and the practical work on ecosystem services following on the MEA were dominated by knowledge from the natural sciences and economics. The natural sciences, and ecology in particular, were used to define 'ecological production functions' to determine the supply of services, conceptualized as flows stemming from ecosystems (stocks of natural capital). However, this predominantly stock-and flow framing of people-nature relationships largely failed to engage a range of perspectives from the social sciences, or those of local practitioners, including indigenous peoples (Diaz *et al*. 2018). In recent years, ecosystem services valuations have increasingly incorporated value pluralism, which is the recognition of different and often conflicting value domains that are not reducible to some ultimate value (Arias-Arévalo *et al*. 2017). The spectrum of ecosystems valuation has broadened through the integration of relational values, which are those concerns associated with relationships and responsibilities between people or between nature and people (Arias-Arévalo *et al*. 2017). Examples of relational values include the ecological conditions ensuring the preservation of life on Earth, the social conditions for maintaining harmonic human–nature relationships (e.g. sacred and cultural values), or the experiences and entities necessary for cultivating the notion of a 'good' life (e.g. aesthetic appreciation or cognitive development in nature based contexts) (Arias-Arévalo *et al*. 2017). Himes & Muraca (2018) draw attention to the need to recognize the different ways in which people articulate the importance of ecosystem services in their specific, socio-culturally embedded language of valuation.

A further key limitation of the assessment reported in this chapter is that it does not cover the institutional context within which ecosystem services are located, although this does receive coverage in Chapter 9 on responses to pressures in the inland aquatic realm. Brill *et al*. (2017) emphasize the need to assess how the concept of ecosystem services has been incorporated into management policies and practices. In the context of urban protected areas, specifically in the global South, rapid urbanisation and the heterogeneity between social, political and economic aspects impact heavily on protected areas and the resources

contained within them including wetlands and rivers (Brill *et al*. 2017). Integral to managing and sustaining ecosystem services is understanding cross-scale processes and spatial relations affecting the provision of ecosystem services, especially in the many cases where the ecosystem service production is spatially separated from where the benefits accrue (De Vos *et al*. 2017). Nel *et al*. (2017) draw attention to how South Africa's Strategic Water Source Areas (i.e. those areas that have a relatively high natural runoff) contribute substantially to development needs, often far away from the source, and therefore this contribution may not be obvious to users and decision makers. Nel *et al*. (2017) recommend that identifying the specific links between strategic water source and downstream users enables new patterns of collaboration between government, business and civil society and the identification of synergies in spatial planning across diverse policy sectors.

Given the above limitations in the assessment carried out in this chapter, it is recommended that future work on ecosystem services in South Africa and the next overall assessment draw much more from the social sciences, and pay much more explicit attention to relational values. It is further recommended that the institutional linkages of ecosystem services be more fully explored, including cross-scale processes and spatial relations.

2.8 Key findings and messages

Key finding: Wetlands provide multiple ecosystem services. Many of the services are supporting or synergistic.

Key message: Seek opportunities to strengthen synergies, e.g. through harvesting of wetland plants as a means of supporting craft production and water quality regulation.

Key finding: A general decline in ecosystem service supply is observed with declining ecosystem health (integrity), and thus intact (non-degraded) wetlands and rivers will tend to provide greater services than degraded wetlands and rivers. However, the specific relationship between integrity and services provision will depend on the particular services examined and the stressors impacting on the wetland.

Key message: If the many benefits which wetlands and rivers provide are to be maintained then the health of these ecosystems must be maintained. However, be careful about general unsubstantiated assumptions about how well natural wetland systems perform particular services relative to transformed systems. As far as possible take the specific context into account and use scenarios to aid in decision making.

Key finding: Different HGM wetland types vary according to the key ecosystem services which they provide, and in many cases these types complement each other in terms of ecosystem services provision.

Key message: Conserve or secure all of the representative types present, but where particular services are especially needed it may be necessary to prioritize certain inland aquatic types over others.

Key finding: The demand for different ecosystem services varies considerably depending on land use context, with the demand for regulatory services being especially high in intensively used (agricultural and urban) landscapes.

Key message: It is important to take ecosystem services demand into account when prioritizing the management or rehabilitation of wetlands and rivers.

Key finding: There are several social imperatives or government mandates to which ecosystem services can make positive contributions (Table 2.4).

Key finding: This chapter has focused primarily on wetlands, which received much greater attention from an ecosystem services perspective than rivers and riparian area.

Key message: Therefore, a key area for further research is ecosystem services associated with South Africa's rivers and riparian areas, from which a fuller overview of ecosystem services and South Africa's inland aquatic ecosystems can be derived.

Table 2.4. Key social imperatives or government mandates to which ecosystem services can directly contribute.

Key imperatives	Types of services
Basic human needs and livelihood	Provisioning services.
Water resource management	Regulating services, in particular water quality regulation.
Job creation	Provisioning services; Supporting services underpinning the ecosystem base of the tourism industry.
Disaster risk management and climate resilience	Regulating services, in particular flood attenuation.

Key message: Use appropriate means to alert decision makers responsible for these social imperatives or government mandates of the above contributions.

Box 2.2. Ecosystem Services Assessment and Rivers: Case Study – Lower Orange River

Prepared by Patsy Scherman from Scherman Environmental

Information is taken from the following study and report: *Department of Water and Sanitation, South Africa, May 2017. Determination of Ecological Water Requirements for surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Report on consequences of scenarios. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. DWS Report No: RDM/WMA06/00/CON/COMP/0117.*

Ecosystem services are natural assets that emerge from features or processes produced by the natural environment. Such services are directly utilised by surrounding communities and are thereby used to enhance human well-being as a direct result of such services. The Millennium Ecosystems Assessment (2005) categorises ecosystem services into the following four groupings:

- Provisioning services
- Cultural services
- Regulating services
- Supporting services

During Reserve and Classification studies in South Africa, the potential impact of development scenarios implying that scenarios that would have a significant impact on the water balance of a system are tested on ecological and non-ecological components. One of these non-ecological components is *ecosystem services* or services that *water held within the water resources* provide.

An example provided below covers the proposed Vioolsdrift Dam on the Lower Orange River, and its potential impact on ecosystem services of a lower Orange River site (EWR site O5 at Sendelingsdrift) and the Orange River Estuary, both downstream of the proposed dam.

The process followed during the assessment was as follows:

1. What is the Present Ecological State (PES), or Ecological Category, of the identified sites?
2. What is the Recommended Ecological Category (REC) for the identified sites? This category incorporates the Ecological Importance and Sensitivity (EIS) of the reach and may request an improvement of the ecological state based on the EIS.
3. What are the ecosystem services (according to the four categories previously mentioned) provided by the river/estuary at present (so linking the Ecological Category to the ecosystem services currently provided)?
4. What will happen to these services under the identified development scenario, e.g. the building of an instream dam, such as the proposed Vioolsdrift Dam on the Lower Orange River?
5. Tabulate the results – see table below:

Table supplementing Box 2.2

Ecological Water Requirements (EWR) site	PES	REC	Ecosystem services **	Ecological Category and summarized change in Ecosystem Services under development scenarios ***	
				Scenario B: large storage dam development and re-regulation of flows	Scenario D: smaller dam development to regulate river flows
EWR O5, Sendelingsdrift*	**B/C**	**B**	Provisioning services - Fishing (subsistence + recreational) - Sedges - Reeds - Grazing/browsing - Trees + other flora - Salt lick	Constant/Positive change	Constant/Positive change
			Supporting services	-	-
			Regulating services - Flood attenuation - Bank protection - Waste assimilation - Waste dilution - Pathogens treatment - Pathogens productivity loss - Pollutants treatment - Black fly	Negative change	Positive change
			Cultural services - Swimming - Canoeing - Ritual use - Fishing (recreational)	Negative change	Positive change
Change in Ecological Category under scenarios				**C**	**B**
Integrated change in Ecosystem services				**Negative change**	**Positive change**
Orange Estuary	**D**	**C**	Provisioning services - Recreational fishing (legal) - Sedges - Reeds - Grazing	Negative change	Negative change
			Cultural services - Swimming - Ritual use - Ecotourism (aesthetic) - Ecotourism (bird watching) - Hunting/poaching	Negative change	Negative change
			Regulating services - Waste assimilation - Pollutants filter effect, vegetation - Pathogens treatment - Flood attenuation - Nursery function	Negative change	Negative change
			Supporting services	Negative change	Negative change
Change in Ecological Category under scenarios				**E**	**D/E**
Integrated change in Ecosystem services				**Negative change**	**Negative change**

** EWR O5 is downstream of Vioolsdrift weir; the location of the proposed Vioolsdrift Dam.*

*** Fish and plant species are listed per service. Information is available as part of the e-data for the Lower Orange River study.*

**** Note that although the main component of the scenario is shown as the size of the proposed Vioolsdrift Dam (so large vs. smaller dam), the scenarios are made up of a list of operational structures, rules and releases in addition to Vioolsdrift Dam.*

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3. CLIMATE CHANGE – OUR CHANGING ENVIRONMENT FROM AN INLAND AQUATIC ECOSYSTEMS PERSPECTIVE

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3.1 Introduction

Climate change drives evolutionary change. The world's biota have adapted to shifts in climate over a time scale that allows for the gradual evolution of adaptive strategies. Anthropogenic climate changes, however, are taking place over a much shorter time period, in a landscape that is increasingly fragmented and threatened by a number of human-induced pressures. Climate change has been identified as one of the key pressures on global inland aquatic ecosystems (MEA 2005; Nel *et al*. 2011), exacerbating existing pressures on these ecosystems and pushing them to extremes of tolerances. The capacity of inland aquatic ecosystems to resist or adapt to the shifts that relate to climate change is reduced as a result of loss or degradation of habitat, while the demand for the ecosystem services offered by inland aquatic ecosystems is expected to increase.

It is only in the last decade or so that attention has shifted from concerns for the effects of climate change on terrestrial ecosystems to include its effects on aquatic ecosystems (Dallas & Rivers-Moore 2014). Globally, inland aquatic ecosystems are considered to be among those ecosystems most vulnerable to climate change (Bates *et al*. 2008; Dallas & Rivers-Moore 2014), especially due to the close relationship between climate and water availability, both on the surface and below ground. In addition, inland aquatic ecosystems are the most threatened ecosystems in the world, specifically as a result of flow modification, invasive alien species, overexploitation, water pollution, and the destruction and/or fragmentation of habitat (Dudgeon *et al*. 2006). World-wide, inland aquatic ecosystems may have the highest proportion of species threatened with extinction as a result of climate change, due to the relatively small habitat ranges of aquatic or semi-aquatic species (MEA 2005; Urban 2015). Amphibians in particular appear to be most vulnerable (Urban 2015). The global degradation and loss of wetlands is occurring more rapidly and the threat status of wetland species is deteriorating faster than for any other ecosystem type (MEA 2005), and South Africa is no exception (Driver *et al*. 2012).

The southern African sub-continent has been identified as one of world's water-related vulnerability 'hotspots', where the impacts of climate change on freshwater resources will be a threat to sustainable development in the years to come (Kundzewicz *et al*. 2008). In terms of biodiversity, inland aquatic ecosystems in South Africa are protected to a lesser extent than terrestrial and marine ecosystems (Amis *et al*. 2006; Nel *et al.* 2011). Furthermore, assessments of the resilience of inland aquatic ecosystems to climate change, with an emphasis on wetlands, have had a biased focus on the more humid, permanently saturated or inundated systems, with a paucity of information on the resilience of aquatic ecosystems in drylands (a collective term for sub-humid, semi-arid, arid, and hyper-arid environments, which comprises a large proportion of the South African landmass (Tooth 2017). This is despite the fact that wetlands in drylands may possibly be disproportionately important in terms of ecosystem service delivery, due to their location in water-stressed, climatically variable environments (MEA 2005). Furthermore, in drylands, a

small change in water availability can lead to a large shift in hydrological regime or hydroperiod (Tooth 2017). South Africa is vulnerable to climate variability (Davis *et al*. 2018).

The most critical climate change drivers are shifts in air temperature, precipitation and evaporative demand (Dallas & Rivers-Moore 2014), and climate change predictions and observations focus on these variables. However, the links between changes in these variables and freshwater ecosystem responses, and the feedback loops between these, are complex and more difficult to predict. Significant progress has, however, been made in South Africa towards understanding climate change and predicting how it will impact on the region (Davis *et al*. 2016). The models and their projections are covered in more detail in Chapter 5 of Volume 1: Terrestrial Realm Report of the National Biodiversity Assessment for 2018 (Skowno *et al*. 2019).

This chapter attempts to show the relationship between climate change, ecosystem responses, biota and the implications of these relationships for people and their livelihoods. The following section provides a summary of the predicted and observed shifts in the main climatic drivers in South Africa (Section 3.2), while the subsequent sections provide reviews of the predicted and observed impacts on South African inland aquatic ecosystems (Section 3.3), and how these will impact on human communities (Section 3.4). Key concerns, messages and recommendations are provided in the final sections (Sections 3.6 and 3.5).

3.2 Climate Change in South Africa

3.2.1 Observed climate changes

Evidence of warming over the African continent over the past 50 to 100 years has now been confirmed with high confidence (Niang *et al*. 2014). Air temperatures across most of southern Africa have been increasing over the past century, at a rate of 0.2 °C per decade over an 85-year period (Kruger & Nxumalo 2017), however, the rate of change has increased over the last few decades. Most recently, from 1961 to 2014, temperatures over the region have risen at a rate of 0.4 °C per decade, with the greatest increases being recorded in summer and autumn (Davis-Reddy & Vincent 2017). In South Africa, temperature increases have been most consistent in the Western Cape and the midlands of Kwazulu-Natal (Mitchell 2013).

Significant decreases in cold spell duration are evident for most places in the eastern half of South Africa as well as along the coast, and a warming of minimum temperatures (during the coldest nights and days), has been measured (Kruger & Sekele 2012; Kruger & Nxumalo 2017). On the other hand, significant increases in warm spell duration are evident over most of the western and northern interior (Kruger & Nxumalo 2017).

As can be expected, increases in air temperature are generally matched by increases in evapotranspiration (Davis-Reddy & Vincent 2017), which can be expected to have a direct impact on aquatic resources or ecosystems. For instance, a steady increase in sea surface temperatures along all latitudes around the southern African coast has been observed. This has implications for the strength of upwelling of the Benguela and Agulhas currents which are important drivers of South Africa's semi-arid climate (Davis-Reddy & Vincent 2017; Jury 2017). Interestingly, increased upwelling along the South African coastline is leading to a cooling of sea surface temperatures at certain times of the year (Rouault *et al*. 2010). For instance, temperatures in the southern Benguela have decreased by up to 0.5°C per decade between January and August (Rouault *et al*. 2010). This may have consequences for coastal climate, and may influence coastal storm intensity.

Observed shifts in rainfall patterns are difficult to interpret with certainty. Dallas & Rivers-Moore (2014) report on a decade-on-decade drying trend in the north, north-east and south-west of South Africa, with an

increase in precipitation in the east, as mean annual precipitation and inter-annual variation in rainfall decreases, and extreme events such as droughts increase. Dry spells are increasing in frequency across the whole African continent, together with an increasing trend in daily rainfall intensity, which has a direct effect on run-off characteristics (Niang *et al*. 2014).

Rainfall is naturally very variable across the whole sub-continent, and there is little evidence of a substantial change in mean annual rainfall from 1961 to 2014 (Davis-Reddy & Vincent 2017). Rainfall intensity, however, has increased at most weather stations across the Western Cape, with 63% of a total of 76 rainfall stations showing an increased intensity of extreme return period rainfalls (i.e. the 1 in 20 and 50 year return period rainfall totals falling within a 24–hour period) in a comparison between the decades 1950–1979 and 1980–2009 (De Waal *et al*. 2017). In many parts of the world, more erratic rainfall has been observed in mountain areas, as well as more intense precipitation, which can destabilise slopes and cause erosion, landslides and flooding (UNDP 2015).

Generally, changes in the frequency and intensity of extreme weather events have been observed over the southern African sub-continent since the 1950s. Long-term trends are beginning to emerge, such as an increased frequency of hot days (Davis-Reddy & Vincent 2017).

3.2.2 Predicted changes

It has been predicted that the mean annual temperature increase is likely to exceed 2°C relative to the late 20th century records over extensive parts of Africa during the last two decades of this century. It is likely that air temperatures will increase more rapidly over Africa than the global average, especially in the hotter and drier parts of the continent (Niang *et al*. 2014). The prediction for South Africa is an increase in between 2°C and 4°C by 2050, and at worse, up to 8.5°C in the interior (Davis-Reddy & Vincent 2017) (see also Volume 1: Terrestrial Realm, Chapter 5; Skowno *et al*. 2019). According to regional climate change scenarios, climate change is unlikely to affect South Africa in a uniform manner. 'Hotspots' of concern have been identified in the south-west of the country, the west coast, and, to a lesser extent, the far north of the sub-continent (Dallas & Rivers-Moore 2014). Warming is expected to be greatest in summer, followed by autumn, winter and then spring (Kruger & Nxumalo 2017). There is likely to be an increased frequency and intensity of extreme weather events, including very hot days (i.e. > 35°C) (Davis-Reddy & Vincent 2017) and heat waves (Engelbrecht *et al*. 2015), and other events such as rainstorms and storm surges. Increased drought, hot days and heat waves are expected to lead to an increased frequency of fires where there is vegetation to fuel fires, such as in savanna regions, and low rainfall (Engelbrecht *et al*. 2015).

There is a greater degree of certainty associated with predictions of the magnitude of temperature changes over southern Africa compared with changes in rainfall, partly due to greater variations between rainfall projection models (Engelbrecht *et al*. 2015; Davis *et al*. 2018). This is also due to the high variability of the African climate, and the low and declining number of weather stations across the country (see Volume 1: Terrestrial Realm, Chapter 5; Skowno *et al*. 2019). However, decreases in rainfall are projected over central southern Africa (i.e. northern Botswana, Namibia, southern Zambia, Zimbabwe and possibly western Mozambique) and over the southern parts of the Western Cape Province of South Africa, with most models predicting this to occur in summer or spring. Increases in rainfall are predicted over East Africa, Angola and south-eastern parts of South Africa (Davis *et al*. 2018). Northern and eastern regions of southern Africa are likely to become wetter in summer and autumn (Dallas & Rivers-Moore 2014). Regionally, the inter-annual variability of rainfall is projected to increase with more irregular events in the southwest. Seasonal rainfall

is changing with regards to onset, duration, intensity, dry spell frequencies (Kay & Washington 2008; Niang *et al*. 2014).

There are uncertainties around the projected changes in the frequency of landfall of tropical cyclones from the southwest Indian Ocean, which have resulted in severe floods during the 20th century (Niang *et al*. 2014). Davis-Reddy & Vincent (2017) predict an increase in the frequency of cyclones, while other researchers have predicted that the number of tropical cyclones reaching the eastern coast of southern Africa will decrease under all climate change scenarios (e.g. Malherbe *et al*. 2013). The 2°C increase appears to be a critical threshold, after which increases in global temperatures no longer have this effect on cyclone frequency. Decreased cyclone frequency will probably lead to decreased rainfall over the Limpopo River Basin and southern, central and northern Mozambique (Muthige *et al*. 2018).

Groundwater is predicted to be less responsive to climate change than surface water (Conrad & Carstens 2017). In the Western Cape Province, the deep sandstone aquifers have shown little response to the 2014–2018 drought (Roger Parsons, Hydrogeologist, November 2018, *pers. comm*.). However, groundwater recharge is dependent on precipitation and therefore a decrease in rainfall over South Africa is likely to lead to decreased recharge. This, in combination with increasing groundwater abstraction, may impact on the water levels below ground.

3.3 Impacts of Climate Change on Inland Aquatic Ecosystems

An extensive review of the climate change literature revealed a substantial body of evidence covering observed and predicted climatic impacts on genes, species and communities, ecosystems and biomes, and biotic relationships. The review is presented in table form in Annexure A, and described in brief in the sections that follow. The results of the review are arranged according to the Essential Biodiversity Variables (EBVs), which are defined as the biological measurements that are required to study, report, and manage biodiversity change (Pereira *et al*. 2010). They define a minimum set of essential measurements to be able to quantify shifts in biodiversity in a globally consistent manner, in order to ease communication between researchers, managers and decision-makers, and amongst environmental change observation networks. Specifically, measurement of EBVs should produce robust indicators that assess progress towards the 2020 Aichi Targets of the Convention on Biological Diversity. In this chapter the following EBV categories have been used:

- Ecosystem function – water quantity or hydrological regime;
- Ecosystem function – water quality;
- Ecosystem structure – habitat structure, ecosystem extent, connectivity;
- Species populations and traits – species distribution, abundance/density, population structure, phenology, migration and dispersion, demographic, physiology;
- Community composition – diversity, structure, species interactions; and
- Genetic composition – genetic differentiation, diversity, co-ancestry.

3.3.1 Ecosystem function - water quantity or hydrological regime

Shifts in rainfall, air temperature and evaporation will have a direct impact on water availability, both surface and groundwater. The main impacts will be changes in runoff patterns such as mean runoff volumes, flow variability, duration and timing, an increased frequency and intensity of droughts and floods,

and changes in groundwater recharge rates (Dallas & Rivers-Moore 2014). In South Africa, these shifts will be exacerbated by the fact that the region has a low conversion rate of rainfall to runoff (9% on average) and groundwater recharge of 55% on average (DEA 2013), and very high inter-annual climate variability (e.g. Kay & Washington 2008; Stuart-Hill *et al*. 2012).

Uncertainty with regard to shifts in rainfall patterns across South Africa is mirrored in the vast range in the projections for runoff. Projections range from a 20% decrease to a 20–60% increase, with the most likely scenario being a decrease over the southwestern region, and an increase over the eastern coastal region and central interior (DEA 2013). This variation in runoff responses to rainfall depend on factors such as topography, soil type and the wetness of the catchment soils prior to a rainfall event (Schulze 2011). Areas showing the highest risk of increased runoff include Kwazulu-Natal, parts of southern Mpumalanga and the Eastern Cape provinces, while increased evaporation, decreased rainfall and decreased runoff are expected in the southwestern region, the western central interior and to some extent the extreme north (DEA 2013; Dallas & Rivers-Moore 2014). In the southwestern Cape, the predicted decrease in runoff is expected to be more pronounced in wet years. Runoff variability between years is expected to increase by between 20% and 30% for most of South Africa, with the exception being the southwestern Cape region, where variability is likely to decrease (Dallas & Rivers-Moore 2014). Rivers that are groundwater-fed will be more resilient to shifts in water availability, compared with those that are mainly reliant on surface water inputs (Dallas & Rivers-Moore 2014).

There has been relatively little research done on the impacts of climate change on groundwater (Dennis & Dennis 2015). It is likely that climate change will affect recharge, groundwater storage (i.e. the depth to water table), and discharge (including the contribution of groundwater to surface baseflows). Impacts on groundwater resources are likely to lag behind the impacts associated with reduced rainfall (Villholth *et al*. 2013). The effect of climate change on local and regional water tables is of concern, especially with regard to how a drop in water table will impact on aquifer-dependent ecosystems (*sensu* Colvin *et al*. 2007) and human communities (Villholth *et al*. 2013).

Flow and inundation patterns (onset, flood frequencies and magnitude, maximum depth of inundation etc.) will also be affected by climate change. In parts of South Africa that will experience reduced runoff, permanent wetlands and perennial rivers may become seasonal or even temporary or ephemeral systems that are reduced in size and possibly isolated from each other (Desta *et al*. 2012; Dallas & Rivers-Moore 2014). In turn, this will affect the diversity and condition of wetland, instream and riparian flora and fauna through impacts on productivity, water-dependant faunal lifecycle events (Dallas & Rivers-Moore 2014), food availability (e.g. Ramírez *et al*. 2018), connectivity between aquatic ecosystems, competition between species (e.g. Joyce *et al*. 2016) and probably many other biotic interactions. Species may be lost or shift to more suitable habitats. Low flows during drought periods in the Western Cape region have already been shown to lead to terrestrial vegetation encroachment into the riparian zone of rivers and the near-shore littoral zones of lakes (Heino *et al*. 2009).

It is also expected that surface flows will be more variable in future decades. In the winter rainfall area of South Africa, many rivers may cease flowing for longer periods than previously recorded (Dallas *et al*. 2017), with a number of geomorphological and biodiversity changes predicted as a consequence.

Impacts such as these are likely to increase the vulnerability of aquatic or semi-aquatic species to decline or extinction, and may benefit other species or communities that are able to fill these voids, such as terrestrial, exotic or invasive species (Dallas & Rivers-Moore 2014). Some ecosystems will be more vulnerable than others. For instance, a combination of climatic and man-made reductions in river

discharges is already reducing habitat availability for riverine invertebrates creating patchy and uneven distributions of suitable habitat (Tharme 2010). Ecosystems that have been made vulnerable by land use impacts are closer to thresholds of change, and so they are more vulnerable to climate change impacts (Dallas *et al*. 2017). Projected over-abstraction and regulation of water resources (both ground- and surface water) will interact with climatic changes, further reducing flows and impacting on aquatic species (Dallas *et al*. 2017).

3.3.2 Ecosystem function – water quality

Water temperature is one of the most important characteristics of aquatic ecosystems, as it affects many other variables. Shifts in water temperature are evident, with increases already observed in some of Africa's large waterbodies in recent decades (Bates *et al*. 2008). Small streams and wetlands with their relatively shallow water depths and lower discharges will be more affected by increases in air temperature and the subsequent rises in water temperature and levels of evaporation. The concern is that these small, high altitude, fast-flowing streams that have acted as thermal refuges for cold-adapted stenotherms and gondwanan species, will be irreversibly impacted, leading to the loss of their only suitable remaining habitats (Heino 2009; Dallas & Rivers-Moore 2014). Montane assemblages are especially vulnerable to extinctions due to their isolated locations in otherwise unsuitable landscapes, and reduced capacity for shifts or migration. Mountain regions have been found to be more temperature sensitive than other regions, and appear to have experienced above-average warming over the 20th century (IPCC 2014).

Predicted increases in the frequency and magnitude of high intensity rainfall and discharge events such as (i.e. storms) will lead to increased flooding, washing greater quantities of sediment into rivers and wetlands, especially for the central western region of South Africa (Schulze 2011). Storms ending periods of drought are expected to flush accumulated sewage and agricultural nutrients into aquatic ecosystems (Whitehead *et al.* 2009; Dallas & Rivers-Moore 2014). It is likely that the region will experience the effects of increased nutrient loading and water temperatures, which in combination will produce lower oxygen concentrations, increased algal growth and greater turbidity (Jeppesen *et al*. 2015). Less frequent flushing of lentic systems (lakes and reservoirs) as a direct result of lower water inputs will also increase the incidence of algal blooms. Eutrophication levels have already risen in waterbodies throughout South Africa since the 1970s (Van Ginkel 2011), and incidences of cyanobacterial surface scums have increased in some reservoirs across the country (Matthews & Bernard 2015). Increased algal growth and the prevalence of cyanobacterial scums increase the costs of water treatment in order to improve taste and odour, and remove cyanotoxins. Algal blooms can also clog filters and add to water treatment and conveyance infrastructure maintenance costs. This poses a severe threat to water security in South Africa (Matthews & Bernard 2015).

Globally, salinity has risen in lakes from reduced inflows, rising evaporation and residence times, especially in semi-arid regions and the Mediterranean climate zone (Jeppesen *et al*. 2015). Increased salinisation is predicted for shallow groundwater and surface water in the semi-arid and arid parts of South Africa (Schulze 2011). As arid climatic zones expand in the South African interior, many inland freshwater or slightly saline pans will become saline to hypersaline, which will change vegetation composition drastically as plants require special adaptations to deal with such levels of salinity (Mofutsanyana 2017). Coastal wetlands are also likely to be impacted by increases in salinity as sea level rise will lead to saltwater intrusion (Fortune 2018).

Increased salinities have been shown to alter trophic structure, with a shift from a clear, macrophyte-dominated waterbody to a turbid, algal-dominated system with increased salinity (Jeppesen *et al*. 2015). Such a shift would have consequences for biodiversity, species abundance, and ecosystem functioning (Aladin *et al*. 2009).

It is also expected that waterborne pathogens and aquatic vectors will increase in number and range with an increase in water temperatures and a decrease in water quality (Bates *et al*. 2008; Dallas & Rivers-Moore 2014). The predicted increase in the magnitude and frequency of extreme rainfall events and floods will lead to the mobilisation of greater quantities of absorbed pollutants (e.g. heavy metals), pesticides and other agricultural chemicals from catchments into receiving waterbodies (Whitehead *et al*. 2009; Dallas & Rivers-Moore 2014).

Shallow lakes will be particularly vulnerable to decreases in the quality and volume of water flowing into them (Whitehead *et al*. 2009) with small ponds and wetlands being most vulnerable, suffering a greater degree of stress, and some possibly becoming intermittent during long periods of drought (Heino *et al*. 2009). Increased isolation of waterbodies from each other, or from their inflowing rivers, will exacerbate deterioration in water quality (Remírez *et al*. 2018).

3.3.3 Ecosystem structure – habitat structure, ecosystem extent and connectivity

Shifts in water quantity and quality will affect the availability and condition of inland aquatic habitat. For instance, it has been shown that reduced flows in South African rivers lead to reduced habitat availability for riverine invertebrates, and increased habitat fragmentation, biotope isolation and dominance by shallow, low flow biotopes (e.g. Tharme 2010). Therefore, it can be expected that parts of South Africa will experience decreased river flows, and thereby also an increase in fragmentation and loss of habitat, and a possible loss of habitat connectivity (Dallas & Rivers-Moore 2014). On the other hand, increasing flood frequencies will lead to inundation of floodplains, incorporating additional habitat and possibly re-connecting isolated floodplain and riparian wetlands (Poff 2002) but also to increased erosion of catchments, rivers and wetlands, and the consequent sedimentation of downstream reaches.

There is a close relationship between river discharge and river morphology. Some rivers are more sensitive to shifts in these characteristics, such as fine-grained alluvial rivers in arid areas (Nanson & Tooth 1999; Goudie 2006), which are plentiful in the arid interior plateaus of South Africa. River discharge is expected to increase in the eastern parts of South Africa, which is likely to lead to channel enlargement and incision, greater channel instability and sinuosity, and increased bank erosion. Conversely, where discharge is likely to decrease in the western parts of the country, channel shrinkage, greater channel stability, vegetation encroachment, and sedimentation in side channels is likely (Goudie 2006).

Ellery *et al*. (2016) showed that the vulnerability of inland valley-bottom wetlands to change brought about by shifts in climatic drivers, and the consequent ecosystem responses, depends on how far the ecosystems are from certain thresholds. They defined these thresholds in terms of wetland area versus wetland gradient, and described a ‘zone of vulnerability’, where an extrinsic factor such as increased flooding and inundation (i.e. increased wetland area at a certain wetland gradient) would drive the wetland from a stable to an unstable state where incision can take place. This is when erosion will occur, sometimes on a large scale. Ecosystems already made vulnerable through land use impacts (e.g. ploughing, fragmentation) are closer to geomorphological thresholds of change, and so are less resilient to climate change (Tooth 2017). Unchannelled valley-bottom wetlands are particularly vulnerable to incision that may occur as a result of climate change impacts (Garden 2008).

In terms of dryland erosion, increased land erosion is expected to be highest in the Eastern Cape, Limpopo and KwaZulu-Natal. Over 30% of land in South Africa is considered to be already at risk of erosion without maintenance or management of current vegetation cover and land use (Le Roux *et al*. 2008).

The desiccation of peat wetlands is of great concern in southern Africa (see Appendix C and D). These wetlands provide important ecosystem services, primarily relating to carbon sequestration, flood attenuation and water quality enhancement. Decreased surface and groundwater availability, increased drought frequency and increased evaporation is already having an impact on the extent and condition of these sensitive wetlands, and has increased their vulnerability to fires and invasive alien plant species (Grundling *et al*. 2017). An increase in the extent and frequency of peatland fires and the subsequent erosion leads to increased sediment loads in rivers and wetlands (Brown *et al*. 2015). Furthermore, erosion of peat results in further draining and desiccation of the in situ peat. Loss and deterioration of peat wetlands creates a positive feedback loop through the release of atmospheric carbon which enhances global warming (Turetsky *et al*. 2015).

Coastal wetlands (including estuaries) and river systems are also particularly vulnerable to inundation and erosion, as a result of land-based floods, sea surges, and sea level rise (e.g. Mitchell 2013; Blankespoor *et al*. 2014; Spencer *et al*. 2016). Current estimates of coastal wetland loss range from 50% (under the low risk scenario of a 29 cm rise by 2100 [Spencer *et al*. 2016]) to 78% (under the high-risk scenario of a 1 m sea level rise [Blankespoor *et al*. 2014]). Coastal wetlands, including both inland wetlands and estuaries, are highly productive ecosystems, providing essential ecosystem services such as flood protection, pollutant assimilation, and biodiversity conservation (e.g. through providing important fish nurseries).

3.3.4 Species populations and traits – species distribution, abundance/density, population structure, phenology, migration and dispersion, demographics and physiology

The observed and predicted shifts in ecosystem function (water quantity and quality) and structure (habitat) described in the previous few sections can be expected to have an impact on the aquatic species inhabiting them, and terrestrial species that may depend on inland aquatic ecosystems for at least part of their life cycles. For instance, the loss of longitudinal and lateral connectivity in and between rivers and wetlands is predicted to lead to the isolation of populations, failed recruitment and local extinctions (Bunn & Arthington 2002). These remaining, fragmented habitats may be the last refuges for some native species. The extent of geographic range contraction varies considerably between the indigenous fish species in the Cape Floristic Region (CFR) of the southwestern Cape in South Africa (Dallas *et al*. 2017). The general trend is predicted to be a retreat from the more northern and eastern limits of the fish species ranges, and a shift towards the cooler, unregulated upper headwaters in the eastern part of the Cape Fold Mountains (Dallas *et al*. 2017).

Water temperature has a critical influence on the fitness, behaviour and life histories of inland aquatic species and has, along with river flow, been labelled a 'master variable' (Dallas 2008; Reizenberg 2017). Research done on freshwater fish species in South Africa using upper thermal limits as a measure of thermal sensitivity, has shown that range contractions in cool-adapted indigenous species may create opportunities for increased invasions by warm-adapted invasive predatory fish (e.g. centrarchids such as Largemouth and Smallmouth Bass (*Micropterus salmoides* and *M. dolomieu*)) (Dallas & Rivers-Moore 2014; Reizenberg 2017). On the other hand, range contractions are expected for cool-adapted invasive fish inhabiting cool stream headwaters (e.g. Rainbow Trout [*Oncorhynchus mykiss]*) in the CFR, as a result of increased ambient temperatures and decreasing river flows (Shelton *et al*. 2018).

The responses of species to the effects of direct climate warming are varied. Resilient species or those that adapt by developing genetic or behavioural tolerance/resilience are largely unaffected by shifts in climate. In contrast, highly sensitive species with narrow habitat tolerances (such as optimal temperature and water depth ranges), that are unable to move, change or adapt to change are at risk of population declines or extinction (Dallas & Rivers-Moore 2014). Other species traits that increase a species' vulnerability include a dependence on environmental cues (i.e. high responsiveness to climatic factors such as temperature and floods), dependence on interspecific interactions, low dispersal distances and poor colonising abilities (Dallas *et al*. 2012).

In southern Africa, some species are currently displaying sensitivity to increased temperatures. The Natal Cascade Frog (*Hadromophryne natalensis*) is an example of this, with tadpoles at lower altitudes being more vulnerable than those at cooler, higher altitude sites (Rivers-Moore & Karssing 2014). According to the South African Bird Atlas Project 2 (ongoing since July 2007 through the Avian Demography Unit, University of Cape Town), 11 species of birds associated with inland aquatic ecosystems in South Africa are observed to be threatened by droughts, storms and flooding (Taylor & Peacock 2018). Furthermore, 37 of the country's Important Bird Areas (IBAs) are listed as being threatened by climate change and severe weather (Taylor & Peacock 2018).

Decreasing inundation and river flows are expected to have a negative impact on faunal species dependent on aquatic and riparian vegetation. In South Africa, the Critically Endangered Riverine Rabbit (*Bunolagus monticularis*) is threatened by a substantial range constriction and possibly risk of extinction due to a projected 97% reduction of suitable habitat in riparian zones resulting from the desiccation of river margins (Hughes *et al.* 2008). Some population declines are occurring as a result of interactions between climatic and human drivers. The endemic Cape Clawless Otter (*Aonyx capensis*) and the indigenous Spotted-necked Otter (*Lutra macullicollis*) are under threat from a combination of impacts including climate change, pollution, invasive plant encroachment and habitat loss or degradation (Jacques *et al.* 2015).

Montane species that generally occur with a high degree of isolation and fragmentation face the highest risk of extinction. These include cold-adapted Gondwanaland relict species of the CFR, which may become increasingly vulnerable as their currently restricted high-altitude ranges becoming increasingly limited under warming conditions (Rivers-Moore *et al*. 2013; Dallas & Rivers-Moore 2014). These invertebrates are tolerant to narrow temperature ranges, and to cool and fast-flowing water, and so they are highly vulnerable to shifts in climatic drivers (Dallas *et al*. 2012).

As habitat niches open up due to range reductions, decreases in abundance and extinction of indigenous species, opportunistic or hardy species that are more tolerant of the altered environmental conditions may establish (Sorte *et al*. 2013; Dallas & Rivers-Moore 2014). Better-adapted invasive species may out-compete indigenous species (Dallas & Rivers-Moore, 2014). For example, multivoltine alien species may respond to warming temperatures by shortening the lifecycles and increasing the number of lifecycles each year, leading to increases in abundance over competing univoltine species (Dallas *et al*. 2012). Some pest species such as the Pitcher Plant mosquitoes (*Wyeomyia smithii*) are developing increased resistance to heat and aridity (Chapman *et al*. 2011), leading to extended breeding periods (Bradshaw & Holzapfel 2008) and more frequent and severe outbreaks of these problem species.

Several of the most common invasive aquatic plants are projected to expand along the coast of South Africa and in the Western Cape (Hoveka *et al*. 2016). Invasive plant species with higher transpiration rates than indigenous plants and that are suited to warm climatic conditions, are enhancing climatic drying effects to further damage moisture-sensitive habitats such as the peatlands of South Africa (Grundling *et al*. 2017).

Some indigenous species may be developing tolerances to climatic shifts and the subsequent changes to inland aquatic ecosystem structure and function. In South Africa, for example, native fish species of the family *Anabantidae* (the climbing perches) are predicted to increase their thermal tolerances and preferences by adapting to warmer conditions (Reizenberg 2017). In other research on 37 frog species, endemic to the CFR, some species have shifted ranges and shown genetic or behavioural adaption, while others went extinct (Mokhatla *et al*. 2015). These changes are expected to continue with a predicted 70% reduction of optimal habitat for these amphibians, driving a range shift northwards and eastwards towards cooler, higher altitudes.

Temperature is known to be the major abiotic factor that influences phenology, i.e. the seasonal timing of life history events (Scranton & Amarasekare 2017). Phenological shifts have been found to occur in certain ectothermic (cold-blooded) species as a direct response to climate warming. In modelled data, peak abundances are expected to occur earlier in the year in regions where mean ambient temperatures are increasing, but are delayed where climate warming is expected to increase seasonal fluctuations (Scranton & Amarasekare 2017).

Some plant species have responded to elevated air temperatures by advancing seasonal changes at differing rates – spring lifecycle events have occurred progressively earlier since the 1960s in conjunction with later onset of autumnal phenological events which are less pronounced and more varied than before (Walther *et al*. 2002). For example, Mediterranean climate spring onset has advanced at different rates than in the neighbouring alpine regions over the last 50 years (Richardson *et al*. 2013).

Across Africa, the start of the annual growing season is now delayed, affecting riparian, wetland and peatland vegetation (Adole *et al*. 2018). Mismatches are occurring over seasonal onset, for example, snow melt is exposing high-altitude perennial and herbaceous plant species to frost damage (Richardson *et al*. 2013), and over different trophic levels in seasonal or life cycle timing (e.g., diatom bloom, and predating zooplankton [Visser & Both 2005]). The germination of wetland plant species is dependent on dry periods when the water level drops and different seasonal triggers may lead to different species establishing a foothold in a wetland. In natural wetland habitat, the opportunities for germination are minimal and most species establish through clonal growth (Sieben & Le Roux 2017). This means that climate change may lead to a decrease in clonal species and thereby even to additional erosion as clonal species can help prevent erosion with their dense rooting network (Mofutsanyana 2016).

In the future, long distance migration and species dispersal between marine and river environments will be affected by temperature and water velocity changes (Whitehead *et al*. 2009), while freshwater bird species also are beginning to be affected by changes in seasonal rainfall timing and volume such as the decline of the Blue Crane (*Anthropoides paradiseus*) (De Villiers 2009).

3.3.5 Community composition – diversity, structure, species interactions

Incidences of shifts in community composition in response to changes in key climatic and environmental variables have already been observed in wetland soils, lakes and riverine environments across the world. In the southern Cape region of South Africa, for example, reduced daily stream flows have led to changes in macroinvertebrate community structure, as flow-dependant taxa have disappeared and been replaced by non-flow-dependant taxa (Eady *et al*. 2014). In seep wetlands in the southwestern Cape, there is a direct relationship between soil moisture and the composition of the algal communities inhabiting the wetland soils (Snaddon *et al*. 2014). A shift from perennially saturated to intermittently saturated soils leads to a change in dominance from filamentous green algal species to diatom species.

Warming atmospheric temperatures are affecting the thermal stratification of lakes in Europe and eastern Africa, isolating nutrients from the euphotic zone lying closest to the water surface (Bates 2008) with implications for available food for lake phytoplankton. More variable and lower flows may have reduced lake water inflows, also lowering levels of nutrients introduced into lake water and so changing lake plankton dynamics, as less available plankton is available as a food source for resident fish, affecting aquatic communities throughout the trophic levels (Bates 2008).

In the future, more resilient species are likely to become more abundant in communities responding to warming temperatures and changes in frequency, duration and intensity of rainfall events, with subsequent flow variation and more frequent and greater extreme events (Dallas & Rivers-Moore 2014). For example, macroinvertebrate species are predicted to lose rare, sensitive species to be replaced by common opportunist species (Eady *et al*. 2014) while shifts within communities will increase their vulnerability to opportunist invasions of invasive species (Snaddon *et al*. 2000). Changes in riparian vegetation composition are anticipated as a result of flow changes and especially flood events, causing species to be lost or to move away. Non-riparian species are expected to increase in abundance in areas where flows decrease. Changes in riparian vegetation will affect the degree of shading, affecting ambient and water temperatures and so altering aquatic community composition, such as the loss of functional feeding groups that are dependent on riparian vegetation as a food source (Dallas & Rivers-Moore 2014)

For wet grasslands and pan vegetation in the interior of South Africa, changes in water availability will alter the competitive relations within communities (Joyce *et al*. 2016). This means that other species, either terrestrial species, or more saline-adapted species can start to gain ground in palustrine wetlands, altering community structure and function, and ultimately also ecosystem services. Of particular concern is the anticipated disappearance of species with a dense clonal network of roots, as they play an important role in protection against erosion in steeply sloped wetlands (Mofutsanyana 2016). Competitive exclusion of a certain group of species may, in this case, affect the geomorphology and hydrology of the wetlands.

3.3.6 Genetic composition – genetic differentiation, diversity, co-ancestry

Climate change clearly is having an impact on species and communities, and so it can be expected to impose natural selection on ecologically important traits (Franks *et al*. 2007). It is probable that drought and other climatic drivers will play a role in the evolutionary response to climate change at the genetic level. In an experiment examining flowering times in the annual, Field Mustard (*Brassica rapa*), it was found that the onset of flowering is an inherited trait, and that individuals were found to flower earlier after droughts, as an adaptation to the shortened flowering season brought about by drought (Franks e*t al*. 2007). This adaptive evolution occurred in just a few generations. In the same study, Franks *et al*. (2007) found that the Thale Cress Plant (*Arabidopsis thaliana*), has 43 candidate genes potentially assisting in climate adaptation, including genes governing flowering times and location, and genes that increase seed production under increased atmospheric CO_2 concentrations.

Although there is little specific information examining genetic response in aquatic species to climate change, there is evidence that species show polymorphisms that are differentiated by climatic drivers. For example, Redband Trout (*Onchorhyncus mykiss gairdneri*) from six montane and desert locations possess five polymorphisms differentiated by water temperature (Ward *et al*. 2000).

Decreased connectivity within catchments may lead to decreased movement of individuals within metapopulations of certain species, and an environment that favours generalist or opportunist species will

also drive populations towards homogeneity (Eady *et al*. 2013). Overall, these factors will lead to a reduction in genetic diversity (Dallas & Rivers-Moore 2014).

3.4 Impacts of Climate Change on People

Climate change impacts in South Africa will primarily be felt in the water sector. The economies of most southern African countries are highly dependent on natural resources and, in particular, water resources. There are millions of subsistence farmers in Africa who depend on rainfall that is already naturally very variable (Engelbrecht *et al*. 2015). In addition, there are parts of South Africa where people in communal rural areas under Traditional Authorities gather their water directly from natural sources such as springs, wetlands and rivers. Groundwater contributes a relatively small percentage of water to bulkwater supply in South Africa, however, more than 60% of South Africa's population is dependent on groundwater resources (Braune & Xu 2010). It has been estimated that 90 million people in rural Africa are at risk of losing access to groundwater resources, should a reduction in rainfall lead to a decrease in recharge (Villholth *et al*. 2013).

Dependency on these natural water sources increases towards the more arid parts of the country. The relationship between human health or economic wealth and the state of these water resources is a close one. Wetlands and rivers that are intact provide the most reliable provisioning services (Russi *et al*. 2013; see also Chapter 2). Climate-resilient natural ecosystems deliver a wealth of ecosystem services, including both climate change mitigation (e.g. through carbon sequestration potential) and adaptation (e.g. through cooling or buffers protecting urban areas from storm impacts and providing water infiltration areas). However, the close relationship between ecosystem condition and ecosystem services is little understood, and in most cases, undervalued by human communities irrespective of their economic status. To provide ecosystem services, natural ecosystems need to be secured and appropriately managed or rehabilitated, and this will simultaneously contribute to both climate change mitigation and improve the resilience of natural ecosystems and human communities to climate change.

Wetlands and rivers are subject to many pressures, and continue to be degraded resulting in a loss of ecosystem services which they can provide (Turpie *et al*. 2010; Snaddon *et al*. 2018). Climate change will exacerbate ecosystem degradation, and this will have an impact on ecosystem services, and the people that rely on them.

These impacts include (see also DEA 2013):

- Reduced water for irrigation and for consumption;
- Increased salinization of water sources as a result of increased evaporation;
- Decreased food security due to unreliability of water supply;
- Increased extreme weather events (strong winds, sea surges, heat, fire, heavy rainfall, floods, droughts) causing damage to and loss of property and infrastructure, fatalities and injuries;
- Increased frequency of sewage spills and other pollution events in areas of high and / or intense rainfall (such as from blockage or overspill from sewage pipes and waste water treatment works);
- Increased mobilisation of catchment pollutants, such as pesticides, herbicides, fertilisers and sediments into rivers, wetlands and groundwater;

- Reduced dilution of irrigation and urban return flows, leading to increased pollution of water sources;
- Loss of topsoil as a result of increased runoff and rainfall intensity, which would lead to reduced agricultural productivity and reduced quality of agricultural products;
- General environmental degradation, leading to forced migration and conflict;
- Decreased air quality due to increased CO_2 emissions and increased occurrence of allergens;
- Increased frequency and intensity of wildfires (in areas with increased drought);
- More favourable conditions for the incubation and transmission of water and food-borne diseases. For instance, for disease vectors such as mosquitoes, molluscs and ticks, as a result of increased ambient and water temperatures; and
- Increased threats to mental health, as a result of increased stress, conflict and discomfort, and decreased food and water security.

Human vulnerability to climate change can usefully be split into three main components – **adaptability** (i.e. capacity or ability to respond to shifts in climate and its consequences), **sensitivity** (i.e. the extent of dependency on resources, in this case inland aquatic ecosystems) and **exposure** to stressors or hazards (i.e. the probability or risk of a community being exposed to a certain impact) (Stuart-Hill *et al*. 2012). Stuart-Hill *et al*. (2012) found that frequently it is the communities that are least able to adapt that are most sensitive to climate change, *and* that face the greatest exposure to the impacts of climate change. Furthermore, the adaptability of human communities is compromised by a lack of information and / or education with regards to climate change, and also a lack of capacity to protect themselves from the impacts of climate change (Villholth *et al*. 2013). For instance, communities that are dependent on open, natural water sources (such as rivers) are vulnerable to waterborne diseases and changes in water quantity and quality (Stuart-Hill & Schulze 2012). Communities with a high dependency on groundwater resources are particularly vulnerable to groundwater drought, especially where there is a combination of a high likelihood of increased meteorological drought (decreased or less reliable rainfall, extended dry periods, *etc*.) and low productivity aquifers (Villholth *et al*. 2013).

People that are particularly vulnerable to these impacts include those that have a limited ability to adapt to the associated changes, are sensitive to the changes, and/or have a high exposure to the impacts. These are the very young and very old, persons diagnosed with chronic medical conditions or who are immunocompromised, pregnant women, the urban and rural poor, and outdoor workers (Ebi *et al*. 2008). More than half of the world's population lives within 60 km of the coast (World Health Organisation [WHO] 2018) and approximately a fifth of the population within 30 km of the coast, placing them at risk of flooding and coastal erosion from sea level rise and increased sea surges (WHO 2018). Many of the countries of the world have their capital cities located on the coast, and most of the world's megacities are in the coastal zone and, furthermore, population numbers in this zone are increasing faster than for inland zones (Neumann *et al.* 2015). Africa is expected to have the highest rates of population growth and urbanisation in the coastal zone, particularly in Egypt and sub-Saharan countries in Western and Eastern Africa (Neumann *et al*. 2015). In Mozambique, 60% of the population lives on the coast (USAID 2018).

Assessments of the impacts of climate change on human health can only be estimated. A World Health Organisation (WHO) assessment, taking into account only a subset of the possible health impacts, concluded that climate change is expected to cause approximately 250 000 additional deaths globally per year between 2030 and 2050, from malnutrition, malaria, diarrhoea and heat stress (WHO 2018).

Public health actions, especially preparedness and prevention, can do much to protect people from some of the impacts of climate change. Early action provides the largest health benefits as threats increase or accumulate, our ability to adapt to changes may be limited. Climate change is likely to exacerbate existing human health problems in South Africa, and the country's weak health infrastructure in rural areas needs to be addressed if the country is to prepare for the impacts of climate change.

3.5 Recommendations

> 'The costs of adapting are less than the cost of doing business as usual. And the benefits many times larger.' Ban Ki-Moon (Secretary General of the United Nations, and leader of the Global Commission on Adaptation)

It is essential to build resilience to climate change within the water and biodiversity sectors of South Africa. Inland aquatic ecosystems can play an important role in climate change regulation or mitigation, and in improving climate adaptation and resilience (Moomaw *et al*. 2018). These relate back to the ecosystem services provided by rivers and wetlands. Intact rivers, inland wetlands and catchments offer the best ecosystem services (Dinerstein 2019). The primary ecosystem service for climate mitigation is carbon storage, while the ecosystem services that relate to climate change resilience include (Moomaw *et al*. 2018; see also Chapter 2 in this volume):

- Flood attenuation;
- Buffering of storm damage and sea surges;
- Water quality regulation;
- Sediment retention;
- Groundwater recharge;
- Water supply during periods of drought;
- Provision of refuges for fauna and flora;
- Provision of corridors for the movement of flora and fauna;
- Maintenance of biodiversity (through provision of habitat); and
- Micro-climate regulation.

Anderson *et al*. (2016, quoted in Moomaw *et al.* [2018:192]) state that 'Protecting wetlands and riparian corridors has been suggested as one of the single best actions in promoting resilience and in sustaining biodiversity (Naiman *et al*. 1993; Fremier *et al*. 2015)'. However, current planning, management and conservation guidelines and policies in South Africa often lack specific detail with regard to how to achieve resilience through ecosystem-based adaptation. It is essential to ensure that responses to climate change to not constrain other, future options or actions, especially due to the uncertainty surrounding climate change predictions (DEA 2013). In other words, South Africa should develop the ability to respond to unforeseen changes and events, monitor appropriate indicators so that changes can be observed, and adopt flexible planning to allow appropriate responses as conditions change.

In practice, such a proactive approach (see Dallas & Rivers-Moore 2009) would require the:

- Development of a coherent and co-ordinated national strategy within an enabling framework for mitigation of and adaptation to climate change;

- Prioritisation and allocation of resources by key institutions at the sub-national level for planning, infrastructure development and conservation and management of inland aquatic ecosystems; and
- Planning and design of local interventions and actions that link with the national strategy while also responding to local challenges, resources and capacity.

3.5.1 Policy and planning for mitigation and adaptation

- A national climate change mitigation and adaptation strategy should inform national, provincial and local policies and guidelines. This will require co-operation between and amongst many levels of governance in South Africa. Specifically, for the water sector, there should be improved co-ordination and co-operation between the Department of Water and Sanitation (DWS) and the Department of Environment, Forestry and Fisheries (DEFF).
- Resilience discourse and rationale should be absorbed into policy and planning, at all levels of government (such as the 100 Resilient Cities initiative) and society (e.g. Folke *et al*. 2004; Walker *et al*. 2012; Anderies *et al*. 2013).
- The Global Deal for Nature (GDN) strongly advocates the urgent conservation of 50% of the Earth's natural habitats in order to maintain the atmosphere within safe limits, and to conserve biodiversity (Dinerstein 2019). This goes well beyond the currently-held principle in South Africa and elsewhere that conserving 20% of inland aquatic ecosystems will effectively conserve and maintain aquatic biodiversity, and embraces the broader notion of climate change resilience, which would require the protection of a significantly larger area of the Earth's surface.
- The planning of water supply and treatment infrastructure needs to build in sufficient operational flexibility to continue to perform under different climate change scenarios (DEA 2013).
- With regards to planning for the protection and management of inland aquatic ecosystems, there is a need for new conservation planning approaches and guidelines for their implementation based on knowledge of the effects of climate change and their impacts on species and ecosystems (Heller & Zavaleta 2009; Magris *et al*. 2014), and even less so in South Africa. Ideally these should be tailored according to local knowledge and in local contexts (Papathoma-Köhle *et al*. 2016).
- Magris *et al*. (2014) found that studies on the incorporation of climate change into conservation planning are predominantly qualitative and subjective. Few of the quantitative statements made (e.g. 'protect at least three examples or a percentage of each conservation feature'), especially with regard to inland aquatic ecosystems, are ecologically justified, or supported by calculations and/or models. Recommendations are frequently based on expert opinion, authors' opinions, and precedents in previous planning exercises, often in other parts of the world. For example, most of the research on urban climate change adaptation comes from cities in the Global North, with little empirical research originating from the Global South (Taylor 2017). More research to identify ecosystems' and species' thresholds under changing climatic conditions in aquatic ecosystems is therefore required.
- There should be a concerted effort to design conservation plans that will improve climate resilience, through avoiding or mitigating climate change impacts and promoting recovery after disturbance. This approach is making headway in at least two South African cities – Durban (Van Rooyen 2018) and Cape Town (Holmes *et al*. 2019), where the approach of embedding climate change adaptation strategies or a climate vulnerability layer into the Strategic Conservation Assessment has been followed as a step towards integrating climate information into biodiversity planning. Note that addressing climate change adaptation in conservation planning is only one of

many approaches required, in concert with improved management and protection, to address the multiple threats to biodiversity (Heller & Zavaleta 2009). Lessons learnt from these cities should be absorbed into conservation planning guidelines and implementation strategies.

3.5.2 Implementation and Management

- The Protected Areas Expansion Strategy should take inland aquatic ecosystems into account, and how these will be impacted by climate change. Protected areas should aim to incorporate climate refugia, future biodiversity hotspots, and habitats for species that are particularly vulnerable to climate change (such as amphibians) or that are of high conservation value (Heller & Zavaleta 2008; Mawdsley *et al*. 2009). For this, data intensive simulations and analytical models of future species, biome or community distributions, such as (but not limited to) bioclimatic niche modelling, is required. Other important considerations include aspects like reserve size, connectivity along rivers and between rivers and wetlands, conserving specific features within protected areas, refugia and bioclimatic variability (Heller & Zavaleta 2008; Holmes *et al*. 2015).
- The overarching goals are to support natural processes, places, and features that minimize or mitigate effects of climate change and, where possible, to create replicate reserves for each species or habitat of concern (Hansen *et al*. 2010).
- Inland aquatic ecosystems outside of protected areas and other conservation areas should be managed in order to retain intactness in order for them to continue to provide refuge for species and healthy ecosystem services (e.g. Dinerstein 2019).
- Inland aquatic ecosystems that are prioritised as Strategic Water Source Areas (SWSAs) should gain some level of protection, or at least be managed according to a set of guidelines that will ensure water security for all, while maintaining environmental flows. These considerations must be key factors in the assessment of the need and desirability of future water supply infrastructure (dams, inter-basin water transfers, pipeline), and may even require the re-design of existing water infrastructure.
- Reduce water demand across sectors: changes in the primary users of water (agriculture, domestic and mining) would require improved technologies and alternative practices for reducing water demands.
- Restoration of degraded inland aquatic ecosystems will become an increasingly important response as demands for their services and the space they occupy continue to grow, and the catchments in which they occur continue to deteriorate (MEA 2005; Glick *et al*. 2011).
- Reduce non-climatic stresses: climate change takes place within a matrix of other, equally destructive, stresses (e.g., pollution, over-exploitation, habitat loss and fragmentation, and invasive alien species), and since stressed ecosystems are generally less resilient to climatic changes, stressors may interact synergistically with climate change (e.g. climate change may compound the erosive flow rates already being experienced by hardened surface catchments).

3.5.3 Monitoring and observation

- There needs to be consensus within the scientific community on key definitions (e.g. resilience) and thresholds of change or of potential concern, so that important indicators of change are being monitored (e.g. Ellery *et al*. 2016; Tooth 2017).

- There should be a research focus on determining how close ecosystems are to thresholds of potential concern (e.g. geomorphological, ecological or even socio-economic), in order to determine their vulnerability, and manage the ecosystems away from these thresholds.
- The effectiveness of monitoring programmes depends on their ability to detect change. This requires the identification of sensitive early warning indicators of change in ecosystem or community structure and function (Grenfell *et al*. 2005; Tooth 2017), and the monitoring of vulnerable species or communities of species (i.e. those most likely to respond to change).
- Government departments with the mandate to protect, conserve, rehabilitate or manage water resources should be encouraged to collaborate on national monitoring programmes. Collaboration can make up for constraints in budget, time or capacity.

3.5.4 Research and conservation

- Research should seek to identify species vulnerable to climate change and understand why they are vulnerable – this is seen as critical to developing climate change adaptation strategies and reducing biodiversity loss in the coming decades (Lauzeral *et al*. 2010; Staudinger *et al*. 2012).
- Funding bodies such as the National Research Foundation (NRF) and the Water Research Commission (WRC) should fund research to improve our understanding of dependencies and responses; e.g. the relationship between groundwater and surface water ecosystems, and how decreases in surface water discharge might impact on groundwater resources, particularly under different climate change scenarios.
- Research institutions need to develop their modelling and analysis capacity, and build the evidence base for species and ecosystem vulnerability under changing climatic conditions.
- Climate change scientists should seek opportunities to take their results, hypotheses and recommendations into the realm of government policy and public discourse (Dallas & Rivers-Moore 2014).

3.6 Key messages

- Inland aquatic ecosystems are likely to be amongst the most vulnerable to the effects of climate change. They are nationally the most threatened ecosystems, and they are significantly under-protected.
- South Africa should embrace the Global Deal for Nature, according it as much importance as the Paris Agreement, and aim to conserve 50% of all inland aquatic ecosystems. This would meet the goal of biodiversity conservation and maintenance and improve the nation's resilience to the impact of climate change.
- Intact rivers, inland wetlands and catchments offer the best ecosystem services (Dinerstein 2019). Ecosystem degradation reduces the resilience of ecosystems and the communities they support to climate change (USCDC 2018).
- While there may be uncertainty with regard to the impacts of the current rate of climate change on rainfall patterns, the high confidence with which increases in temperature have been projected and the high probability that the impact of increases in temperature for sectors such as agriculture and biodiversity will be significant despite uncertainty around rainfall, highlight the need for action, in terms of both mitigation and adaptation.

- South Africa is warming up, with greatest increases being observed over the past few decades. The greatest increases have been observed in summer and autumn. Temperatures across Africa are projected to rise at about 1.5 times the global rate of temperature increase in the subtropics and at a rate somewhat higher than the global rate in the African tropics (Engelbrecht *et al*. 2015).
- To varying degrees all rivers and inland wetlands are vulnerable to climate change and to degradation that will reduce their efficiency in responding to the impacts of climate change.
- Intact rivers, inland wetlands and catchments are refugia for species particularly during times of extreme weather events.
- Corridors linking intact ecosystems with degraded ecosystems are essential to allow movement of species during climate extremes and to sustain ecosystem function.
- River and inland wetland rehabilitation is a critical strategy to increase resilience to climate change and to improve climate change mitigation.
- There is a worrying lack of sufficient records on species and monitoring systems to understand species, community, or ecosystem vulnerability and the extent of adaptation, and therefore an inability to determine thresholds of change.
- Current baseline and impact monitoring are insufficient for ephemeral systems, particularly ephemeral wetlands, for monitoring the impacts of climate change.
- The DWS, whose mandate is to protect inland aquatic and groundwater resources, continues to cut budgets set aside for the monitoring of water quality and water quantity. There is a lack of baseline data which would enhance the ability to detect changes that may be related to climate change. This lack of baseline data will undermine water security in the country and delay our responses to changes in water availability, especially during droughts.
- Understanding the vulnerability of human communities to the impacts of climate change, in terms of adaptability, sensitivity and exposure (*sensu* Stuart-Hill & Schulze 2012), will greatly enhance our ability to develop adaptation strategies.

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4. KEY PRESSURES ON THE INLAND AQUATIC ECOSYSTEMS

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4.1 Introduction

Several studies have speculated that about 50% of wetlands have been lost as a result of land conversion and multiple pressures on inland aquatic ecosystems (DEA&T & CSIR 1999; Finlayson *et al*. 2005; Díaz *et al*. 2019). More recent estimates of losses of wetland extent, range between 35% and 71% since 1900, with an increasing rate of decline noted since the 1970s (Davidson & Finlayson 2018; Darrah *et al*. 2019; UN Report 2019). In fact, the most recent United Nations' (UN's) Global Assessment Report (Díaz *et al*. 2019) released on 6 May 2019, and the first global assessment following the Millenium Ecosystem Assessment (MEA 2005), estimates that > 85% of wetlands (area) present in 1700 had been lost by 2000. In South Africa, an estimated 58% of the inland wetlands in the uMfolozi secondary catchment in KwaZulu-Natal Province were found to be highly transformed by 1988 (Begg 1988). The full extent to which river and inland wetland have been transformed from their natural state is not known, since full inventories of the representation of these ecosystems are not available, and methods to track and monitor these automatically and at regional scale, have several limitations (Dudgeon *et al*. 2006; Van Deventer *et al*. 2018).

The location, extent and severity of pressures on inland aquatic ecosystems are also poorly understood, while uncertainty in the threshold of transformation from a natural to degraded ecosystem is complicated (IUCN 2016). Several drivers, such as urbanisation and a higher demand for water and food, are drivers of changes which results in increasing pressure on natural ecosystems (following the Driving Forces–Pressures–State–Impacts–Responses (DPSIR) framework; Smeets & Weterings 1999). Internationally, key pressures on inland aquatic ecosystems have been identified as 'overexploitation, water pollution, flow modification, destruction or degradation of habitat and invasion by exotic species' (list compiled from review by Dugeon *et al*. 2006:163). Similar pressures have also been listed for South Africa in the National Freshwater Ecosystems Priority Areas (NFEPA) project and the National Biodiversity Assessment of 2011 (NBA 2011) which has been used for this assessment (NBA 2018) too (Nel *et al*. 2011a; 2011b; Nel & Driver 2012). The extent and degree of impact of these pressures on rivers and inland wetland ecosystem types in South Africa remains deficient.

Rivers and wetlands are often at the receiving end of surface runoff from the landscape as well as interflow and being interconnected, the impact of pressures is widespread (Dudgeon *et al*. 2006). The severe degradation of rivers and wetlands have consequently impacted freshwater species, with their threat status considered to be worse than that of terrestrial species, and their rate of decline considered to be globally higher than estimated statistics (Sala *et al*. 2000; Darwall *et al*. 2009; Collen *et al*. 2014). Freshwater species have adapted to these dynamic aquatic environments and often migrate up and downstream in river systems or disperse and migrate across the landscape between rivers and inland wetlands. Their physiological adaptations and dependency on the aquatic environment make them highly dependent on these range-restricted habitats, where their adaptations to the aquatic environment resulted in further

vulnerability to multiple and cumulative pressures in the aquatic environment. Very often, species are also limited in the thermal, depth and nutrient ranges that they require for habitation or breeding, and connectivity for dispersal and migration (Dallas 2008; Sievers *et al*. 2018). The multiple pressures in the landscape that accumulate within rivers and wetlands, result in a higher risk for extinction of freshwater species compared to terrestrial species (Collen *et al.* 2014). A global assessment of freshwater species showed that the loss of habitat and subsequent fragmentation is one of the major pressures causing their decline (Collen *et al*. 2014). These results were primarily influenced by studies done in countries with a higher availability of water, and considering that South Africa is a semi-arid country, water availability may be the key limiting factor and other pressures potentially secondary. Knowledge on the degree to which ecosystems and species can survive the impact of a variety of pressures, and the cumulative impact of pressures on systems and species, remains to be determined.

Rivers and inland wetlands are a pivotal resource for both biodiversity and socio-economic development and management is therefore a challenge. To this extent, the use of systematic and spatially explicit assessment and conservation planning of rivers and inland wetlands increased globally in the past two decades (Nel *et al*. 2007). In South Africa, the National Spatial Biodiversity Assessment of 2004 (NSBA 2004) was the first national assessment using systematic conservation planning principles and spatial explicit data for assessing river ecosystem types (Driver *et al*. 2005; Nel *et al*. 2007). The Aichi target 11 (CBD 2011–2020) aims to protect at least 17% of inland water by 2020, while target 12 aims to prevent the extinction of threatened species (CBD 2011–2012). This implies more than just including these ecosystem types within a protected area network. Being situated within a protected area network does not guarantee that systems are maintained in a natural or near-natural ecological condition, since pressures outside the boundaries of protected areas will affect rivers and inland wetlands within the network (Nel *et al*. 2007). Water is often a limiting factor for river and wetland ecosystem types, and more so in a semi-arid country such as South Africa, where half of the country receives a mean annual rainfall of 400 mm per annum; a value significantly less than the estimated global of > 1 000 mm (Schulze & Lynch 2007; Kidd & Huffman 2011). Consequently, rivers and inland wetlands in South Africa are a pivotal resource for both biodiversity and socio-economic development, and therefore management is remains challenging.

In summary, the four gaps related to the pressures on rivers and inland wetlands include:

- a lack of knowledge on the extent of rivers and wetlands;
- a lack of knowledge on the extent of different types of pressures;
- the cumulative impact of these pressures on inland aquatic ecosystems; and
- the ability of ecosystems and freshwater species to withstand or recover from a multitude of pressures.

This chapter provides an overview of the known pressures which influence rivers and inland wetlands in South Africa. We have built on the existing pressures which have been listed in the National Freshwater Ecosystems Priority Areas (NFEPA) project, which include flow alteration, water quality, habitat degradation and fragmentation, invasive species and climate change (Nel *et al*. 2011). These pressures have been extensively workshopped and agreed on through various stakeholder workshops held during the NFEPA project.

The process and categorisation of the ecological condition for rivers has been formally adopted by DWS (Box 4.1). The Present Ecological State (PES) categories are used in the River Eco-status Monitoring Programme (REMP) and National Wetland Monitoring Programme (NWMP), and include variables related to flow, water quality and habitat. Metrics to be used for inferring the PES for inland wetlands have,

however, not been formalised to the same degree as for rivers. Therefore, owing to a lack of formalisation of the metrics for modelling the PES of inland wetlands, available knowledge and spatial datasets related to pressures should be investigated to understand how ecological condition of inland wetlands can be modelled, as well as the future monitoring of the pressures and their impacts. Likewise, regional to national information on the extent of pressures on rivers are also reviewed, to see how these could inform their ecological condition.

For each NFEPA pressure category, a number of questions guided the evaluation:

- Are the extent and severity of pressures and related impacts on inland aquatic ecosystems well understood, well mapped and well monitored?
- Which datasets, surrogates or indicators are available at a national scale for describing the pressures and impacts? Is any trend analysis available for these indicators? Are there any international trends and indicators which can serve South Africa?
- Is monitoring of these pressures and impacts sufficient to determine the status and trends of the ecosystems, and to inform policy and decision making?
- Would any particular aspect of climate change exacerbate the current pressures and impacts on inland aquatic ecosystems? Do we have knowledge on the geographic distribution of these potential impacts and the severity thereof?

The next section (Section 4.2) provides a summary of the key pressures associated with inland aquatic ecosystems, whereas Section 4.3 provides a more in-depth overview of the selected pressures. Section 4.4 gives an overview of the emerging and intensifying pressures, followed by Section 4.5 on the Interactions, combinations and synergy of the pressures. Changes in pressures are discussed in Section 4.6 and the Chapter concludes in Section 4.7.

4.2 Key pressures

The key pressures considered for the inland aquatic ecosystems of the NBA 2018 include:

- **Changes to the hydrological regime and subsequent fragmentation.** Water abstraction and diverting of water result in reduced flow in lotic systems and a reduction in water levels in lentic systems. South Africa is an arid to semi-arid country, receiving less than half of the mean annual precipitation of the world. An increasing demand for water and food production results in cumulative pressures on rivers and inland wetlands. Estimations from the 1990s indicated that about 62% of South Africa's water consumption is allocated to the agricultural sector for food production. Other land uses, such as forest plantations, reduces the groundwater availability and surface runoff to inland aquatic ecosystems. Changes to the hydrological regime result in degradation of ecosystems, a loss of connectivity of the habitat which endangers aquatic species and a risk that the system is not intact during critical life stages of organisms.

- **Deteriorating water quality**. Increased levels of sedimentation as well as nutrient, chemical, and thermal pollution impact rivers and inland wetlands. Microplastics are an emerging pressure and concerns around the impacts of endocrine disrupting compounds (EDCs) and the detectability of these pharmaceuticals needs to be addressed.

- **Habitat alteration, modification from natural state and subsequent fragmentation**. Habitat degradation is difficult to detect and map for inland aquatic ecosystems. These objects are fine-

scale features in a broad landscape and may require field assessments for detecting and monitoring degradation. Land cover is a poor surrogate for land uses which impacts rivers and wetlands. Land uses which may result in degradation includes for example overgrazing, drainage of wetlands and other infrastructural developments within these systems. Theses disturbances disrupt functional processes such as fire and flood regimes which are essential for the ecology. Inland wetlands in a poor condition with high levels of organic substrate (peatlands) are prone to long-term burning, and at least 17 wetlands have been identified as having potentially collapsed.

- **Invasive species**. The presence and increase of invasive species, whether faunal or floral, affects the condition of inland aquatic habitats.
- **Over-exploitation of freshwater species** are regulated and managed through the Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES).
- **Climate change is expected to exacerbate existing pressures** particularly in areas where changes in precipitation and temperatures are expected (see Chapter 3 for more details).

4.1 Overview of types and severity of key pressures

4.1.1 Alterations to the hydrological regime of inland aquatic ecosystems

The hydrological regime of inland aquatic ecosystems refers to the 'typical cycle of water movement in an aquatic ecosystem' whereas the 'hydroperiod' refers to the 'frequency and persistence of saturation and/or inundation within an aquatic ecosystem (Ollis *et al*. 2013:97). These natural cycles of river flow or inundation and soil saturation in inland wetlands vary across South Africa. The hydroperiod can be measured by the onset, peak, duration and end of the aquatic phase, very similar to vegetation phenology (Jackson *et al*. 2014). In South Africa, very little is known about the annual and interannual hydroperiod and associated flood-pulse of rivers and wetlands (see Junk *et al*. 2014 for examples of Brazil). Few inland aquatic ecosystems are permanently inundated (Van Deventer *et al*. in review) and therefore the majority would have typical annual signatures in the semi-arid systems, to larger cycles across a number of years, particularly for the arid systems. Pressures which cause deviations from these natural cycles are highly likely to have a negative impact on the ecosystems, changing their functionality. These cycles also impact the resilience of the system and its ability to reset to a near-natural state.

Many aquatic species are highly dependent on inter and intra-annual cycles of the hydrological regime for their life cycles and for reaches to be connected and have good habitat diversity during these times. Anguillid eels (*Anguillidae*), for example, use rivers to migrate inland and back to the marine environment for spawning (see Section 7.1.3). Two of the four eel species have been assessed at Near Threatened, and their major threats are hindering of the migration pathways. Fish species in the mainly winter rainfall fynbos biome are especially vulnerable to unsustainable water abstraction during the hot dry summers – a time when rivers are naturally low and juvenile fish are plentiful in the river. These juvenile fish require good quality habitat of sufficient diversity and quantity to recruit successfully. Alteration of the hydrological regime would negatively impact the ability of the inland aquatic ecosystems to sustain species diversity or offer refugia under conditions of drought (see Chapter 3).

Box 4.1. Deriving the ecological condition of rivers in South Africa (Kleynhans & Louw 2007).

The EcoClassification and EcoStatus Determination approach (or Present Ecological State / PES model) for the assessment of the ecological condition of rivers in South Africa was developed by Kleynhans & Louw (2007) (See Section 5.2.1), taking into account abiotic and biotic components, as well as the pressures and impacts on the ecosystems and species (Figure 4.2). The assessment of the ecological condition of rivers (see Section 5.2.1 for a desktop level assessment) uses habitat drivers (e.g. flow, water quality, instream habitat) and biotic responses (vegetation, fish and invertebrates) to the pressures. The PES model therefore recognises that secondary 'drivers' may result as a consequence of the impact that resulted from the pressures (DPSIR) or stressors (PES model). The River Health Programme, conceptualised since 1994 and in operation between 1998 and 2010, adopted the EcoClassification or EcoStatus approach and was forward-thinking in considering both the pressure (stressors) and resilience of ecosystems and species to the pressures (Strydom 2003; Strydom *et al*. 2006). In this NBA, we distinguish pressures from impacts similar to the DPSIR model, whereas the PES model and EcoClassification approach is used in guiding the ecological condition categories of rivers and inland wetlands.

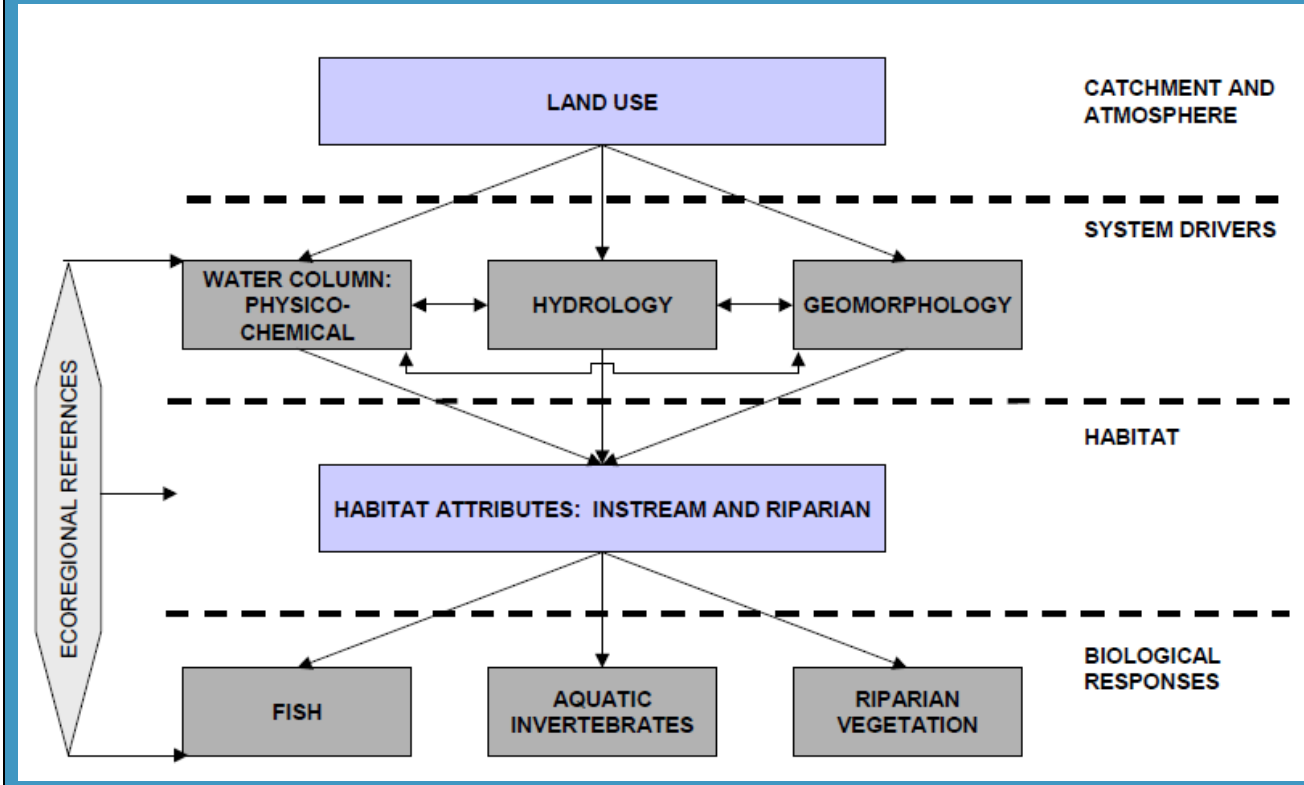


Figure 4.1. Desktop Present Ecological State (PES) assessment (Kleynhans & Louw 2007).

In 2016, the Department of Water and Sanitation (DWS) has renamed the River Health Programme, now referred to as the River Eco-status Monitoring Programme (REMP). At the same time, the monitoring of inland wetlands has been conceptualised in the National Wetland Monitoring Programme (NWMP) (Wilkinson *et al*. 2016). Both these programmes are yet to be operationalised as part of the National Aquatic Ecosystem Health Monitoring Programme (NAEHMP).

A decline in water availability in wetlands results from a number of pressures. **Water abstraction** from aquifers, rivers and inland wetlands for human consumption as well as for use in economic activities such as crop irrigation, stock watering, forestry, manufacturing and mining, result in the decline of available water to wetland ecosystems (e.g., Durand 2012). Approximately 14.7 billion m^3/annum of surface and groundwater is abstracted from the environment for multiple purposes (Malai *et al*. 2018). The bulk of the

water balance is supplied from surface water (±97%) while groundwater forms a small proportion of the total supply (Malai *et al*. 2018; DWS 2018; 2019). The majority of the water is used for agricultural activities, estimated to range at 46–66% of the total use (Basson *et al*. 1997; Malai *et al*. 2018; DWS 2018; 2019), this is followed by municipal water use as the second biggest user at around 27%. An estimated 33% of this return to the environment, primarily from urban and agricultural water users (Malai *et al*. 2018), but the flow is not necessarily returned to the point of abstraction. This return water is often of a poorer water quality than what was abstracted. Uncertainties prevail in the statistics of agricultural use since this sector is largely unmetered, with concerns about unauthorised abstraction (DWS 2018) and in general it is acknowledged that South Africa needs to get a better grip on water availability and usage trends in the country.

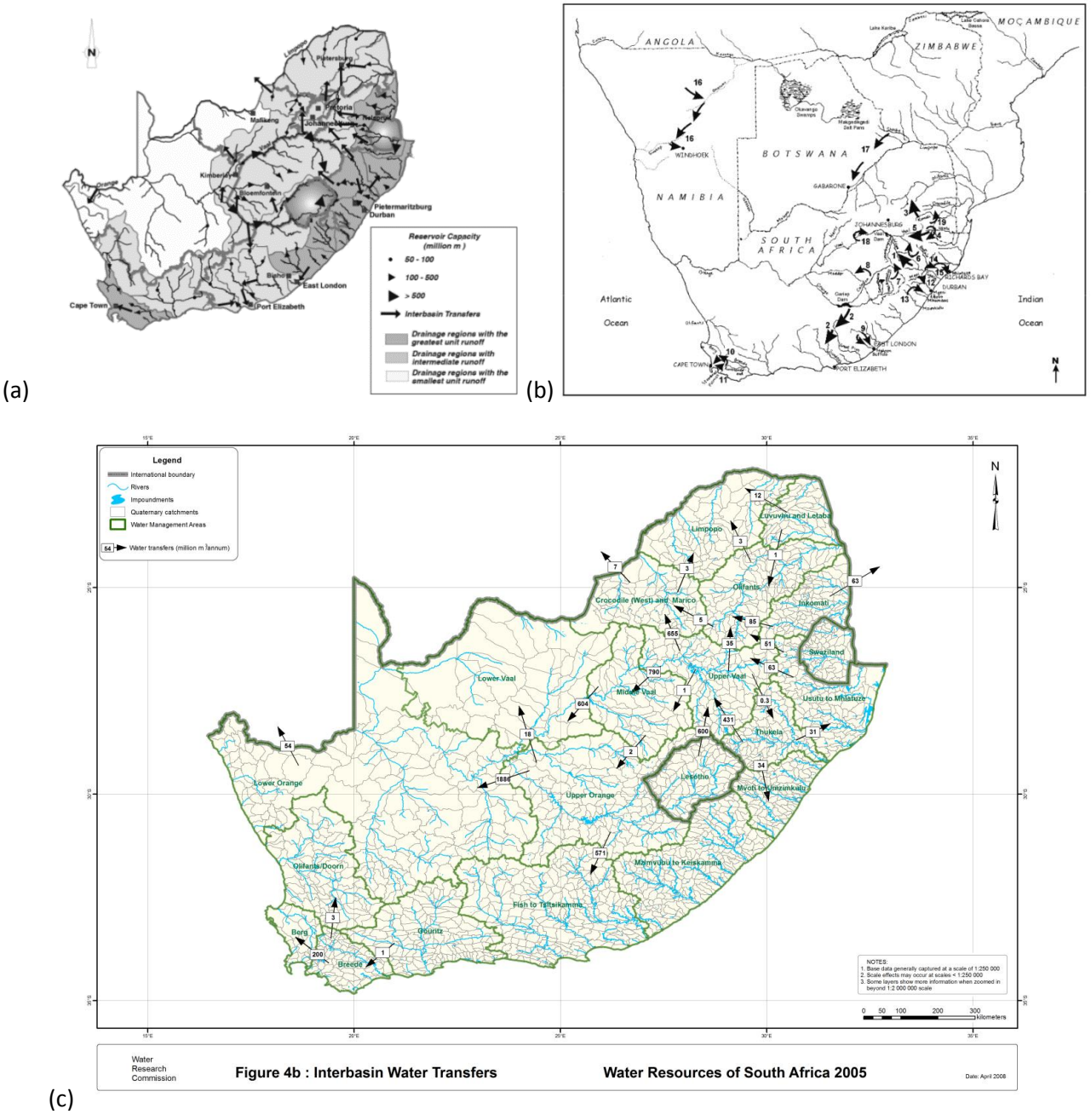


Figure 4.2. Interbasin transfer schemes as mapped by (a) Basson *et al*. (1997:9); (b) Snaddon *et al*. (1999:16) and (c) Bailey & Pitman (2012).

Channels and drains are used to drain wetlands and reduce the soil saturation or inundation, so that the land can be used for grazing or crop production. Water diversion can occur at a small or large scale, from local rerouting of surface water to **interbasin transfers** (Figure 4.2; Basson *et al*. 1997; Snaddon *et al*. 1999). A reduction in water availability may have several impacts, including the deterioration and loss of habitats, changes in species composition, loss of sensitive species, bank and bed erision in recipient catchments, species invasion and hybridization, mobilisation of trace metalds and changes in the chemistry and thermal ranges of recipient rivers. One of the largest interbasin transfers in South Africa, the Orange River to Great Fish or Sundays River, transfers a total amount of 1.7 billion m^3/year water and results in a 500–800% increase in flow in the recipient catchment (Snaddon *et al*. 1999). This has resulted in the Sundays River changing from a seasonal flood-pulse pattern to a permanently flowing river.

Groundwater abstraction can impact rivers and wetlands to different degrees, since only some rivers and wetlands are Aquifer Dependent Ecosystems (ADEs). ADEs are difficult to determine, and require understanding of the geology and sub-surface hydrology of an area (Appendix D; Box D.1). For example, almost half of the 53 springs investigated in a part of the Table Mountain Group aquifer were perched groundwater systems, and therefore not vulnerable to abstraction that were situated in the vicinity. Only sixteen of the springs had deep groundwater connection and therefore vulnerable to groundwater abstraction. Knowledge across the country is lacking to determine the ADE and impact of both surface and groundwater abstraction on these systems.

A loss of available water in peatlands can result in sub-surface fires, changing these systems from sinks of greenhouse gasses to sources (Grundling 1997; Appendix C). Peatlands are unique inland wetlands which store a high amount of organic carbon and sequester carbon. Excessive water abstraction in local and the upper catchments, as well as certain land uses in the catchment, reduces the amount of water in wetlands. The impacts can be severe, particular for aquifer-dependent ecosystems. Droughts, potentially made more extreme through climate change (Blamey *et al*. 2018), would exacerbate the situation and increase the risk of sub-surface fires. The substrate of at least 17 peat wetlands in South Africa has been known to have burnt to date or became desiccated (Figure 4.3; Figure 4.4). Of these, two are situated within Estuarine Functional Zones (EFZs) – KwaMbonambi and Verloren – whereas the rest are all within inland wetlands. The extent of two of these eighteen wetlands is not mapped within the National Wetland Map version 5 (NWM5). These peatlands have formed under permanently inundated conditions over thousands of years. The fact that the substrate of these systems is burning or the surface desiccated, show that their water level has reduced to well below the level of inundation it had been during their formation.

The collapse of these ecosystems results in powerful greenhouse gas emissions such as nitrox oxide and methane gasses. The huge cost to extinguish the fire is often prohibitive. Local municipalities are ill equipped to extinguish the fire. Persistently burning peat fires pose a threat to local communities, their livestock as well as wildlife (Grundling 1997) and contribute to greenhouse gas emissions. Sub-surface peat fires can burn for many years as is the case of the Lichtenburg peatland at the Harts River Catchment in the North West Province (Grundling & Marneweck 2000; Grundling 2018) and the Sibaya wetlands close to the Ezemvelo KwaZulu-Natal Wildlife guard camp (S. Janse van Rensburg, *pers. comm.*). The Mazengwenya and Mbazwne plantations north of Lake Sibaya in the KwaZulu-Natal Province have caused a reduction in the water levels of the Vasi Pan and Vasi Pan North, north of Lake Sibaya and the Mgoboseleni-Shazibi estuarine systems. Consequently, the peat substrate had been burning for 8 months between May 1996 and January 1997 (Grundling 1997). More recently, in July 2015, the Working for Fire team from the Department of Environmental Affairs (DEA) had been called in to extinguish another sub-strate fire in the Vasi Pan (Van Rooyen 2017). This system has subsequently burnt again and more extensively, destroying

the entire northern section (Vazi north) wetland (Appendices C and D). Subsequently, the Betty's Bay fire in January 2019, has also set the Onrus peatland on fire (Grundling 2019).

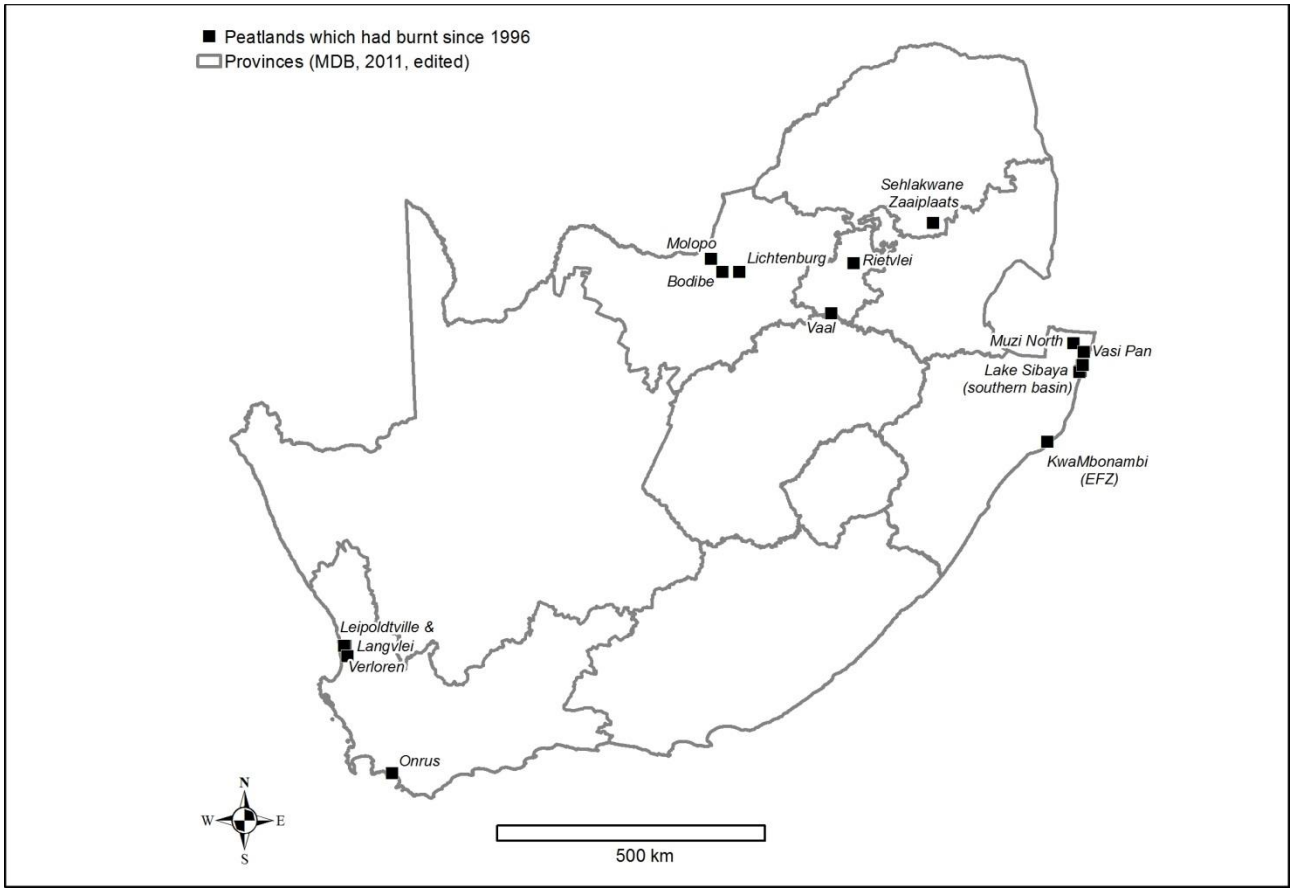


Figure 4.3. Location of 17 wetlands with peat substrates that have burnt or became desiccated since 1996 (see Appendix C and D). A total of four wetlands in close proximity is situated on the southern basin shore of Lake Sibaya.

Burning peat in the Molopo System, North West Province. Photo: P-L. Grundling, 8 May 2016.

Burning peat in the Molopo System, North West Province. Mr Eric Munzhedzi (DEA: NRMP, Directorate: Operations Wetlands) sampling peat with an auger. Photo: P-L Grundling, 8 May 2016.

Molopo System, North West Province Recovering after peat fires. Photo: A. Grundling, 11 May 2018.

Excessive water abstraction in the karstic Molopo River's catchment (North West Province), as well as poor land use practices and droughts, has resulted in the lowering of the groundwater levels below what it has been for an estimated 7 300 years before present. Consequently, an estimated 46 ha of the wetland's peat substrate has been burning since May 2016, and the system therefore considered to have 'collapsed'.

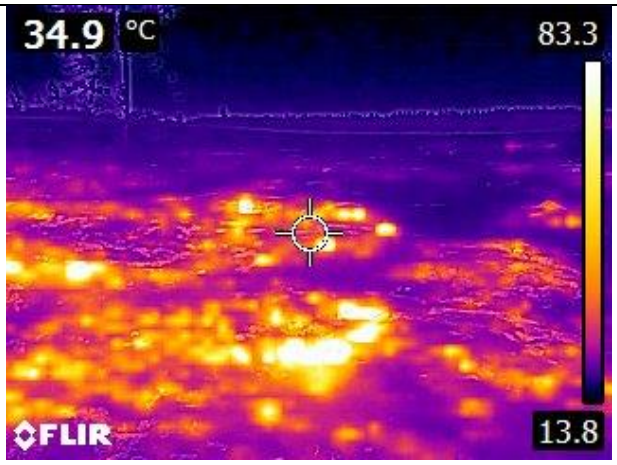
Photo: P-L. Grundling, 8 May 2016.

Burning peat Vazi Pan, KwaZulu-Natal Province.

Photo: A. Grundling, 3 Jul 2015.

The complete loss of loss of peatlands was heart-breaking to local Isibusiso Esihle, Science Discovery Centre Chief Executive Officer Siphesihle Bukhosini "Our wetland is dead! What have I got to show our children now?" September, 2018 (excerpt from Ms Susan Janse van Rensburg, Appendix D).

Vazi Pan North burning September 2017 (Excerpt from Ms Sue Janse van Rensburg, see Appendix D).



Thermal camera used to see burning peat hotspots, Vazi Pan North, September 2017 (excerpt from Ms Susan Janse van Rensburg, Appendix D).

Figure 4.4. Photographs showing the impact of peatlands burning.

Inland wetlands located on the coastal Cenosoic deposits are predominantly aquifer dependent and **highly sensitive to changes in the hydrological regime**. Surface-groundwater interaction is highest in these areas, except where the wetland is fed by a river (P-L. Grundling, *pers. comm.*). These regions include the Maputaland, Algoa, Bredasdorp, Sandveld and West Coast Geological Groups (Roberts *et al*. 2006). Geographically three broad coastal regions are identified for the NBA 2018, including the coastal plain of the West Coast from Oranjemund to the Eerste Estuary, the southern coastal plain between the Lourens and Sikatsha Estuaries, while the Maputaland coastal plain stretch from the Sikatsha to the Kosi (Bay) Estuary along the KwaZulu-Natal Province's coast. To date, seven wetlands have been burning or became desiccated on the Maputuland Coastal Plain (Grundling 1997; Appendix C; Appendix D). The Maputaland Coastal Plain is about 60 km wide near the Mozambican border, and stretches inland up to approximately 300 m above mean sea level (amsl) and constricts southward towards Mtunzini (Visser 1989; Roberts *et al*. 2006). In the West Coast geological Group, at three peatlands have been noted to burn or became desiccated, whereas the Onrus peatland in the Western Cape has been ignited in January 2019 (Figure 4.3).

An increase in the amount of water to inland aquatic ecosystems may result from back-flooding of dam walls, interbasin transfers, Waste Water Treatment Works (WWTWs) and industrial effluent (Figure 4.5). These pressures result in changes in the hydrological regime of the receiving and downstream habitats (Begg 1988; Mitchell *et al*. 2014; Van Heerden 2014). Flooding results in an alteration of habitat from potentially more a seasonally or permanently soil saturated wetland, to an aquatic environment and the displacement of one habitat type by another. If the water quality of the incoming water is different in nutrient, chemical and thermal ranges than that of the receiving environment, the habitat and biodiversity is altered. According to DWS (2018), 56% of the 859 WWTWs are in a poor or critical condition, while 11% are dysfunctional. In January 2019, the Minister of the DWS announces that 46 WWTW were under critical review and municipalities were expected to respond with an emergency plan (News24 2019; Figure 4.5). Discharge may cause minor to severe modifications to the ecological condition and natural community assemblage (Van Heerden 2014).

The Kamfers Dam (North West Province) and the Maryvale (Gauteng Province) wetlands serve as examples in this case. Kamfers Dam was originally an intermittently inundated pan dependent on precipitation, modified to a permanently inundated artificial wetland through storm water runoff and 30–40 mL/day partially treated sewage discharge from the Homevale WWTW (Anderson 2015). It has become the breeding site of large populations of the globally threatened Lesser Flamingos (*Phoenicoparrus minor*) and Chestnut-banded Plover (*Charadrius pallidus*) (BirdLife South Africa 2015). The site has therefore been listed as an Important Bird Area (IBA) and a conservation priority in the Sol Plaatjie Local Municipality's Spatial Development Plan (Nemai Consulting 2010). Kamfers Dam has turned into a management crisis with a lack of water during the 2016 drought period, while both sites have witnessed an increase of water quality and invasive species problems. In addition, effluent hosted avian pox virus which impacted the health of the flamingos in 2007–2008 (Anderson 2015; Zimmermann *et al*. 2011). As a result of the multiple impacts of the various pressures, management costs have increased for sites which sustain unnatural habitats. In January 2019 the Kamfers Dam dried up completely as a result of both drought conditions and the diversion of contaminated and nutrient-rich wastewater from the Homevale WWTW away from the Kamfers Dam. This resulted in the adult flamingo's abandoning newly-hatched chicks and the subsequent effort to save these chicks (Wildenboer 2019).

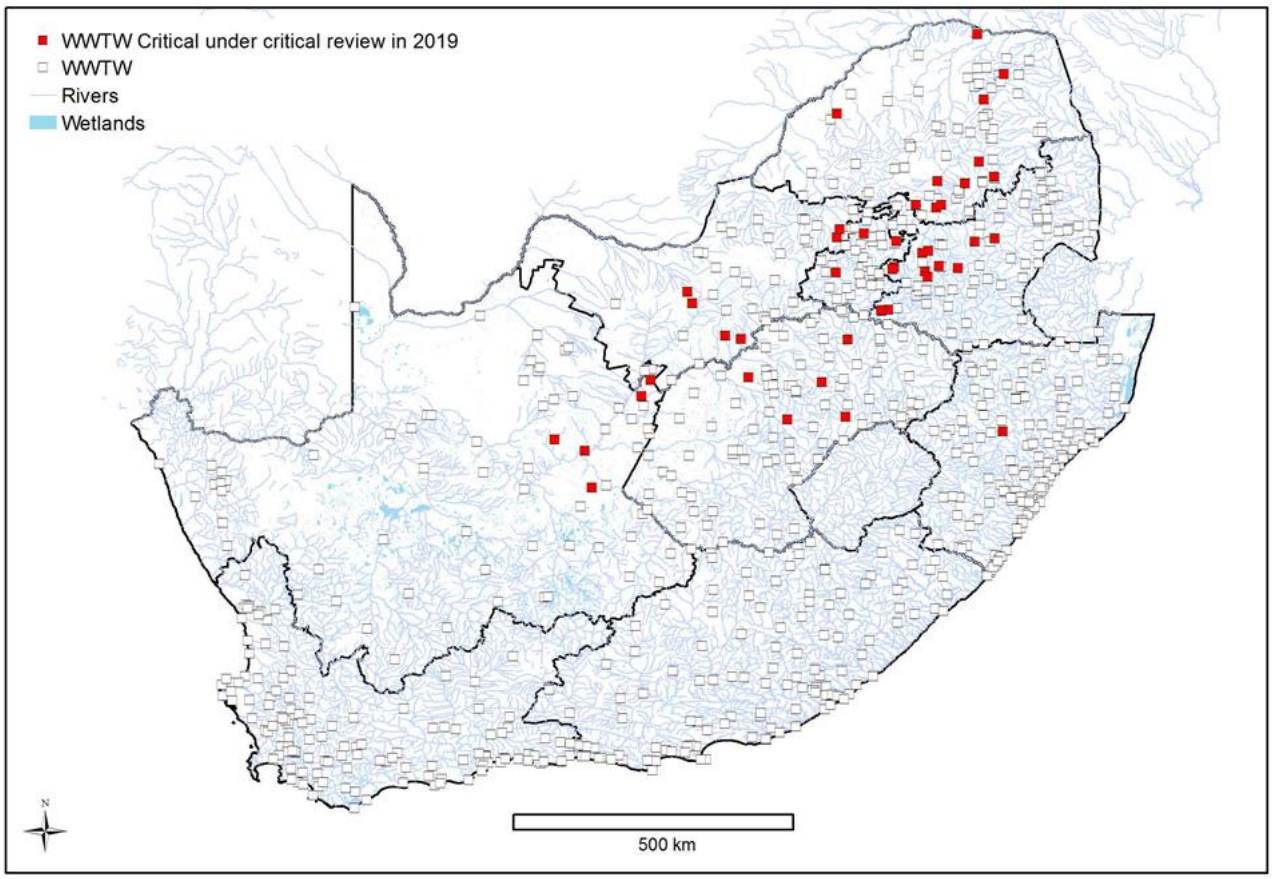


Figure 4.5. Location of Waste Water Treatment Works (WWTW) in South Africa. Rivers and inland wetlands are displayed in the background. WWTW placed under critical review in early 2019 by the DWS is shown in red (News24 2019).

The Blesbokspruit used to be a seasonal wetland up to the 1980s, however mining and industrial water effluent has changed the hydrological regime to a permanently inundated system, overgrown by common reed (*Phragmites australis*) (information from Stan Madden, an environmentalist who has worked in the wetland for over 30 years, see Springs advertisers 2014). The wetland was listed in 1986 as a Ramsar site which is an International Wetland of Importance yet, owing to mining discharges which had taken place since 1995, the wetland deteriorated in ecological condition and was consequently listed on the Montreux Record[8] in 1996 (Durand 2012; Ambani & Annegarn 2015). Regardless of the contribution of Kamfers Dam and the Blesbokspruit to biodiversity, the original wetland ecosystem types have been modified completely from its natural ecosystem type and the management of both sites have become costly.

Alterations to the hydrological regimes can result from dams and weirs being built along rivers and subsequent fragmentation in these linear ecosystems. This can also be caused by unsustainable rates of direct abstraction (pumps) from rivers. Fragmentation of longitudinal connected riverine and inland wetlands have several negative impacts on ecosystem health and biodiversity. Dam walls and weirs reduce the ability of rivers to deliver sediment budget to the downstream catchments and particularly to the coast, while inhibiting the migration of biota along the river channel for various parts of their life cycles. Most of South Africa's freshwater fish species are river dwellers and engage in upstream and downstream migrations for a variety of reasons (spawning, feeding, seasonal migrations etc). Some species migrate great distances (e.g. Anguilid eels (*Anguillidae)*, see for example Figure 4.6) whilst well known fishes such as

[8] A register of sites where significant changes in ecological character have resulted from pollution or other human interference (Ramsar Convention on Wetlands 1996).

the Striped or Zambezi Tigerfish (*Hydrocynus vittatus*) and Yellowfish (*Labeobarbus*) have smaller and well studies migrations. Home ranges, for example, of Smallmouth (*Labeobarbus aeneus*) and Largemouth yellowfish (*L. kimberleyensis*) in the Vaal River varied between 1 to 13 km (O'Brien *et al*. 2013) whereas the movement ranges of tigerfish tagged in the Incomati River ranged from 75 m to 3.2 km (Roux *et al*. 2018). Fragmentation can also result from land uses which reduce the connectivity between inland wetlands. Linear transport infrastructure had for example a severely negative impact on the ability of the Giant or Highveld Bullfrog (*Pyxicephalus adspersus*) to move between depressions. Their population have seen a decline to such a degree that the species are considered Near Threatened in South Africa (Du Preez & Cook 2018). Stabilization of river flow may also result in a deterioration of water quality and consequently the growth of harmful bacteria and disease outbreak, as in the case of eutrophication of large dams and the increase of cyanobacterial blooms, as well as the outbreaks of *Anopheles* mosquito carrying the malaria parasite and bilharzia (*Schistosoma haematobium*) (Quayle *et al*. 2010; see Section 4.2.2 on water quality).

The most recent dams register of DWS, dated to 2016 (DWS 2016), lists 5 169 dams (Table 4.1). In contrast, the spatial data layer of artificial dams associated with the South African Inventory of Inland Aquatic Ecosystems (SAIIAE) mapped 204 893 dams (Van Deventer *et al*. 2018). The majority of the dam register's records (83%) have size categories and dates assigned, distinguishing between large (3%), medium (20%) and small (76%) dams.

Six large dams have a capacity of > 1 billion cubic metres (m^3) with four of these located in the Free State Province (Table 4.2). The Vanderkloof Dam has the highest dam wall height of 108 m of all the dams in the register. Approximately 43% of the dams in the register have wall heights ≥ 10 m (Figure 4.7). A larger percentage (61%) of dams has been built after 1960 (Figure 4.8).

(a)

(b)

(c)

Figure 4.6. Fragmentation of rivers negatively impact the up- and downstream migration of freshwater fish, such as (a–b) the giant mottled eel (*Anguilla marmorata*, caught and photographed by Dr Pieter Kotze in the Mzimvubu River, September 2016); the Tigerfish (*Hydrocynus vittatus*). Photo credit: Dr Gordon O'Brian.

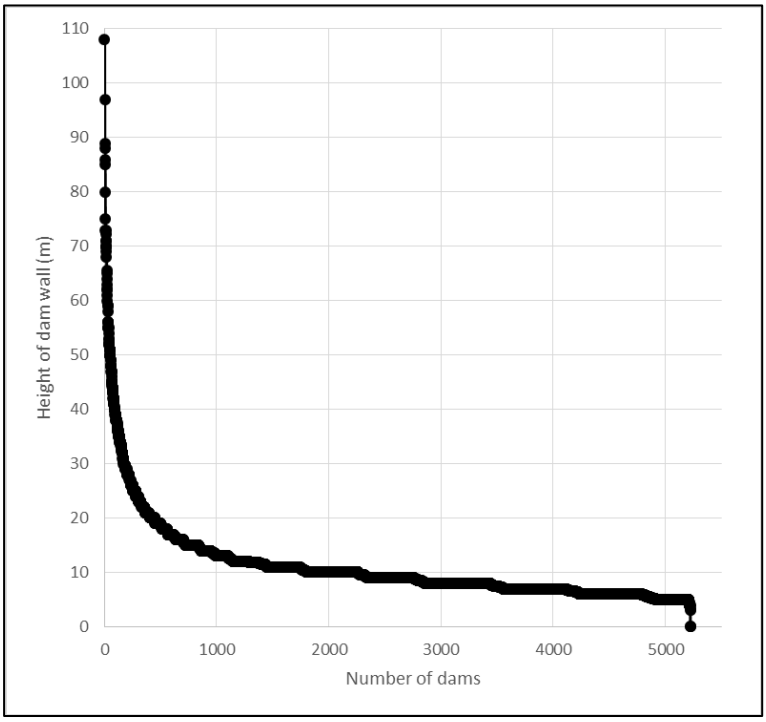
Table 4.1. Numbers of dams per size category in the DWS 2016 dams register (DWS 2016). *The percentage of dams with or without dates is shown in brackets as a total for each size category. The percentage of dams per category out of the total number of dams is shown in italicized brackets.*

Size of dams (across) / Sub-category (down):	Large	Medium	Small	Not classified	Total
Without date	5 (2.9%)	87 (8.4%)	746 (18.9%)	19 (28.8%)	857 (16.4%)
With date	166 (97.1%)	948 (91.6%)	3 208 (81.1%)	47 (71.2%)	4 369 (83.6%)
Total number of dams per category	171 *(3.3%)*	1 035 *(19.8%)*	3 954 *(75.7%)*	66	5 226

Table 4.2. Largest dams of South Africa with a capacity > 1 billion cubic metres (m^3). Information extracted from the DWS 2016 dams register (DWS 2016).

No of dam	Name of dam	Quaternary Drainage Area	Town nearest	Province code	Region Code	Completion date	Completion date raised	River or Watercourse	Wall type	Wall height	Crest Length (m)	Spillway Type	Capacity (1000 cub m)	Surface area (ha)	Purpose
D350/02	GARIEP DAM	D34A	GARIEP	FREE STATE	FREE STATE	1971		ORANGE	ARCH	73	884	UNCONTROLLED OGEE	5 342 932.0	35216	IRRIGATION, DOMESTIC, INDUSTRIAL AND POWER GENERTION
D310/01	VANDERKLOOF DAM	D31E	VANDERKLOOF	FREE STATE	FREE STATE	1977		ORANGE	ARCH	108	756	UNCONTROLLED OGEE AND FOUR GATED CHUTES	3 187 557.0	13343	HYDRO-ELECTRICITY,IRRIGATION AND DOMESTIC USE
C801/10	STERKFONTEIN	C81E	HARRISMITH	FREE STATE	GAUTENG	1980	1986	NUWEJAAR SPRUIT	EARTHFILL	97	3060	NONE	2 616 000.0	6937	DOMESTIC USE & INDUSTRIAL
C120/01	VAAL DAM	C83M	DENEYSVILLE	FREE STATE	GAUTENG	1938	1985	VAAL RIVER	EARTHFILL & GRAVITY	63	3302	CONTROLLED OGEE WITH CREST GATES	2 536 000.0	32275	MUNICIPAL USE & INDUSTRIAL USE
W440/01	PONGOLAPOORT DAM	W44E	PONGOLA	KWAZULU NATAL	KWAZULU NATAL	1973		PHONGOLO	ARCH	89	451	OGEE	2 445 900.0	13272.8	IRRIGATION
C900/07	BLOEMHOF DAM	C91A	BLOEMHOF	NORTH WEST	NORTHERN CAPE	1970		VAAL RIVER	EARTHFILL & GRAVITY	33.7	4270	OGEE SPILLWAY	1 269 000.0	23066.5	IRRIGATION

(a)



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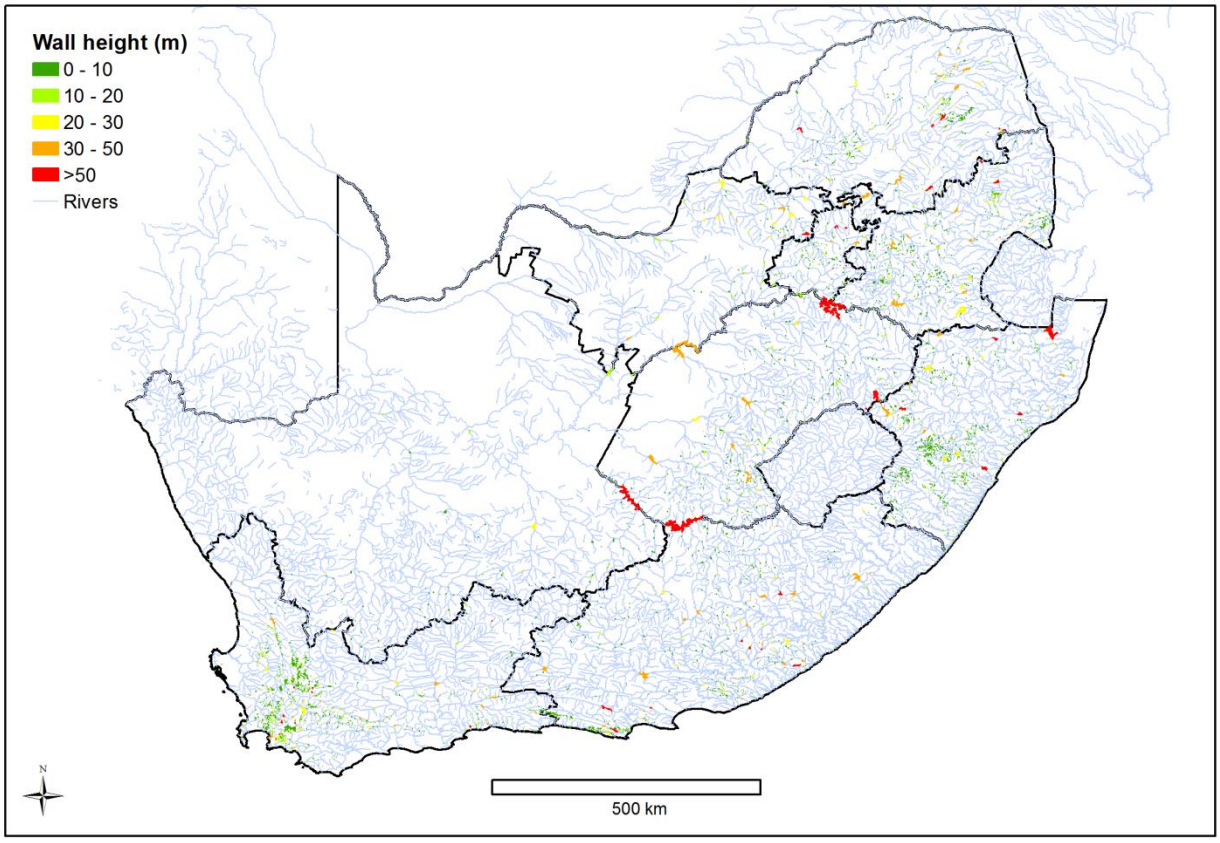


Figure 4.7. Heights of dam walls in South Africa. (a) Number of dams per height of their dam walls and (b) sizes of dam wall heights across the country (DWS 2016).

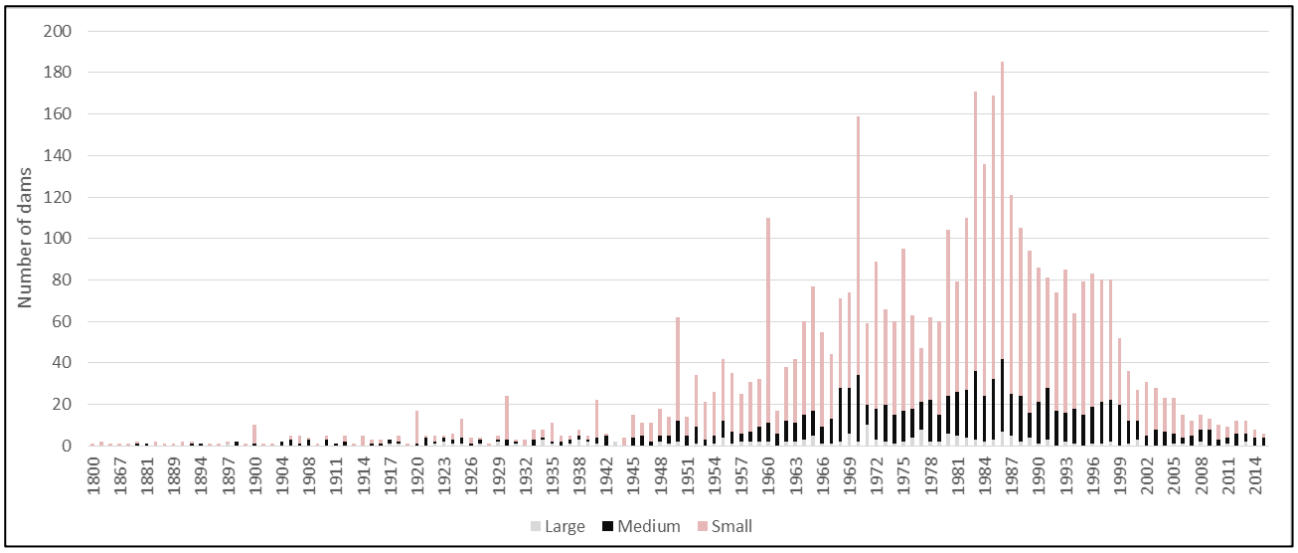


Figure 4.8. Number and size of dams built per year in South Africa (known dates and categories as reflected on graph *n* = 4 322 [83% of total in register]; unknown dates or no categories not reflected on graph *n* = 904 or 17%).

The dependency and interaction between groundwater, interflow and surface water on aquatic ecosystem types is poorly understood for the majority of bioregions in South Africa. Three main types of aquifer dependent ecosystems have been identified, including (i) aquifer and cave systems where stygofauna reside (includes hyporheic zones of rivers and floodplains); (ii) ecosystems dependent on the surface expression of groundwater (e.g. springs, base-flow rivers, streams and wetlands) and (iii) ecosystems which are dependent on the presence of sub-surface groundwater within the rooting depth of the ecosystem (Eamus 2006). In South Africa, Colvin *et al*. (2007) has identified seven habitat types associated with Aquifer Dependent Ecosystems (ADE), including those related to the dolomitic regions in South Africa, the springs and seeps in the Table Mountain Group sandstone of the Western Cape, Kalahari sands, inland wetlands situated on the shallow sand aquifers on the KwaZulu-Natal coastal plains, the riparian zones of the Limpopo alluvial systems and seeps on the Karoo dolerite sills, to mention a few. The sensitivity and aquifer dependence of vegetation groups were evaluated at that stage, since the National Wetland Map (NWM) was still in the early phases of development. A re-evaluation of dependencies should be done, however similar to Colvin et al. (2007) the authors support the notion that a catchment approach should be followed, since fine-scale *in situ* mapping would be required for accurately detecting and mapping ADE. The Normalised Difference Vegetation Index (NDVI) has been suggested as a means to identify ADEs, however this should take place in collaboration with export knowledge on the area (Colvin *et al*. 2007). Green reflectance signatures during the dry season may indicate potential connection with aquifers. Using coarse-scale imagery with a spatial resolution > 30 m, it is often inadequate for separating terrestrial and wetland features from one another, particularly where inland wetlands are smaller than 90 m². Terrestrial woody vegetation may have deep roots which tap into deeper water levels. Hence, water is available for these large trees which are associated with terrestrial acosystems, but not for the the surface wetland (Appendix D). Any desktop interpretation of water availability or greenness can also not indicate whether the source of the water is interflow or groundwater. It is crucial to identify dependencies of inland aquatic ecosystems on groundwater to better understand the potential impact of a pressure within a catchment, and to inform planning and management. The example of the impact of water abstraction on wetlands that are ground-water dependent, is well described for the Maputaland coastal plain (Appendix D). More recently, fine-scale research has shown different strategies of tree species in

sourcing water from the environment, and that the use of more recent technology facilitates improved understanding of the interaction between species and water sources (Kotzé 2015).

4.1.2 Changes in water quality

Water quality pressures on inland aquatic environments and the impacts on ecosystems are numerous and include different groups (Table 4.3; Figure 4.9). The data describing the spatial distribution of water quality pressures is sporadic and not available in equal detail for the different water quality pressures. Ashton (2010) summarised the overall water quality pressure trends and distribution in South Africa in 28 river systems (Figure 4.9). Although produced almost a decade ago, these trends remain valid as they tend to be industry and sector related.

Water pollution has dire, long-lasting consequences for aquatic organisms and hence ecosystems function. The Olifants River, which flows through the Kruger National Park, is a prime example of a river at the receiving end of a heavily utilised and degraded landscape. The impact of pollutants entering the river system have led to the demise of Endangered species such as the Nile Crocodile (*Crocodylus niloticus*), attributed to pansteatitis, as well as the mortality of several fish species in Loskop Dam (Ashton 2010; Dabrowski *et al*. 2013b). A decline in piscivorous bird species has also been observed, including Pel's Fishing Owl (*Scotopelia peli*) (Myburgh & Botha 2009). Pollution to freshwater can have far reaching consequences other than at its source. Oberholster *et al*. (2013b) found that the ecological impact by a WWTW to freshwater organisms were detectable over a distance of 40 km downstream. The study showed that in addition to river flow regime, temperature and bottom river substrate, the distance from the sewage outfall from the Riverview WWTW played a major role in phytoplankton assemblage and biological uptake of phosphorus for river assimilation (Oberholster *et al*. 2013b). However, Oberholster *et al*. (2013a) showed that river self-purification is possible with increased distance from a pollutant source or stressors provided that the stressors are also significantly reduced. Similar results were reported by Van Heerden (2014) for an arid valley-bottom system. They found that phosphorus decreased after 50 m away from the source and soil potassium levels decreased after 25 m from a sewage effluent stream.

Table 4.3. Summary of the main pollutants of water resources and the associated sources and impact.

WATER QUALITY DETERIORATION	POTENTIAL SOURCES	PRESSURES / IMPACT
Sedimentation	• Urbanisation • Natural erosion and other (e.g. bank trampling by livestock) • Changing land cover/use • Agriculture	• Loss of habitat for aquatic biota. • Alterations in the food web structure of freshwater, estuarine, and coastal marine ecosystems, with ramifying effects on every trophic level.
Nutrient pollution	• Waste Water Treatment Works (WWTW) • Agricultural runoff • Animal/human waste • Fertilizer application • Urban runoff • Atmospheric deposition	• Nitrification with resultant loss of oxygen and eutrophication of water bodies. • Acidification of surface water affecting primary and secondary producers. • Increased biomass in wetland vegetation and changes in productivity and species composition, of freshwater macrophytes, including nuisance aquatic weeds. • Losses of species diversity in phytoplankton, periphyton, macrophyte and macroalgae communities can have effects on environmental cues for life histories of biota such as such as spawning and migration for fish.
Chemical pollution and emerging contaminants		
Salinity	• Agricultural return flows (irrigation) – surface and subsurface • Saltwater intrusion in groundwater (coastal areas) • Land use change from deep-rooted indigenous perennial vegetation to shallow rooted cropping systems • Saline industrial effluent	• Aquatic organisms are more adaptive to a rate of change in salinity. • Salinity can either be an antagonist or synergist in relation to a range of toxic pollutants but generally it provides protection from heavy metals by modifying the chemical speciation (Dallas & Day 2004). • Due to great variation in rainfall across South Africa irrigation of crops is central to food sustainability in drier areas. The salinization of irrigation water due to land cover and use can therefore have a detrimental impact on food production (Van Rensburg *et al*. 2011). • Salinity results in alterations in distribution patterns of species or communities (Dallas & Day 2004).
General chemical pollution	• Mining waste	• The impacts of mining on water resources are considered to be some of the biggest current environmental threats. • Mining affects fresh water through pollution from discharged mine effluent and via seepage from tailings and waste rock impoundments. • Toxicity of high sulphate and metal concentrations leads to loss of species. • Waters that receive AMD are often characterised by very low biodiversity, and the flora and fauna become dominated by highly resistant organisms and acidophilic (acid-loving) biota. Sensitive species are systematically reduced or eliminated altering ecological relationships. In severe cases of AMD contamination, all biota except for a few species of bacteria are killed. • Adverse health effects from mining activity downstream can be substantial. Several of the contaminants typically associated with mining are hazardous to human health, including arsenic, cadmium, and lead (Malatse & Ndlovu 2015). Although uranium oxide is present at trace amounts (0.0064%) its presence is significant as uranium is radioactive and can present health effects (Malatse & Ndlovu 2015).
Industrial effluent and urban runoff	• Industry • Urban runoff	• Various organic and inorganic pollutants.
EDCs	• Aquaculture • Agriculture • Mining	Endocrine Disrupting Compounds (EDCs) include: • Hormones from animals and humans; • Pesticides; and • Metals – i.e. mining. EDCs exert significant influence on behavioural responses (e.g. enhancing feeding rates), have transgenerational effects and trophic cascades, causing ecological consequences to EDC exposure.
Pesticides and fertilizers	• Agricultural – cultivation with or without irrigation	In both rural and urban areas, pesticide distribution to water resources can be reduced by means of wetlands or riparian buffer strips by which the pesticide dispersal is reduced. Studies have shown that the half-life of pesticides can be reduced in vegetated wetlands in comparison with non-vegetated wetlands, indicating that vegetated wetlands have more potential to reduce the toxicity of the pesticide. For example, Schultz and Peall (2001) showed an 89% reduction of azinphos-methyl in water in a constructed wetland, whilst Leistra *et al*. (2003) found that in dense stands of aquatic plants as much as 50% of the pesticide lambda-cyhalothrin was absorbed to the plant material after one day after application. Pesticides also have the potential to bioaccumulate in aquatic organisms such as fish. A recent article published showed that carcinogens were found in the Sharptooth Catfish (*Clarias gariepinus*) in the Klip River in South Africa, related to banned pesticides which bioaccumulated in the flesh and which is often consumed by people. This poses a serious health threat to humans (Pieters *et al*. 2018).
Microbial pollution	• Livestock waste • Human waste	• Stormwater and wastewater effluents contain microbial pathogens of animals, plants and humans and anti-microbial resistance genes to their pathogens from, for example, abattoirs.
Thermal pollution	• Industrial effluent • Stream regulation • Changes to the riparian zone	• Increased water temperatures result in changes to water quality, which will impact aquatic biodiversity. Since freshwater organisms are unable to control their body temperatures, they are reliant on the ambient water temperatures. • Decreased oxygen solubility and increased toxicity of chemicals cause stress to aquatic organisms. • Disruption in the cues for life cycle characteristics such as migration, breeding or emergence. • Changes to the metabolic processes and life cycle patterns by changing reproductive periods, rates of development and emergence times of aquatic organisms (Dallas & Day 2004).
Microplastics	• WWTW • Industrial spillages • User discards	• WWTW are not designed to remove microplastics which may be taken up by numerous aquatic organisms. • There is limited evidence of the effects on aquatic organisms, but indications are that the ingestion of microplastics leads to reduced energy reserves and effects on other physiological functions.
Pharmaceutical products	• WWTW • Pharmaceutical landfilling • Pit latrines	• Harmful impact on primary producers such as algae, which will impair assemblages further up the food web such as invertebrates and fish. Increases in pharmaceutical products can therefore affect the secondary production of organisms such as fish and invertebrates as well as the indirect role they have in processes such as organic matter recycling through the consumption of it or of its consumers (Osorio *et al*. 2016).
Aquaculture	• Land-based farms • Cage-based farms (instream and dam-based)	• Nutrient enrichment of nitrates and phosphates and promote algal and macrophyte growth. • Organic enrichment and increase in turbidity and suspended solids. • Increase in bacterial densities. • Increase in toxins such as nitrite and ammonia and reduced dissolved oxygen concentrations. • Water abstraction, chemical supplements and cleaning agents can impact on biological communities in receiving water bodies. • Aquaculture practices in mountain stream catchments will have a greater impact on water quality and biota than farms further downstream. • The type of aquaculture farm will impact effluent differently. For example, earth dam farms have lower suspended organic material concentrations than plastic-lined tanks (Dallas & Day 2004).

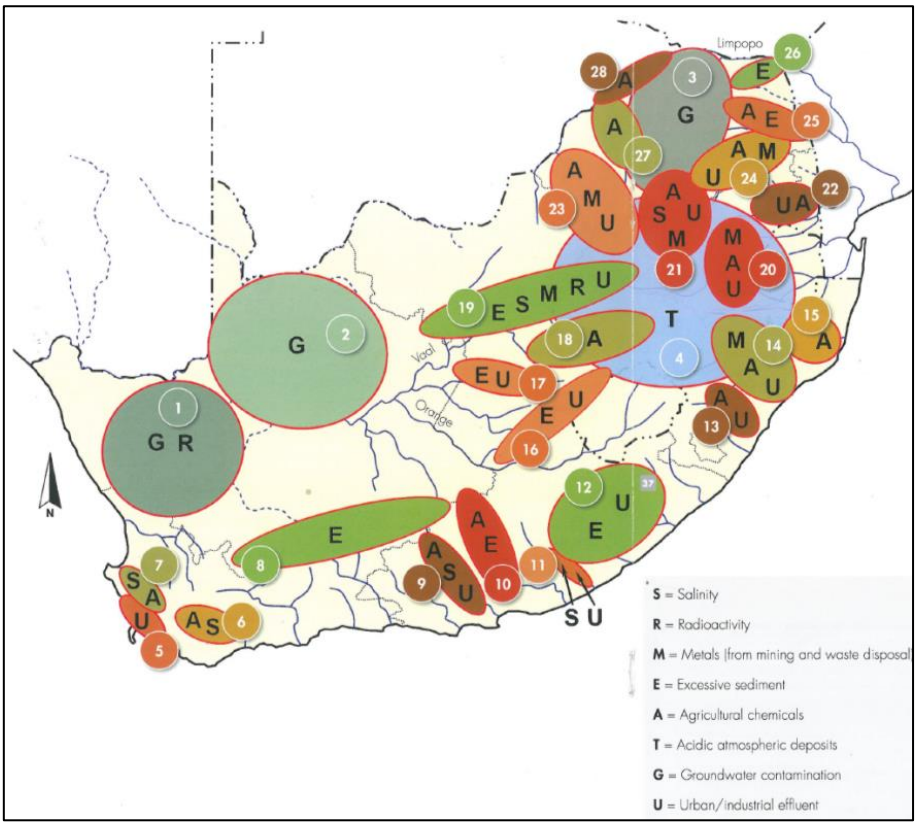


Figure 4.9. Water Quality Pressures (Ashton 2010).

Inefficient operating WWTW is a very serious and growing concern in the management of the quality and health of South African water resources and ecosystems. The resulting nutrient enrichment of water courses contributes to eutrophication in rivers such as the Orange-Senqu and several large dams across the country, escalating the cost of water treatment to potable standards. The published Green Drop Progress Report of 2013 (DWS 2013), indicated that of the 859 WWTW, only 7.3% received Green Drop certification, while 30% (248 WWTW) were considered critical. Systems with Purple Drop status were primarily located in the Free State and Mpumalanga provinces, with fewer in the remainder of the provinces and none in Gauteng. According to Mitchell *et al*. (2014), South Africa's rivers do not have the dilution capacity to cope with the effluent from large WWTW. Appendix C lists the monthly compliance status of WWTWs in South Africa between 2011 and 2018. In a recently reported case, residents and communities in the vicinity of an important water source river, the Vaal River, complained about raw sewage spillage and toxic industrial effluent being discharged into the river. This caused a major fish kill over a substantial length of river in a region which supports the countrys' largest flyfishing industry for indigenous freshwater fishes such as Yellowfish (*Labeobarbus*). The situation became serious enough for the South African Human Rights Commission to hold a formal inquiry as the pollution was directly infringing on a number of human rights under the Constitution, one of which was the right to access clean water (Timeslive 2018). By the 1st of January 2019, the former minister of DWS announced 46 WWTW (5%) to be under critical observation as a result of malfunctioning (News24 2019).

Other anthropogenic sources of contamination to substrate, surface water and especially groundwater, are those originating from cemeteries or burial grounds. Studies on this source of pollution to water quality is increasingly being documented in a number of regions including Brazil, Australia, South Africa, Portugal, the United Kingdom and Poland (Żychowski & Bryndal 2014). Studies have shown that the leachate from cemeteries provides nutrients for the growth of micro-organisms where pathogenic viruses, protozoa and

helminths are transferred to groundwater. The chemical parameters in groundwater were also found to be increased due to cemeteries when compared to the regional groundwater quality (Engelbrecht 2004). The chemical parameters in leachate can include nitrogen, phosphorus, chlorine, calcium, sodium, bicarbonate and various metals compounds including titanium, chromium, cadmium, lead, manganese and nickel. The leachate is also characterised by a high pH, conductivity and biochemical oxygen demand (Hart & Casper 2004; Żychowski & Bryndal 2014).

Sedimentation

Sediment forms an important component of aquatic ecosystems as it provides habitat, feeding and spawning areas for many aquatic organisms (Oberholster *et al*. 2005). Although soil erosion is a natural process it is accelerated or worsened by human activities such as over-grazing or vegetation removal. Water erosion is a major cause of erosion in South Africa and is largely induced by agricultural practices as well as urbanisation, mining and forestry. Soil erosion plays a major role not only in loss of soil resources and productivity, but also in the degradation of water quality (Lenat & Crawford 1994; Le Roux *et al*. 2008). Many South African rivers carry a naturally high suspended-solid load and excess sediment to river systems which not only impacts river ecology by degrading habitat quality for aquatic fauna such as fish and benthic macroinvertebrates, but with increased sedimentation it also leads to dam siltation (Pegram & Görgens 2001; Dallas & Day 2004; Le Roux *et al*. 2008). Increase sedimentation causes turbidity due to suspended solids, which decreases primary productivity due to decreased photosynthesis as a result of light reduction. A map providing sediment yield prediction for ungauged catchments in South Africa was created (Msadala *et al*. 2012; Msadala & Basson 2017). However, comprehensive sediment monitoring programmes are lacking, and monitoring is generally limited to reservoir siltation surveys. The potential for sediment production is shown in Figure 4.10, although it is difficult to discern natural erosion from human-induced erosion.

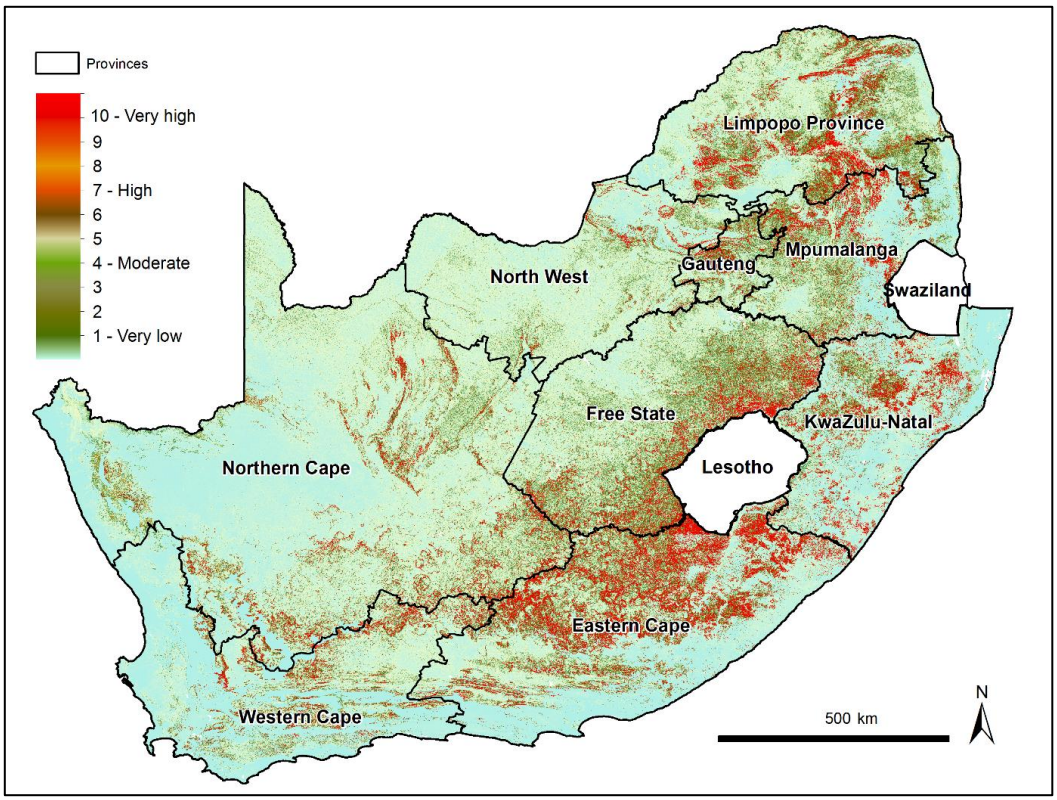


Figure 4.10. New sediment yield regions showing erosion hazard classes (Le Roux *et al*. 2008; Msadala *et al*. 2012).

Nutrient pollution

An excess of phosphorus and nitrogen (eutrophication) in water can be harmful to aquatic life and to people, leading to algal and invasive plant (e.g. water hyacinth) blooms which can reduce or eliminate oxygen in the water, causing illnesses or death of aquatic animals (Nyenje *et al*. 2010; Oberholster *et al*. 2013b). Some algal blooms are harmful to humans and animal life through toxin production. The major anthropogenic point sources of inorganic nitrogen and phosphorus in aquatic ecosystems include municipal sewage effluents and storm water, wastewater from livestock farming, industrial wastewater effluents and mines. The main anthropogenic diffuse sources include agricultural activities such as the use of manure and nitrogenous fertilizers, and the cultivation of N_2-fixing crops, runoff from burned forests and grasslands, urban runoff from areas where sewers are lacking, and failed septic systems.

Eutrophication monitoring information is available for more than 80 impoundments in South Africa. The National Eutrophication Monitoring Programme (NEMP) provides six monthly assessments of chlorophyll *a* monitoring results and can be viewed on the DWS website and compared to previous assessments. An example of this is shown in Figure 4.11. In addition to chlorophyll a monitoring results, total phosphorous concentrations for these sites are also provided. A case study on the sensitivity of a river to phosphate levels is discussed in Box 4.2.

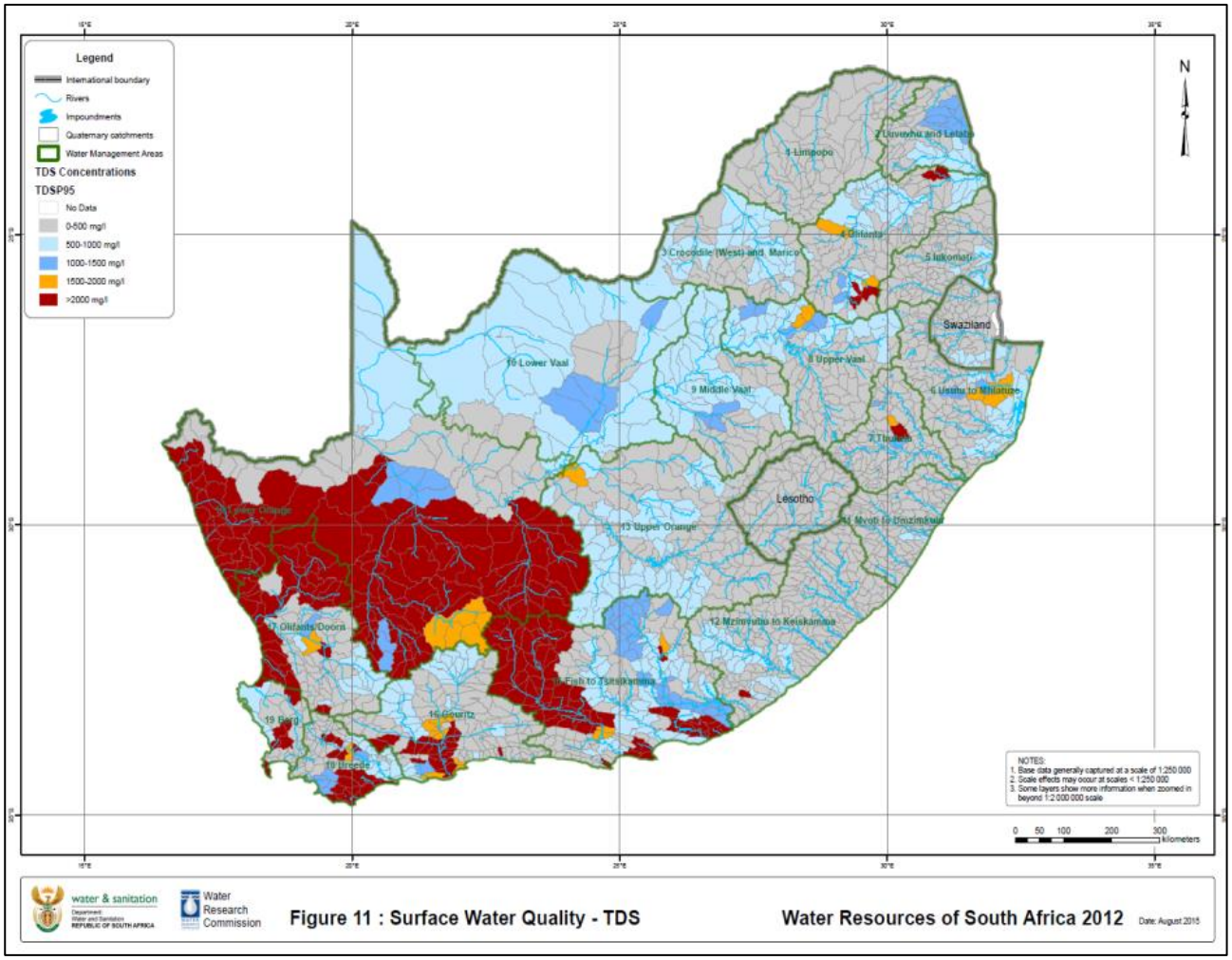


Figure 4.11. Total Dissolved Solids mapped in the Water Resources of South Africa (Water Resources of South Africa 2012 or WR 2012 [Bailey & Pitman 2012]).

Box 4.2. Case study of phosphate sensitivity of a river stretch of the Berg River (Oberholster *et al*. 2013a)

Over the last 20 years the accumulation of phosphorus (P) entering into the Berg River has increased by more than tenfold, and according to De Villiers (2007) its load exceeds the 15% maximum allowable change with reference to the South African water quality guidelines for aquatic ecosystems. Physical, chemical and biological processes within streams influence the transport, transformation and retention of nutrients during downstream transport. High nutrient inputs impoverish biological diversity.

First to third order streams are highly efficient at nutrient retention (Mulholland *et al*. 2000). This self-purifying capacity of a stream to reduce nutrient loads within a relative short distance aids in nutrient sequestration if the capacity of the stream is not overwhelmed by excessive nutrient loading from e.g. a WWTW (Elósegui *et al*. 1995).

Knowledge of the phosphorus sensitivity of a system and how it will respond to increases or decreases in *P* loads is important to assist in managing eutrophication. A recent study by Oberholster *et al*. (2013b) showed that phosphorus sensitivity of rivers is determined by using physical, chemical and biological processes which influence the transport, transformation and retention of nutrients during downstream transport. Using the criteria to measure a system's phosphate sensitivity, the river was found to be highly sensitive to phosphate loads.

Mining waste

Mining is the cause of water quality pressures such as acid mine drainage, metal contamination, and increased sediment levels in streams (McCarthy 2011; Durand 2012; WRC 2016). Sources include active or abandoned surface as well as underground mines, processing plants, waste-disposal areas, haulage roads, or tailings ponds. The South African Mine Water Atlas (WRC 2016) produced an assessment of surface water threat from mining shown (Figure 4.12). This map reflects the assessment of the threat of mining to surface water resources at quaternary catchment level. The available PES status of the water resources was used in the determination of the level of threat that mining posed to the water resource (WRC 2016).

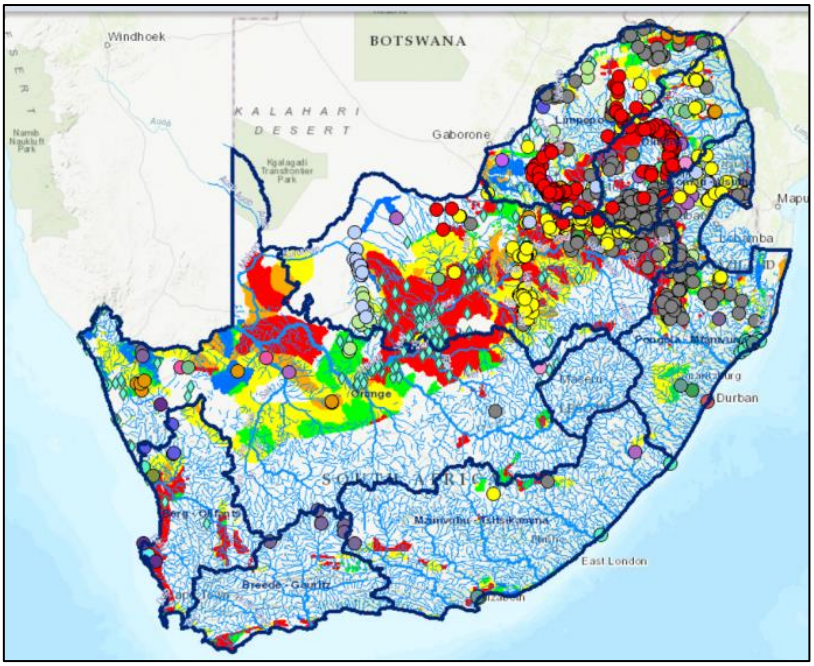


Figure 4.12. Overview of the threat to the surface water resources within mining areas of South Africa incorporating PES and state of water quality per quaternary catchment (WRC 2016).

Microbial pollution

Microbial pollution generally does not impact aquatic ecosystems directly, with the reverse occurring, where pollution normally impacts the microbial ecology in the aquatic ecosystem.

Pollution frequently associated with microbial contamination will have impacts on the aquatic ecosystem with implied financial cost of intervention (Box 4.3). These co-contaminants include metals, pesticides, and nutrients such as nitrogen and phosphates which may cause eutrophication and cyanotoxin blooms with resulting largescale impacts on aquatic ecosystems such as fish kills.

Box 4.3. Case Study: Financial impacts of algal pollution in Berg River (De Lange 2015)

The Berg River in the Western Cape Province serves as one of the most important water supply services in the region with a total irrigation area of about 23 000 ha, and production from irrigation contributing a gross farm-gate value of about R1.3 billion per annum. Algae have become a significant problem in the Berg. It was estimated that algal pollution from increased phosphate levels is responsible for additional costs of R1 887 per ha per year (equivalent to R579 591 per year for deciduous fruit in the study area). This figure could be extrapolated to R98-million per year for the South African deciduous fruit industry (52 000 ha). The costs result from the need to clean irrigation systems more frequently when algal loads are high. The study looked at the amount of time staff spent cleaning equipment because of algal clogging, the cost of electricity, servicing and labour. Given an estimated 355 ha under vines in the study area, the cost of algae for the wine grapes is estimated at R670 400 per year. This figure could be extrapolated to R188 million per year for the 99 800 ha under wine grapes in South Africa (assuming all regions struggles equally with algae).

Pre-harvest production cost for plums is R61 880 per hectare, hence the cost of algae pollution represents approximately 3.1% of pre-harvest cost. Pre-harvest production cost for wine grapes is R35 739 per hectare, which implies that the algae problem represents 5.2% of the pre-harvest cost.

These figures might seem quite small, but within an industry with extremely small producer profit margins, these figures are substantial. It is likely that these impacts could be given through to consumers, which could imply that consumers could pay more for their fruit if nothing is done to curb the impacts of pollution.

Thermal pollution

Changes in temperatures can occur naturally e.g. groundwater inflows, tributary confluence or due to anthropogenic causes such as riparian vegetation removal, heated industrial discharges, stream regulation, inter-basin transfers or climate change (Dallas & Day 2004). Increased water temperature results in changes to water quality through the changes to the solubility and thus toxicity of certain compounds. Dissolved oxygen concentrations are dependent on temperature with warmer water able to hold less oxygen which will impact aquatic biodiversity as and the water may not contain enough dissolved oxygen for the survival of different species of aquatic life. Since freshwater organisms are unable to control their body temperatures, they are reliant on the ambient water temperatures, which therefore act as cues for migration timing, spawning or emergence. Water temperature rise will have physiological effects, modification of life-cycle stages and effect community abundance, diversity and composition (Dallas & Day 2004). In freshwater ecosystems species will function, grow and reproduce at an optimal temperature. If the temperature range, either minimum or maximum is exceeded, lethal or sub-lethal effects on particularly vulnerable species, prevails (Dallas & Day 2004; Schmutz & Sendzimir 2018). In light of the growing anthropogenic stress and impact to freshwater ecosystems including climate change, research on increasing water temperatures in South Africa is ongoing but still in its infancy (Rivers-Moore *et al*. 2013a). With climate change predictions of rising air temperatures in vulnerable areas, e.g. aseasonal catchments,

thermal pollution becomes a growing threat to freshwater ecosystems. The climate is particularly important in freshwater ecosystems processes as it influences hydrological (through runoff from precipitation) and thermal (through atmospheric heat exchange) regimes (Schmutz & Sendzimir 2018). The structural aspect of a region, catchment or river such as the vegetation cover, channel form, water depth or turbidity will also influence water temperature. Both the hydrological and thermal regimes will have different direct and indirect effects on freshwater ecology (Schmutz & Sendzimir 2018). Rivers naturally warm in temperature along their longitudinal gradients with cooler water in the upstream catchments and warmer water further downstream.

Emerging contaminants

Emerging contaminants creates further challenges in managing the health of aquatic ecosystems and water quality since little is known about their occurrence and associated risks. According to the National Research Council (NRC 2012) examples of different types of chemicals of emerging concern are given in the following table (Table 4.4). Several research organisations are attempting to determine the source of the pressure and studies are being conducted on the sources, pathways and drivers of such contaminants to water resources to develop clear guidelines for water quality and formulate appropriate policies and legislation for the management thereof (Walters 2017). For example, the Water Research Commission (WRC) has set out funding to specifically respond to this. Research funding is particularly provided for more knowledge on antiretrovirals (ARVs) (Walters 2017).

Table 4.4. Types of Chemicals of Emerging Concern with Examples (NRC 2012).

Type	Examples
Industrial chemicals	1,4-Dioxane, perflurooctanoic acid, methyl tertiary butyl ether, tetrachloroethane
Pesticides, biocides, and herbicides	Atrazine, lindane, diuron, fipronil
Natural chemicals	Hormones (17β-estradiol), phytoestrogens, geosmin, 2-methylisoborneol
Pharmaceuticals and metabolites	Antibacterials (sulfamethoxazole), analgesics (acetominophen, ibuprofen), beta-blockers (atenolol), antiepileptics (phenytoin, carbamazepine), veterinary and human antibiotics (azithromycin), oral contraceptives (ethinyl estradiol)
Personal care products	Triclosan, sunscreen ingredients, fragrances, pigments
Household chemicals and food additives	Sucralose, bisphenol A (BPA), dibutyl phthalate, alkylphenol polyethoxylates, flame retardants (perfluorooctanoic acid, perfluorooctane sulfonate)
Transformation products	N-Nitrosodimethylamine (NDMA), haloacetic acids (HAAs), and trihalomethanes (THMs)

Given the thousands of chemicals that are potentially present in the aquatic environment and that information about contaminants of emerging concern (CECs) is rapidly evolving. Numerous international studies have shown that a wide variety of pharmaceuticals are present in wastewater effluents, surface waters, and groundwater (GWRC 2004). Various definitions of chemicals of emerging concern were examined and are covered in the all-encompassing definition provided by the United States Geological Society (USGS 2014). '*Any synthetic or naturally occurring chemical or any microorganism that is not commonly monitored in the environment but has the potential to enter the environment and cause known or suspected adverse ecological and/or human health effects. In some cases, release of emerging chemical*

or microbial contaminants to the environment has likely occurred for a long time, but may not have been recognized until new detection methods were developed. In other cases, synthesis of new chemicals or changes in use and disposal of existing chemicals can create new sources of emerging contaminants.' (USGS 2014).

Emerging contaminants such as microplastics and pharmaceuticals for human health have been found to be transported to rivers and other surface water resources by inefficient operating WWTW. Microplastics and pharmaceuticals are considered to be emerging pollution in the aquatic environment and discussed in more detail below.

Microplastics

Micro-plastics have recently come to the attention of aquatic research community, with indications that the ingestion of microplastics by aquatic organisms leads to reduced energy reserves and effects on other physiological functions. The time required to completely mineralize plastics is estimated to be on the order of hundreds to thousands of years (Barnes *et al*. 2009). Initial studies have shown that all trophic levels of aquatic organisms such as fish, filter feeders, zooplankton, rotifers, ciliates, crustaceans, and amphipods, showed evidence of ingesting microplastics (Anderson *et al*. 2016). Due to growing concerns from the scientific community regarding microplastics, a ban on microplastics in personal care products was called to the European Union Environment Ministers (UNEP 2015). A ban on microplastics in cosmetic products was signed into United States federal law in January 2016. Canada also proposed to include microbeads on the List of Toxic Substances (Environment Canada 2015).

Since these initial bans, several countries have banned products and subsequent investment in research and clean-up projects. More recent results showed that the source of the microplastics and microthreads are inland macroplastics, breaking down along several pathways, one being rivers (Jambeck *et al*. 2017; Naidoo *et al*. 2015). They key sources of the microplastic pollution have been identified as textiles from washing machines and tyres, whereas microbeads in the cosmetic industry was much lower (Boucher & Friot 2017). The most recent results of coastal surveys released in 2018 shows a list of the top ten items which end up on beaches (Table 4.5).

In South Africa there is limited knowledge on the risks of micro-plastics to the aquatic environment especially related to the release, fate, transport and composition, airborne contribution to water resources as well as leaching of the chemicals from plastics in South Africa conditions (high temperatures, droughts, ultra violet) (Bouwman & Verster 2018; Bouwman *et al*. 2018). Several hotspots have been identified in South Africa, including the metropoles of Gauteng and Bloemfontein as well as the metropoles and large rivers along the coastline, including the City of Cape Town, Port Elizabeth, East London and the eThekwini (Durban) (Jambeck *et al*. 2015; 2017). The lack of proper waste removal and management in these areas result in macroplastic pollution in water pathways and subsequent breakdown to microplastic (Jambeck *et al*. 2017). Furthermore, WWTW are unable to adequately remove a large percentage of micro-plastics, which further exacerbates the extent to the problem in water resources (Nel *et al*. 2016).

Plastic and microplastic pollution also form part of the new emerging contaminants. The World Health Organisation (WHO) launched a health review after it was discovered that 90% of bottled water contained microplastics (The Guardian 2018). The plastic pollution in the marine environment is well documented but this is not the case for freshwater resources. The potential exists for large impact to freshwater resources and freshwater-dependant biological processes by plastic and microplastic pollution, especially given the low dilution capacities of most South African rivers in addition to deficient waste management (Bouwman *et al*. 2018). This prompted the initiation of a dialogue discussion on microplastics and microbeads in the

environment on 21 November 2018 by the Department of Environmental Affairs (DEA) and the Water Research Commission (WRC) during 2018. These discussions intended:

- To consider the effectiveness of some recent or current initiatives to address the challenge. The lessons from the dialogue would assist in pointing the possible projects or programmes that South Africa could take to address marine plastic pollution at national level;
- To be a report on national microplastics state of knowledge and ideas that will inform further research noting the bridging of the gap between policy, research and society; and
- To review available information on the sources, levels, fate (from source to sea) and impacts within the environment.

Table 4.5. Top ten items collected from coastal cleanups (extracted from Ocean Conservation 2018:16-7).

Product	Globally	South Africa
Cigarette butts	2 412 151	11 783
Food wrappers	1 739 743	15 752
Plastic beverage bottles	1 569 135	10 860
Plastic bottle caps	1 091 107	17 107
Plastic grocery bags	757 523	3 306
Other plastic bags	746 211	2 723
Straws, stirrers	643 562	9 728
Plastic take out/away containers	632 874	1 355
Plastic lids	624 878	2 618
Foam take out/away containers	580 570	2 896

Pharmaceuticals

Pharmaceutical constituents, similar to the microplastics, can also be directly transferred to rivers by communities in the vicinity of the water resource where there is no formal sanitation provided for human waste, which includes pit latrines (Wood *et al*. 2015; Madikizela *et al*. 2017). Other sources of contamination identified include the improper disposal of expired pharmaceutical stocks such as leachate from pharmaceutical landfilling (Wood *et al*. 2015).

Many of these chemicals express endocrine disrupting effects or are known as Endocrine Disrupting Compounds (EDCs). Research has shown that they exert significant influence on behavioural responses (e.g. enhancing feeding rates), have transgenerational effects and trophic cascades, causing ecological consequences to EDC exposure (Windsor *et al*. 2018). In addition, interactions between EDCs and our limited understanding of the effects of various compounds on different biotic systems generate uncertainty in our understanding of the ecological effects of EDCs within aquatic ecosystems. EDC effects from exposure to bisphenol A in Rainbow Trout (*Oncorhynchus mykiss*) range from lower energy in larvae to first feeding, reductions in specific growth and restricted food conversion (Windsor *et al*. 2018) in addition to causing transient effects or more permanent ones.

Aquaculture

Aquaculture is also identified as an emerging contaminant and can pose a risk to human health. Human health impacts resulting from aquaculture may be caused by microbial and chemical contamination or nutrient enrichment of the water environment. The type of system used (e.g. running water aquaculture, recirculatory systems or aquaculture cages), the intensity of the aquaculture, and where it is placed will

affect the likelihood of an adverse health effects since the contamination levels will vary. The risk of pollution to water bodies due to the discharge of organic wastes is usually associated with land-based aquaculture facilities. Chemicals used in aquaculture production, such as therapeutic chemicals for cultured stock and antifouling treatments for infrastructure, have the potential to pollute both marine and freshwater environments that may in turn have indirect, downstream negative impacts on food chains and human health (Pillay 2004). The chemistry and fate of metals and organic compounds is complex. In addition, microbial contamination with pathogens will depend on the site location, and practices used in the aquaculture process.

A number of studies (Sapkota *et al*. 2008; Watterson *et al*. 2012) have shown that elevated levels of the following health related substances may originate from aquaculture practices:

- antibiotics and their residues;
- antibiotic-resistant bacteria;
- pesticides;
- persistent organic pollutants (POPs);
- metals;
- endocrine disrupting chemicals;
- microbial pathogens including bacteria, parasites, and viruses; and
- high nutrient loads from fish excreta and food leading to cyanotoxin blooms.

Chemical contamination may occur through the overuse and misuse of chemicals in the aquaculture operations. Serpa & Duartes (2008) noted that type of culture system used determines the extent of the application of these chemicals. In addition, the intensity of the farming also determines the extent of chemicals applied/used. Intensive pond cultures need a higher number of chemicals compared to cage systems which make use of disinfectants, anti-fouling agents and veterinary medicines.

4.1.3 Loss of natural habitat and subsequent fragmentation

The loss of natural habitat entails the '… (c)onversion of natural habitat in an ecosystem to a land use or land cover class that results in irreversible changes in the composition, structure and functional characteristics of the ecosystem concerned' (SANBI 2016:27). The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) includes processes which result in the 'decline of biodiversity, ecosystem functions or ecosystem services' (IPBES 2018:4). Land conversion is distinguished from land degradation, where conversion refers to the process of converting a natural ecosystem to another land use (Fisher *et al*. 2018) and land degradation, on the other hand, refers to the continuous, '… persistent changes in ecosystem services, function and biodiversity' (Fisher *et al*. 2018:19). Land conversion can easily be mapped and quantified through the use of land cover classification products, whereas the severity, magnitude and duration of land degradation is much more difficult to track, quantify and monitoring over time, compared to land transformation.

The extent of land conversion in South Africa

At least 16.2% of the extent of South Africa has been permanently modified from its natural state through agriculture (12%), plantations (2%), mining (0.2%) and urban areas (2%) (GTI 2015; Skowno *et al*. 2019). In addition, grazing is practised across an addition 70% of the extent of the country, leaving <15% to be

natural. Land conversion in the rural areas is predominantly driven by conversion of natural ecosystems for agricultural purposes including crop production and grazing, as well as plantations (International Union for Conservation of Nature or IUCN threat classification system – Bland *et al.* 2017; see also Skowno *et al*. 2019). It is estimated that approximately 50% of inland aquatic ecosystems (rivers and inland wetlands) have been transformed by land conversion and the persistent associated land use practices, including draining of inland wetlands, bulldozing of river beds and banks, tillage, application of herbicides, pesticides and fertilizers (Begg 1988; Taviv *et al*. 2009). Begg (1988) has, for example, demonstrated that 58% of inland wetlands have been irreversibly transformed to agricultural land and degraded to such an extent that he refers to these ecosystems as 'lost'. In both rural and urban areas, land conversion can also result from industrial or residential development and linear transport infrastructure, although these are less extensive compared to agriculture (Nel *et al*. 2011a; 2011b). The conversion of land from natural land to other uses such as agriculture, plantations, mining, urban, often is associated with the clearing of natural vegetation, changes to the hydrogeology of rivers and inland wetlands, whether locally or in the catchment, and a a subsequent loss in ecosystem services of these ecosystems (Nel *et al*. 2011a; 2011b; Durand 2012; Dabrowski *et al*. 2013a; IPBES 2018; Ramsar Convention Secretariat 2018).

Land degradation

Several drivers cause land degradation, including the management practises of grazing, agriculture and plantations; extractive industries and energy development; infrastructure, industrial development and urbanisation; and changes in fire regimes (IPBES 2018). Poor management practices may lead to long-term reduction of water availability, an increase or decrease in run-off, sedimentation, erosion, changes in the fire regime and also fragmentation of habitats (Dabrowski *et al*. 2013a). Land degradation can negatively affect the health and well-being of humans, resulting in an increase in diseases and socioeconomic costs (IPBES 2018). Urban development and crop agriculture have, for example, caused a loss of > 80% of the Giant Bullfrog (*Pyxicephalus adspersus*) population in the past 20 years in parts of the Gauteng Province as a result of loss of natural habitat (Harrison *et al*. 2001; Frogmap 2018). Globally, amphibians are considered to be most susceptible to land conversion, fragmentation, pollution and invasion (Sievers *et al.* 2018). Urban, agricultural and mining development has also resulted in a decline in habitat for the Pickersgill's Reed Frog (*Hyperolius pickersgilli*), which is endemic to the inland wetlands of the KwaZulu-Natal Province (see Chapter 9, Box 9.1). Fences in the landscape, similar to transport infrastructure, also prohibit species from dispersing and migrating (Lindsey *et al*. 2012). A study of Beck (unpublished, cited in Lindsey *et al*. 2012 Table 12.1), done between July 2007 and June 2008 in South Africa showed that electric fences has frequently killed or injured freshwater species such as the Marsh Terrapi (*Pelomedusa subrufa*) and the Giant Bullfrog (*Pyxicephalus adspersus*). Examples of transport infrastructure development which causes fragmentation across river ecosystems are shown in Box 4.4 and 4.5.

A number of these impacts of land use practises and disturbances to regimes are discuss in more detail, however a full review of all pressures related to the loss of natural habitat and subsequent fragmentation will not be covered in this report.

Box 4.4. Olifants River in flood on Selati Railway

Photograph #868 in QDS 2430BB (Limpopo Province) is a view of the 'Olifants River in flood on Selati Railway' with a description of the tree species that lined the banks of the river and was taken by I.B. Pole Evans in 1918 (http://rephotosa.adu.org.za/Search_photos.php?option=search-rec&rec=868). The incredible repeat photograph was taken by citizen scientist, Bernardine Altenroxel in 2016.

Box 4.5. Leeugamka River Western Cape

This #ThrowbackThursday features historical photograph #5144 of, 'Leeugamka River' near Leeu Gamka in the Western Cape province of South Africa (3221DD) taken by David Jones in 1966 and its fantastic repeat taken by Zander Venter in 2018 (http://rephotosa.adu.org.za/Search_photos.php?option=search-rec&rec=5144). The most obvious change is the major increase in vegetation in the river. There are also many standing dead trees in the photograph that look as though they have been burnt. Woody plants (predominantly Acacia spp.) have increased in density and height along the river banks.

The impacts of herbivory and overgrazing

Herbivory affects both the biotic and abiotic components of wetlands, and ultimately wetland functioning (Keddy 2002). Evidence suggests, however, that herbivory is far less important than other factors such as the hydrological regime, fertility and natural competition at determining and influencing these wetland characteristics (Keddy 2002). Herbivory, depending on its intensity, will to a greater or lesser degree affect the structure, species richness, diversity, productivity, succession and nutrient dynamics of the plant communities of wetland vegetation (Tanner 1992; Mesléard & Perennou 1996; Crosslé & Brock 2002).

Excessive trampling, especially in the wetter months when the soils are soft, may damage underground plant organs. While this may be harmful for some species, those that reproduce vegetatively will benefit from such a disturbance (Mesléard & Perennou 1996). Hoof induced compacting may cause reduced soil porosity and oxygenation, thereby affecting possible germination opportunity, growth and establishment of aquatic plants (Mesléard & Perennou 1996). The physical presence of animals can also impact on plant community dynamics. Both domestic and wild animals tend to establish fixed routes along which they move. Over time the vegetation within and along these paths open up and the soil becomes compacted and depressed. The diminished vegetation exposes these paths and makes them more vulnerable to erosion of which the risk is increased by the focussed and increased water flows. Many such paths develop into gullies which has the potential to seriously alter wetland hydrology and functioning.

The susceptibility of wetlands to grazing and its associated impact is also influenced by the combination of its hydrogeomorphic type and climatic setting. Depression wetlands, for example, are inward draining and are therefore not subjected to the same unidirectional flow energies of wetlands types that are located in the valley floor landscape position. Exposed and dislodged soil particles in the latter (because of e.g. animal disturbance), are more readily transported and removed from the wetland, and if soil loss exceeds net inflow, then the wetland will be eroded until such time as the sediment balance is reversed. Unilateral flow energies will be higher in areas of higher rainfall so that the susceptibility of the same hydrogeomorphic type but in different climatic regions will also differ. Saline wetlands tend to develop in the more arid regions of which the associated halophytes are of limited grazing value (Norman *et al*. 2013) and are not considered to be preferred grazing by domestic or wild animals. Wetlands, and especially depression wetlands in such arid regions, are less likely to be affected by grazing compared to their counterparts in mesic regions. The salt tolerant grasses in such arid regions are usually low in biomass production and the grazing resource is therefore relative quickly depleted. Ungulates therefore have less resident time in such habitats as opposed to similar habitats in the mesic regions. The impact of herbivory is also influenced by the state of inundation and the amount of plant matter that is removed. If wetlands plants are grazed to below the resident water level, as is often the case when overgrazed, then the emergent plant tissue is susceptible to rot and ultimately death (Mesléard & Perennou 1996). Plant morphology may also determine the impact of grazing where species of which the meristem is located at the top of the stem are more seriously affected by continuous grazing than others (Mesléard & Perennou 1996).

The impact of grazing on wetland vegetation also affects many wetland dependant fauna. Many wetland species, especially birds, are sensitive to wetland hydrology and plant physiognomy. The impact of grazing on wetland dependant fauna is not necessarily negative and while some species will abandon wetlands of which the vegetation structure has changed, others benefit. The removal of excess plant material may result in increased habitat diversity, thereby providing habitat to a wider range of species than would have been the case in the absence of grazing (Keddy 2002; Mesléard & Perennou 1996). Herbivory is not limited to ungulates alone. Wetland plants are utilized by a range of species. Other organisms that are known to utilize wetlands plant include insects, molluscs, small mammals, and birds. Birds do not only forage in

wetlands but may also impact on wetland vegetation by removing plant material for other purposes, e.g. for nesting. These examples do not all feed off the same plant parts and while some use the stems, others utilize the rhizomes and can be extremely destructive in their efforts to get to them. The latter, of which the Porcupine (*Hystrix africaeaustralis*) serves as an example, can have a marked impact on plant community structure (Keddy 2002). The impact of Ice Rats (*Otomys sloggetti robertsi*), Gerbil (*Tatera leucogaster*) and Mice (*Mus musculus*) on peatlands in South African and on Marion Island is further described in Appendix C.

Erosion

The majority of South Africa is a naturally erosional surface as a result of uplift and tilting from the escarpment to coast (Ellery *et al*. 2009). Erosion is therefore a natural process which creates valley morphological settings conducive to wetland formation over centennial to millennial timescales (Tooth & McCarthy 2007; Pulley *et al*. 2018), while the morphodynamic interplay between processes of erosion and deposition of sediment creates topographically-complex and thus habitat-rich wetland environments over decadal to centennial timescales (Grenfell *et al*. 2018). However, anthropogenic pressures such as the excavation of agricultural drainage systems, channel straightening and diversion, and artificial valley confinement by road crossings or fill-platforms, accelerate the process of erosion. Rebelo *et al.* (2018), for example, showed that channel erosion over the past ~80 years has accelerated the loss of alluvial soils, and has been associated with changes in species composition and the introduction of invasive species, as well as changes to base saturation and soil chemistry. Anthropogenic pressures also impede natural wetland recovery processes in systems characterised by climate or threshold-driven cut-and-fill cycles (Holmes *et al*. 2003; Ellery *et al*. 2016; Pulley *et al*. 2018). At present, rehabilitation programmes focus primarily on interventions that target symptoms of erosion, such as building structures in gullies or at gully headcuts, and appear to have little capacity to develop interventions that target the underlying causes of erosion and impediments to natural recovery, such as re-designing road crossings.

Destruction and modification of rivers banks and floodplains reduces the filtering capacity of these areas, and destroys valuable river buffer habitat (Nel *et al*. 2011a; 2011b). Damage to and loss of riparian areas and associated floodplains is a major impact in South Africa, especially in the fynbos biome and in the sugar belt area of the KwaZulu-Natal Province (KZN). In the fynbos biome, orchards and vineyards have been planted within floodplains, often extending to the river bank. When these orchards are damaged during floods, farmers typically respond by canalising the channel which further degrades the ecological health and functioning of the river (Rowntree 2013). Sugarcane has been planted within floodplains of the lower reaches of many KZN rivers, and the loss of the native vegetation buffer next to these rivers has resulted in severe erosion and downstream sedimentation, reducing habitat quality and quantity in estuaries. The value of healthy riparian buffers, which should encompass the floodplain of each river, is therefore vital for riverine (and downstream estuarine) biodiversity and ecosystem functioning. No development should be permitted in such areas, and where possible and feasible such areas should be rehabilitated, especially in areas of high importance for conservation and/or water supply.

Changes in the fire regime impacts wetlands

Fire is a natural phenomenon with a large percentage of the grassland and savanna biomes affected by lightning (Gijben 2012). In these biomes fire is also used to enhance grazing at least once or twice per season. Surface fires can have a stimulating effect on both indigenous and invasive species as summarised in the review '*The effects of fire on wetland structure and functioning*' by Kotze (2013). Ground fires, however, may have a significantly negative impact on vegetation structure, should the system be dried out, as was illustrated in the cases of the 17 burning peatlands in Section 4.3.1 and Appendices C and D.

Changes in the fire regime may impact wetlands habitat. For example, the suppression of the fire regime in the fynbosch has resulted in a decline of the habitat of the Rose's Mountain Toadlet (*Capensibufo rosei*) (Da Silva & Tolley 2018; see Chapter 8, Box 8.1). Whether fires originate from natural (lightning) or anthropogenic causes, it can have a significant contribution to greenhouse gas emissions, particularly where it ignites dried out peat wetlands (Kotze 2013; Appendix D). Fire is therefore a significant process to take into account in management of wetland habitats.

Sand mining – and emerging pressure

The Department of Mineral Resources (DMR) under the Mineral and Petroleum Resources Development Act (MPRDA), Act 28 of 2002, has national jurisdiction over the regulation of sand mining. Sand mining is regulated by Sections 22 to 25 (mining rights) and Section 27 (mining permits) in terms of the MPRDA. It is easier to obtain a mining permit as the the environmental requirements for this permit type are less rigorous. An Environmental Impact Assessment (EIA) is not required but the prospective sand miner must submit an Environmental Management Plan (EMP) that indicates mining impact and associated rehabilitation procedures. The main national environmental regulatory authorities are the Department of Environment, Forestry and Fisheries (DEFF) and the Department of Water and Sanitation (DWS) (Chevallier 2014).

These authorities use the National Environmental Management Act (NEMA), Act 107 of 1998 and the National Water Act (NWA) (Act 36 of 1998), respectively, to regulate certain environmental aspects of sand mining. There are essentially three ways in which sand mining may be regulated by the NEMA: through the environmental principles set out in Section 2 of the Act; through section 24 of the Act and the associated Environmental Impact Assessment regulations; and through the Duty of Care provisions in Section 28 of the Act. Sand mining is an activity that has a significant environmental impact and also has implications for land use planning. Hence, it is subject to the environmental and land use planning legislative framework. However, many sand mining operations do not follow existing legal requirements (Chevallier 2014).

Similar to the international trends listed by World Wide Fund (WWF), illegal sand mining has started to emerge in South Africa. Recently there has been a drastic increase in uncontrolled and unauthorised sand mining activities in rivers and valleys throughout the country. These illegal activities constantly move location, leaving behind unproductive and unrestored land that usually become quickly overgrown with invasive alien vegetation. The dredging of sand from river beds is performed mainly through open pit methods and requires only basic equipment. This includes a bulldozer to clear vegetation and build access roads, an excavator or front-end loader to remove sand deposits and trucks for transportation. The extracted sand is then transported short distances and sold privately to individuals and local sand companies. Therefore, the barriers to entry are low while the operations are highly lucrative (Chevallier 2014).

Most of the illegal operators in the KwaZulu-Natal and Eastern Cape provinces extract sand directly from main rivers and their adjacent riverbanks (Chevallier 2014). Similarly, there is a huge challenge of unregulated sand mining in the Kruger 2 Canyons (K2C) Biosphere Region, a United Nations Educational, Scientific and Cultural Organization (UNESCO) listed world conservation and heritage site situated in the north-eastern section of South Africa. The K2C biosphere comprises, roughly, the area from the Kruger National Park in the east to the Blyde Canyon in the west. Site examples include the Klaserie River (Sekwataleng Village, Mpumalanga) and Madudungwe River (Willows Village, Limpopo Province) (view *Where the river flows* @ https://www.youtube.com/watch?v=eC7nx9Dv_6o&t=69s). Illegal sand mining is also found in the semi-arid and arid rivers (e.g. the middle and lower Orange River reaches) of the Northern Province (Ben Benade, *pers. comm.*, 10 October 2018). These river ecosystems are seasonal and ephemeral

in nature, and changes to the amount of sand prohibit infiltration into the aquifer, placing more pressure on arid and semi-arid regions which are already prone to drought.

Although these illegal operations appear small and localised, their cumulative impact is yet to be fully determined. An evaluation of the cumulative impact of illegal sand mining in a given environment should inform permitting decisions. Very often the extent and volume of river sand mined can also not be monitored. Hence, there is a need for a more comprehensive national inventory of legal operations to ensure that ecological limits and sand budgets are respected and enforcement closely monitored. These results must inform planning and resource allocation, while trade-offs with other sand users should be considered. It is essential to enhance the capacity of national and provincial government to curb illegal mining and carry out compliance assessments. Better environmental regulation should deter illegal sand mining, which affects the availability of sand, costs and the competitiveness of legal mining companies. Proper implementation and enforcement of EMPs should be prioritised, including in relation to the inspection of environmental authorisations and waste licences (Chevallier 2014).

Unsustainable sand mining or aggregate mining, has a detrimental impact on river ecosystem process and structure. However, there is very little focus and emphasis placed on these impacts by decision makers or river managers considering that as much as 50 billion tonnes of sand and gravel are mined year to meet construction and land reclamation demands. The demand for sand mining shows rapid increases in developing countries of Asia and Africa (Koehnken & Rintoul 2018).

In 2018, the WWF commissioned a review of available scientific literature, government reports and media articles related to sand mining and the impact to river resources globally and locally. The final product was released during the World Water Week in 2018, which outlines the scale of impact on rivers by the sand mining industry. According to Koehnken *et al*. (2018), the physical impacts to rivers caused by sand mining are changes to the channel morphology (river bed and floodplain), changes to the instream habitats, sediment budgets, flow regimes, groundwater reserves and water quality. The lowering of the channel bed can cause channel instability leading to bank erosion. This can impact the riparian vegetation by either removal of vegetation by bank collapse or by lowering the water table thereby reducing vegetation dependent on groundwater in riparian areas (Eamus *et al*. 2006). Sediment forms an important component of aquatic ecosystems as it provides habitat, feeding and spawning areas for many aquatic organisms (Oberholster *et al*. 2005). Alteration to the river bed and floodplain will have a direct impact on the river biodiversity and health by degrading habitat quality causing changes to the diversity and abundance of aquatic fauna such as fish and benthic macroinvertebrates. Sand mining therefore also has a detrimental impact on the ecosystem goods and services that rivers provide. The WWF review concluded with recommendations on a way forward to reduce the sand mining demand in developing countries which included (WWF 2018):

- Reducing the reliance of the construction industry on river sand and gravel as a source by the substitution of materials or changes in the building design and methods to reduce extraction to levels that have minimal ecological impact;
- A shift in societal views will be required to necessitate change in the way rivers are perceived and cities are designed and constructed;
- Increase public awareness of the growing demand and finite supply of sand;
- Conduct research into economic incentives or certification schemes that could reduce extraction of sand from rivers;

- Conduct scientific research into sand mining in rivers, which includes short-term rapid assessments and longer-term research to understand changes over the time scales at which rivers and ecosystems respond to change; and
- Address the severe lack of information regarding rivers in developing countries.

Quantification and monitoring of degradation

Quantification and monitoring of degradation is contentious and problematic, since an agreed reference target or baseline is required against which degradation should be measured (Fisher *et al*. 2018; Kohler *et al*. 2018). The benefits and limitations of different approaches, including expert opinion, satellite-derived net primary productivity, biophysical models and tracking abandoned cropland, have been discussed with a focus on terrestrial ecosystems (Gibbs & Salmon 2015). Rivers and inland wetlands are however more challenging, consisting of dynamic mosaics of vegetation, water and soil, which complicates the detection and monitoring of these systems. In arid and semi-arid countries, such as South Africa, the natural hydroperiod and indicators of inland aquatic ecosystems may differ to such a degree, that a different metrics would be required for the detection of loss of habitat and degradation. The intensity and spatial extent of different impacts on inland wetlands in the Northern Cape have, for example, been workshopped by the Northern Cape Wetlands Forum (Kotze *et al*. 2019). Grazing of cattle and sheep has been identified as a prominent pressure in this arid region of South Africa, a metric which would be difficult to track and monitor. Often satellite-derived products, such as land cover and the frequency of fire mapping, is done at a country-wide scale using affordable coarse-scale space-borne sensors which are not suited for inland wetlands or rivers of narrow or small spatial extent. Vegetation species composition, biomass and nutrient mapping with remote sensing technology, as Essential Biodiversity Variables (EBVs) have been done regionally for terrestrial ecosystems, however requires refinement for inland aquatic ecosystems, and upscaling to country-wide scale before these can be used as degradation metrics (Pereira *et al*. 2013).

Hydraulic fracturing

On-shore Shale Gas Development (SGD) necessitates the process of hydraulic fracturing or fracking, which is the process of drilling into geological formations in order to release the natural gas stored underground. Fluid is injected into boreholes in order to fracture the rock formations, and keep the fractures open during exploitation (Weinhold 2012; Westra & Vilela 2014). Exploration processes employ similar techniques, but generally impact on a wider area due to the nature of the appraisal phase.

South Africa is estimated to have the fifth largest shale gas reserve in the world. International oil companies, notably Shell SA, Bundu Gas & Oil, and Falcon Gas & Oil, applied for shale gas exploration permits in the Central Karoo in 2010 (The Economist 2011; Vecchiatto 2012). Shale SA's application covers exploration rights for 90 000 km² in the Karoo. Most of the phases within the life cycle of shale gas development require large quantities of water, a scarce resource in South Africa, and particularly in the arid Karoo biome. A recent Strategic Environmental Assessment (SEA) of SGD in the Central Karoo found that there is insufficient water in the region to sustain this industry. Water would have to be imported into the Karoo.

The expected impacts of hydraulic fracturing on inland aquatic ecosystems range through pollution of groundwater (such as through the use of numerous chemicals in the fracking fluid), release of methane, drawdown of groundwater impacting on ephemeral aquatic ecosystems, seismic activity during

exploration, large-scale removal of indigenous biota, and the cumulative impacts relating to infrastructure development (roads, pipelines and boreholes) (Holness *et al*. 2016).

4.1.4 Invasive alien species

Invasive alien species are both fauna and flora that have established sustained self-propagating populations, often producing offspring in abundance and spreading considerable distances from the parent and/or site of introduction and causing harm to humans and / or the natural environment (Van Wilgen & Wilson 2018). These species have been introduced intentionally or unintentionally. Intentional introductions included alien species brought into the country for horticulture, angling, aquaculture, agriculture, forestry or the pet trade. Many species have escaped from the original sites of introduction and become invasive. Unintentional introductions involved species that were introduced as commodity contaminants, or as stowaways on various forms of transport (road, air and water). Once these species arrived, some naturalise to the local conditions including climate factors, and through superior competitive capabilities (fast growth, high reproductive output, high adaptive capacity to a wide range of physical environments), established dominance, in many cases forming monocultures or homogeneous populations. Once such species arrive, it becomes difficult to control their spread because of transport connectivity and the widespread and popular plant and pet trade (Van Wilgen & Wilson 2018).

In rivers or streams and their margins, collectively known as riparian zones, and wetlands, these species spread fairly rapidly because these systems are inherently highly dynamic and connected. These systems, which usually cover only a small part of the landscape, experience high disturbance due to natural processes (fluvial processes – flooding, erosion and deposition) and anthropogenic activities (river damming, land use in the floodzones of rivers), hence are highly susceptible to invasion (Naiman *et al*. 2005; Tererai 2012). Rivers serve as conduits for substantial fluxes of materials and energy (Ewel *et al.* 2001), thus easily dispersing alien propagule or species, especially during flood. Wetlands are known for trapping material that is transported by rivers hence acts as a sink for alien invasive species or their propagules. As a result, rivers and wetlands are amongst the most heavily invaded ecosystems globally, but also in South Africa (Richardson *et al*. 2007), causing substantial changes to ecosystem structure and function.

Degradation of rivers and wetlands by invasive species often results in attrition of ecosystem resilience, i.e. the long-term capacity of these systems to deal with disturbance and at the same time to evolve (Folke *et al*. 2010). Invasions in rivers and wetlands threaten ecosystem integrity and reduce their ability to deliver vital services in several ways (Gaertner *et al*. 2009; Vila *et al*. 2011). Invasive alien species displace indigenous species (either by superior competitive abilities for resources or predation) resulting in the reduction and/or loss of biodiversity (Tweddle *et al*. 2009; Tererai *et al*. 2015), they threaten water security due to high water consumption (e.g. Le Maitre *et al*. 2002; Engel *et al*. 2005; Oumar & Mutanga 2010; Dzikiti *et al*. 2016), and alter fire regimes due to their ability to produce large volumes of highly flammable biomass (e.g. Van Wilgen 2009), as well as threatening habitat integrity. All these impacts threaten human livelihoods and wellbeing, thus South Africa must address the problem of invasive alien species in sensible way and using best practice methods. The realities of the effects of invasive alien plants on water security and fire regimes have been amplified in South Africa recently, with huge socio-economic costs (e.g. Knysna and Betty's Bay fires). The Western Cape is one of the provinces with the highest abundance of invasive alien plants, in particular Australian trees like Wattle (*Acacia* spp.) and Gum trees (*Eucalyptus* spp.), but in particular the River Red Gum species (*Eucalyptus camaldulensis*) which is a riparian specialist (Vilà &

Gimeno 2007; Rejmánek & Richardson 2011). Along with *Acacia* spp., it is the greatest threat as it is found throughout much of South Africa and has already transformed long stretches of perennial, seasonal and intermittent rivers and dam shores (Forsyth *et al*. 2004). A eucalyptus tree of about 50 cm diameter at breast height, has transpiration rates of about 300 litres/tree/day in the summer season, which drops to about 60 litres/tree/day in the winter (Le Maitre *et al*. 2016). This is a tremendous amount of water as these trees can attain densities of about three to four trees of this size per square meter in riparian zones (Tererai unpublished data) and this may result in entire catchments or rivers being dried up. Excessive water consumption by invasive plants is a huge threat to water security particularly in water scarce areas, including towns and cities, and the impacts are dire in drought situations, as was the situation in the City of Cape Town in 2017. The detrimental effects of fire are compounded by the highly inflammable invasive alien plants biomass. The vicious Knysna and George fires in 2017 and 2018 respectively were both compounded by the dense Pine (*Pinus* spp.), Wattle (*Acacia* spp.) and *Hakea* spp. invasions in the Cape Mountains. Invasive fish species (e.g. three bass species) are the prime threat to most Red Listed indigenous fish species due to predation (see Chapter 7).

In addition, for South Africa to effectively manage these Invasive Alien Plants (IAPs) and meet its international obligations such as the Convention on Biological Diversity's Aichi Biodiversity Targets, it is critical to determine or establish what the top invaders of rivers and inland wetlands are, what their distribution is, whether they are being monitored or not, and whether there is sufficient data and information to manage them effectively and efficiently.

The ecological impacts and consequences have also been immense. Invasive fishes are the prime threat to the highly endemic and threatened freshwater fishes of the fynbos biome (Tweddle *et al*. 2009; Ellender *et al*. 2017). Invasive fishes dominate the inland waters of large areas of the fynbos region. The indigenous fishes face a cocktail of threats here which encompass most of the river system. There is over-abstraction, pollution and river canalisation in the middle and lower reaches of rivers, whereas almost throughout the river length there are one or more invasive fishes. Trout favour the upper reaches, with bass in the middle reaches and carp, sharptooth catfish and banded and Mozambique Tilapia in the lower reaches. The impact of invasive fishes is less of a problem in the summer rainfall areas of South Africa, as the majority of threatened species occur in the winter rainfall area (Cape Fold Ecoregion – CFE), with invasive alien species being the main driver of extinction risk, while in the summer rainfall areas, over abstraction and water pollution are more important. Although invasive fishes are a major ecological problem, several species are classic conflict species (Ellender & Weyl 2014) in that they also sustain valuable recreational (trout, bass, carp) and subsistence fisheries (carp, catfish, tilapia).

What are the top invaders of rivers and wetlands in South Africa?

Of the 2 033 alien species recorded (or assumed to be present) outside of cultivation or captivity in South Africa, 191 are found in the aquatic biome (Appendix E). Of these, 65 are known to be invasive, nine are naturalised but not invasive, and 53 are present, but not naturalised (Table 4.6). For the remainder 64 species there is insufficient information to assign them to an introduction status category. Four of the alien species recorded as present in the country are currently listed in the Biodiversity Act regulations as prohibited (i.e. species assumed to be absent from South Africa and which may not be imported).

Table 4.6. The number of alien species known to occur in inland aquatic biome in South Africa, assigned to various categories of introduction status. *Legal status refers to species listed under the Alien and Invasive Species Regulations (2016) under the National Environmental Management: Biodiversity Act (10 of 2004), introduced = present in South Africa but is not established outside of captivity or cultivation, Naturalised = established outside of captivity or cultivation, Invasive = established outside of captivity or cultivation and spreading, and NA = Occurs in South Africa but there is insufficient data to assign status. Information extracted from Van Wilgen & Wilson (2018).*

Taxon	Legal category	Introduced	Naturalised	Invasive	NA	Total
Microbes	Prohibited					**0**
	Listed					**0**
	Unlisted		1			**1**
Plants	Listed	1		26	2	**29**
	Unlisted	2		8	1	**11**
Invertebrates	Prohibited			1		**1**
	Listed	2		3	4	**9**
	Unlisted	2	2	14	1	**19**
Fish	Prohibited					**0**
	Listed	7		6	2	**15**
	Unlisted	4	1		6	**11**
Amphibians	Prohibited	2				**2**
	Listed	3	1	2		**6**
	Unlisted	12		1		**13**
Reptiles	Prohibited					**0**
	Listed	5	1		9	**15**
	Unlisted	3			21	**24**
Birds	Prohibited		1			**1**
	Listed	1	1	1	1	**4**
	Unlisted	9	1	3	11	**24**
Mammals	Listed				6	**6**
	Unlisted					**0**
Total		53	9	65	64	191

Records drawn in 2018 from the Southern African Plant Invaders Atlas (SAPIA) database give an indication of the most common invaders of rivers and their riparin zones. These are the Weeping Willow (*Salix babylonica*), Poplar trees (*Populus alba and P. canscens*), Australian Thorn trees / Wattles (*Acacia mearnsii, A. delbata* and *A. saligna*), Mesquite trees (*Prosopis grandulosa var. torreyana/velutina),* Bugweed (*Solanum mauritianum Scop*.), Spanish gold (*Sesbania punicea (Cav.) Benth*.), Big-sage (*Lantana camara L. sensu lato),* Triffid weed (*Chromolaena odorata*), and the River Red Gum (*Eucalyptus camaldulensis*) in their order of abundance of locality records. The common instream species include the Giant Reed (*Arundo donax*), Water Fern (*Azolla filiculoides Lam*.) and the notorious Water Hyacinth (*Eichhornia crassipes*). For wetlands, the top five invaders are the Water hyacinth, the water ferm (*A. filiculoides* Lam.), the Spear thistle (*Cirsium vulgare* (Savi) Ten.), the Honey mesquite (*P. glandulosa var. torreyana/velutina*) and the purpletop (*Verbena bonariensis*). Among these species are those identified by Nel *et al.* (2004), Kotze *et al*.

(2010) and by the South African National Biodiversity Institute (SANBI) and the Centre for Invasive Biology (CIB 2018) as major invaders.

While the confidence levels in this list are moderate, because they are often based on observation rather than real targeted surveys. It will be useful to validate this list through taxon specific expert workshops.

In terms of invasive fish, the most serious invaders in terms of ecological impacts are likely the basses in term of predation (fynbos biome) and carp in terms of water quality impacts (especially impoundments but also rivers). Note that translocated fish invaders are also a serious problem such as sharptooth catfish in the Western Cape Province where it does not naturally occur and has been widely and illegally introduced for angling purposes (Impson *et al*. 2017). The pet trade is likely going to be an increasing source of new invasive fishes, if hobbyists release or dump unwanted fish into inland waters. Guppies (*Poecilia reticulata)* and Goldfish (*Carassius auratus)* are established and suckermouth Sailfin Catfish (*Pterygoplichthys disjunctivus)* have recently become invasive in Kwazulu-Natal. The pet trade is also the likely source of several aquatic snail invasions for example Helisona Snail (*Helisoma duryi)* (Weatherby 1879) and Physa Snail (*Physa acuta)*.

Spatial extent and abundance of invasives in South Africa

SANBI and the CIB (2018) reported that of the 107 species identified as having major impacts based on an expert opinion study by Zengeya *et al*. (2017), 75% are terrestrial and freshwater plants. They further reported that the Savannah biome has the highest species richness of invasive species, the Fynbos and Coastal areas are dominated by tree and shrub invaders, arid areas are dominated by Mesquite, riparian zones are invaded by invasive tree species and rangelands are invaded by cacti and herbaceous annual and perennial plants.

There is, however, limited understanding of the geographic distribution of IAPs in rivers and wetlands of South Africa. In many cases surveying is not targeted at rivers and inland wetlands. Mapping is often patchy where it has occurred, with individual species-level mapping for management purposes e.g. *Mesquite* spp. mapping in the Northern Cape (Van den Berg 2010). The databases containing two considerable mapping initiatives are noteworthy, that is, the SAPIA and the National Invasive Alien Plants Survey (NIAPS) (Kotze *et al*. 2010). However, these databases are not without their own limitations.

SAPIA is mostly point occurrence data, and there is a sampling bias towards road networks that are easily accessible, however there are also some ad hoc records available. The NIAPS is a fairly comprehensive survey with distribution data but is also an estimate of species composition and abundance (density), however its coverage is far from complete. Figure 4.13 shows aquatic invasive species per quarter degree square based on SAPIA data, as was collated for the recently published the State of Biological Invasion report.

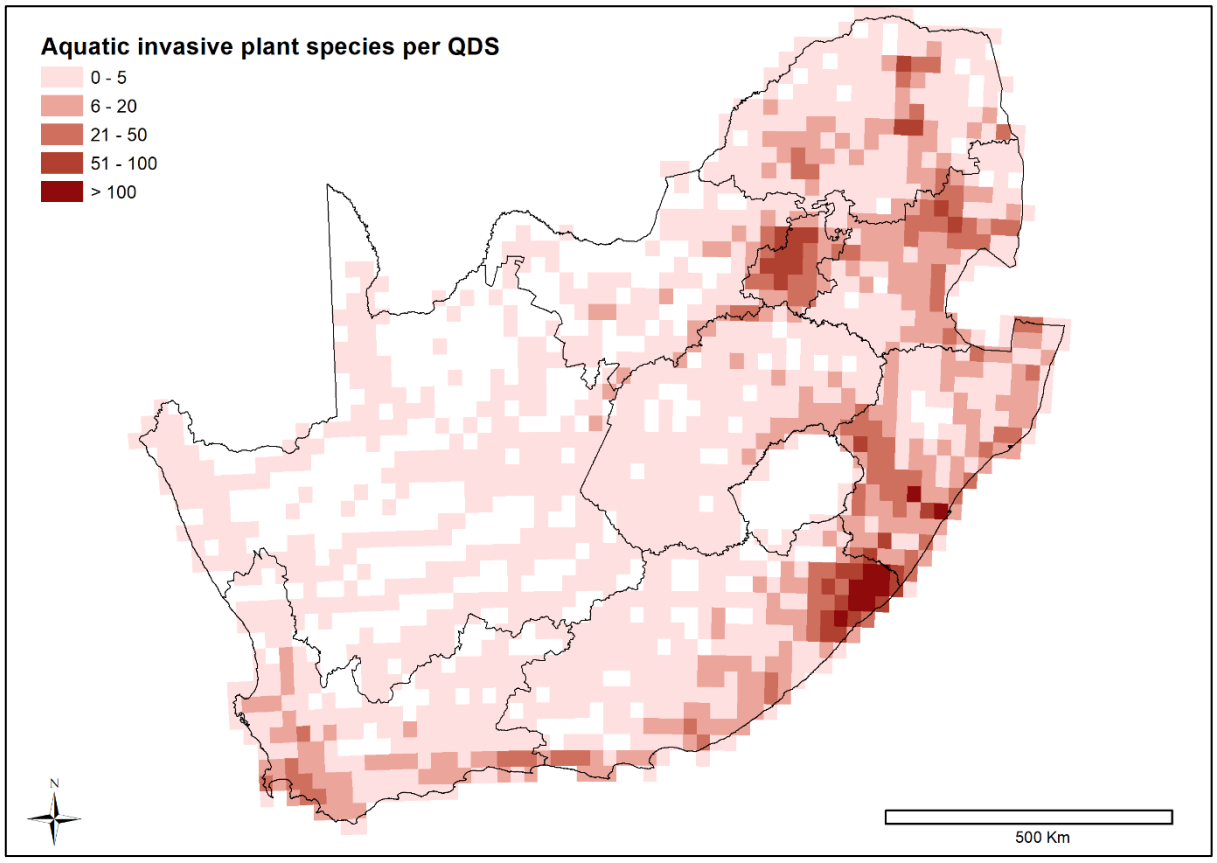


Figure 4.13. Number of invasive aquatic plants per quarter degree square (QDS). Data from the Southern African Plant Invaders Atlas, accessed May 2016. Information extracted from Van Wilgen & Wilson (2018).

The National Species Regulations (NSRs) used two major sources of abundance data - the 1998 report of the Water Research Commission (Appendix 5 in Versfeld *et al*. 1998) and the NAIPS of the Agricultural Research Council (ARC) (Kotzé *et al.* 2010). In terms of confidence levels, NSR describes the estimates as very crude and 20 years out of date, and NIAPS only targets only those species targeted for control by Working for Wetlands (mainly trees and shrubs) and excludes very large proportion of arid South Africa (Van Wilgen & Wilson 2018). The methodology for the NIAPS was never adequately documented thus there can only be low confidence in the estimates. In addition, extent data of these two sources are not comparable because of differences in methodology used.

Because distribution data is at Quarter Degree Grid Cells (QDGCs), freshwater invertebrates and mammals appear to be less widespread, thus there are no reliable for invasive freshwater fish species at this scale (Van Wilgen & Wilson 2018).

In terms of invasive alien fishes, carp are likely the most widespread and common invader across South Africa, followed by largemouth and smallmouth bass. Rainbow and Brown Trout have been widely introduced into cool mountain streams and have invasive populations in almost all provinces, with documented negative impacts of biodiversity (Rivers-Moore *et al*. 2013b; Shelton *et al*. 2014). They are, however, very popular with flyfishermen and for aquaculture and sustain economies at a local scale in Rhodes, the Eastern Cape Province, the Underberg region of KZN and Dullstroom in Mpumalanga (Impson 2016). In terms of translocated invasive fishes, the most widespread and common invaders are likely sharptooth catfish and banded tilapia, which thrive in the larger river systems of the fynbos biome.

Types and magnitude of impact across different geographic regions?

The impacts of IAPs have rarely been assessed in South Africa, and where these have been assessed, they are for single species, and localized areas for which the results are not comparable (Van Wilgen & Wilson 2018). While a number of invasive alien plants are acknowledged as problematic in riparian zones of South Africa, the extent and magnitude of these impacts in not well understood. This is also the case on the global scale where detailed quantitative assessments are rare (Hulme 2003; Hulme & Bremner 2006; Jäger *et al*. 2007; Pyšek & Richardson 2010). Ecosystem-level impacts of IAPs are better understood than community level impacts, thus limiting the successful implementation of effective management of IAPs (Starfinger *et al.* 2003). A few studies conducted particularly in riparian zones outline these impacts as ranging from decline in water quantity (Dzikiti *et al*. 2013 in arid environment; Görgens & Van Wilgen 2019) and quality (Chamier *et al*. 2012), decline in native plant (Tererai *et al*. 2015) and animal (Mangachena & Geerts, 2017) species diversity, soil chemistry legacy effects (Tererai *et al*. 2015), and alteration of river morphology (Tererai 2012). However, the full suite of these impacts is yet to be studied across different species and regions or realms in the country.

Aquatic invasives reduce surface water runoff by 1 450–2 450 million m^3 per year, and if nothing is done reductions in water resources can rise to between 2 600 and 3 150million m^3 per year, which will further exacerbate the threat of water insecurity in drought-stricken areas like Cape Town. While reductions in rangeland productivity and in biodiversity intactness are low at present, these impacts are expected to increase rapidly as invasives enter a phase of exponential growth.

The Honey Mesquite (*Prosopis grandulosa*) which is known to invade the karoo and arid savanna biomes reduces native species diversity, depletes groundwater and reduces rangeland quality. In South Africa's Alien and Invasive Species Regulations, Mequite spp. are listed as category 3 (may be retained but not replaced) in the Northern Province, but elsewhere is it category 1b (to be controlled) (Van Wilgen & Wilson 2018). Black wattle (*Acacia mearnsii*), a category 2 species (may be retained, and traded, with a permit, but should be controlled elsewhere) is widespread in the humid parts of South Africa and in the riparian zones of rivers in the fynbos biome. Among its major impacts are surface and groundwater depletion and outcompeting indigenous riparian vegetation. The Red River Gum (*Eucalyptus camaldulensis*) is classified as category 1b in riparian zones and is known for high water usage and negative biodiversity effects. The invasive Wild Sage, *Lantana camara* (category 1b) is a common invader of rivers and wetlands and is poisonous to fauna. The Smallmouth Bass (*Micropterus dolomieu*) is a category 2 species which has severe impacts on indigenous fishes in the Western and Eastern Cape, but is category 1b in protected areas allowing for control.

Using the Environmental Impact Classification for Alien Taxa (EICAT) scheme, 10 terrestrial species were assessed as having a severe impact, and 17 as having a major impact (Table 4.7). Of these major to severe ranked species, most (15) are plants, five are invertebrates, five are fish and two are amphibian species.

Most of the ten species with severe impacts were plants (five species) that included four species of Australian Acacia trees and shrubs (Table 4.8). Acacias have been implicated in reducing grazing potential and surface water runoff and negatively impact on biodiversity. The list also includes the North American Velvet Mesquite tree (*Prosopis veluntina*), which reduces grazing potential, depletes groundwater resources and negatively impact on biodiversity.

Table 4.7. The number of alien species known to occur in South Africa in the inland aquatic realm, assigned to different impact scores based on expert opinion of the impact in South Africa. *The impact scores are grouped into five categorises that correspond in spirit to the categories of the Environmental Impact Classification for Alien Taxa (EICAT) and these are data deficient (DD); negligible impact (score 1–2) – Minimal Concern (MC); few impacts (3–4) – Minor (MI); some impacts (5–6) – moderate (MO); Major impacts (7–8) – Major (MR); Severe impacts (9–10) – Massive (MV). NE = not evaluated. The impacts assessments are based on expert opinion, and consequently the level of confidence in the estimates is low (Zengeya et al. 2019).*

Taxon	Impact						
	DD	Negligible	Some	Major	Severe	NE	Totals
Plants		8	8	10	5	9	**40**
Invertebrates		16	4	1	4	4	**29**
Microbes						1	**1**
Fish	1	5	9	4	1	6	**26**
Amphibians	15	3	1	2			**21**
Reptiles	5	8	4			22	**39**
Birds		2	1			26	**29**
Mammals		4	2				**6**
Totals	**21**	**46**	**29**	**17**	**10**	**68**	**191**

Examples of severe impacts in other high-level taxa includes two crayfish species, namely the Australian Red Claw Crayfish (*Cherax quadricarinatus*), and the Red Swamp Crayfish (*Procambarus clarki)* which has negative impacts of indigenous species and habitat modification; two fish parasites which are the Fish Gillworm (*Pseudodactylogyrus anguillae*) and Asian Tapeworm (*Pseudodactylogyrus acheilognathi*) that were co-introduced with alien fish and can also affect indigenous fish species, and a predatory fish, Smallmouth Bass (*Micropterus dolomieu*), implicated in extirpation of indigenous and endemic fish in streams, rivers and dams (Table 4.8).

Data gaps for invasive species

There is greater need for more evidence on the type and magnitude of impacts of invasive alien plans in rivers and wetlands specifically. Much of the evidence on the impacts of IAPs is anecdotal.

The results of the modelling exercise using the NIAPS data have been presented in detail for invasions in dryland, riparian and groundwater aquifer settings by Le Maitre *et al*. (2013; 2016). The condensed invaded area in South Africa is 1.5 million ha (Le Maitre *et al*. 2016). The taxon with the greatest estimated impact was the Australian thorn trees or wattles (*Acacia mearnsii*, *A. dealbata*, *A. decurrens*) with 34% of the total reductions, followed by Pinus species (19.3%) and Eucalyptus species (15.8%). The revised estimate is considered on the low side largely because the extent and impacts of riparian invasions have been underestimated. If the current estimates that 4–6% of *Acacia mearnsii*, Eucalyptus, Populus and Salix invasions are riparian, are adjusted to a more representative 20%, 50%, 80% and 80%, respectively, the total reductions increase by nearly 70% to ~2 444 million m^3yr^{-1}.

Most of what is known about the impacts of alien species in South Africa is based on expert opinion, and consequently the level of confidence in the estimates is low (Zengeya *et al.* 2019). The use of semi-quantitative impact scoring schemes such as EICAT (Blackburn *et al.* 2014; Hawkins *et al*. 2015) have thus been advocated because they provide a consistent method for rating impacts across different mechanisms and taxa. Notably, expert opinion studies do not always align very well with EICAT assessments. These

differences stem mainly from the fact that most of the using expert opinion is based on observed and perceived impacts, while formal assessments focus on published evidence.

Table 4.8. Invasive species assessed to have severe impacts in the inland aquatic biome in South Africa. *The regulatory category 'context specific' applies to species that have been placed into various categories depending on their location. QDGC = quarter degree grid cells.*

Taxon	Species	Regulatory category	Extent (QDGCs occupied)	Examples of impacts
Freshwater plants	*Acacia dealbata* (silver wattle)	2	240	Forms closed-canopy stands, excluding most other species, especially in riparian areas; uses excessive amounts of water.
	Acacia longifolia (long leaved wattle)	1b	53	Forms closed-canopy stands, excluding most other species; uses excessive amounts of water.
	Acacia mearnsii and hybrids (black wattle)	2	369	Forms closed-canopy stands, excluding most other species, especially in riparian areas; uses excessive amounts of water.
	Acacia saligna (Port Jackson willow)	1b	126	Forms closed-canopy stands, excluding most other species.
	Agrostis stolonifera (creeping bent grass)	Context specific	Offshore islands	Forms extensive clonal patches by means of long stolons, impacting on indigenous plant species on offshore islands.
	Prosopis velutina (velvet mesquite)	Context specific	5	Many well-documented impacts on biodiversity, groundwater supplies, rangeland productivity and human livelihoods.
Freshwater invertebrates	*Cherax quadricarinatus* (Australian red claw crayfish)	1b	3	Negatively impacts indigenous freshwater species. It also carries parasites which could have further impacts on indigenous species.
	Pseudodactylogyrus acheilognathi (Asian tapeworm)	Unlisted	5	A parasite introduced on alien fish that attacks indigenous fish species.
	Pseudodactylogyrus anguillae (fish gillworm)	Unlisted	2	A parasite introduced on alien fish that attacks indigenous fish species.
	Procambarus clarkii (red swamp crayfish)	Prohibited	4	Physical damage to aquatic habitats; disrupts nutrient cycling; preys on indigenous species.
Freshwater fish	*Micropterus dolomieu* (smallmouth bass)	Context specific	60	Predatory fish that negatively impacts of indigenous fish and freshwater invertebrates.

From the introduction, occurrence and abundance currently available, it is difficult to conduct any quantitative trend analysis because either the data records are not long enough, of limited coverage, contains bias (e.g. SAPIA roadside surveys), do not focus on rivers and wetlands or variables are not consistently monitored, and sampling and reporting effort is not consistent (thus caution must be taken not to mistake increase in reporting and sampling effort as increase in the coverage of invasions. There have been attempts though to conduct some analysis of the SAPIA (Henderson & Wilson 2017), and earlier by Nel (2004) and NIAPS databases (Le Maitre *et al*. 2016). The Henderson & Wilson study identified species that have shown the greatest increase in range and local abundances between 2000 and 2016, however this result must be interpreted with caution as discussed earlier. The Le Maitre study (2016) has the added advantage of having considered invaders of riparian zones as a category.

Aquaculture in South Africa is an emerging pressure. The former Department of Agriculture, Forestry and Fisheries (DAFF) has set out a plan to increase food production through aquaculture (Table 4.9). A Strategic Environmental Assessment (SEA) led by the CSIR is under way to advise on the geographic areas and

mitigation measures needed to minimise the risk of aquaculture on the environment. This SEA focused on several freshwater species that are already prominent in aquaculture or are seen as holding significant potential, namely rainbow and brown trout, Mozambique and Nile tilapia, sharptooth catfish and marron (Lizande Kellerman, *pers. comm.,* 10 August 2017). At least five freshwater fish species and five crayfish species are identified as important (Nunes *et al*. 2017). The most important freshwater fish species in terms of current annual production is rainbow trout, with much smaller but growing industries for ornamental fish and Nile tilapia. Generally, alien species are kept in various production systems ranging from low (recirculating aquaculture systems) to high risk (cages in dams) systems and high-risk systems may contribute to modification in water quality as well as accidental and deliberate release of species into inland aquatic ecosystems. Waste is naturally produced from the farm in the form of fish faeces and uneaten food and can result in either nutrient pollution or chemical pollution or both when farms release wastes into rivers and dams. The diseases and parasites on farmed fish can easily be transferred to indigenous fish species in open systems. The distribution of farmed species and associated parasites may even take place at a transboundary level affecting more than one country (e.g. Nile tilapia invading Limpopo River from Zimbabwe (Van der Waal & Bills 2000), Red claw crayfish, invading the Crocodile River from Swaziland [Petersen *et al*. 2017]).

Table 4.9. Number of farms where aquaculture is practised in the provinces of South Africa (adapted from DAFF 2016:18).

Species	EC	FS*	GT	KZN	LP	MP	NC	NW	WC	Total number of farms
Tilapia spp.	2	3	20	5	16	14	1	14	2	77
Rainbow Trout	2	1	0	5	0	18	0	0	13	39
Sharptooth Catfish	1	1	1	0	3	0	0	1	0	7
Marron Crayfish	1	0	0	0	0	0	0	0	0	1
Carp	0	1	1	0	0	0	1	0	1	4
Koi carp	0	2	5	2	0	1	0	0	1	11
Ornamental species	0	1	4	3	1	0	0	0	3	12
Total	**6**	**9**	**31**	**15**	**20**	**33**	**2**	**15**	**20**	**151**

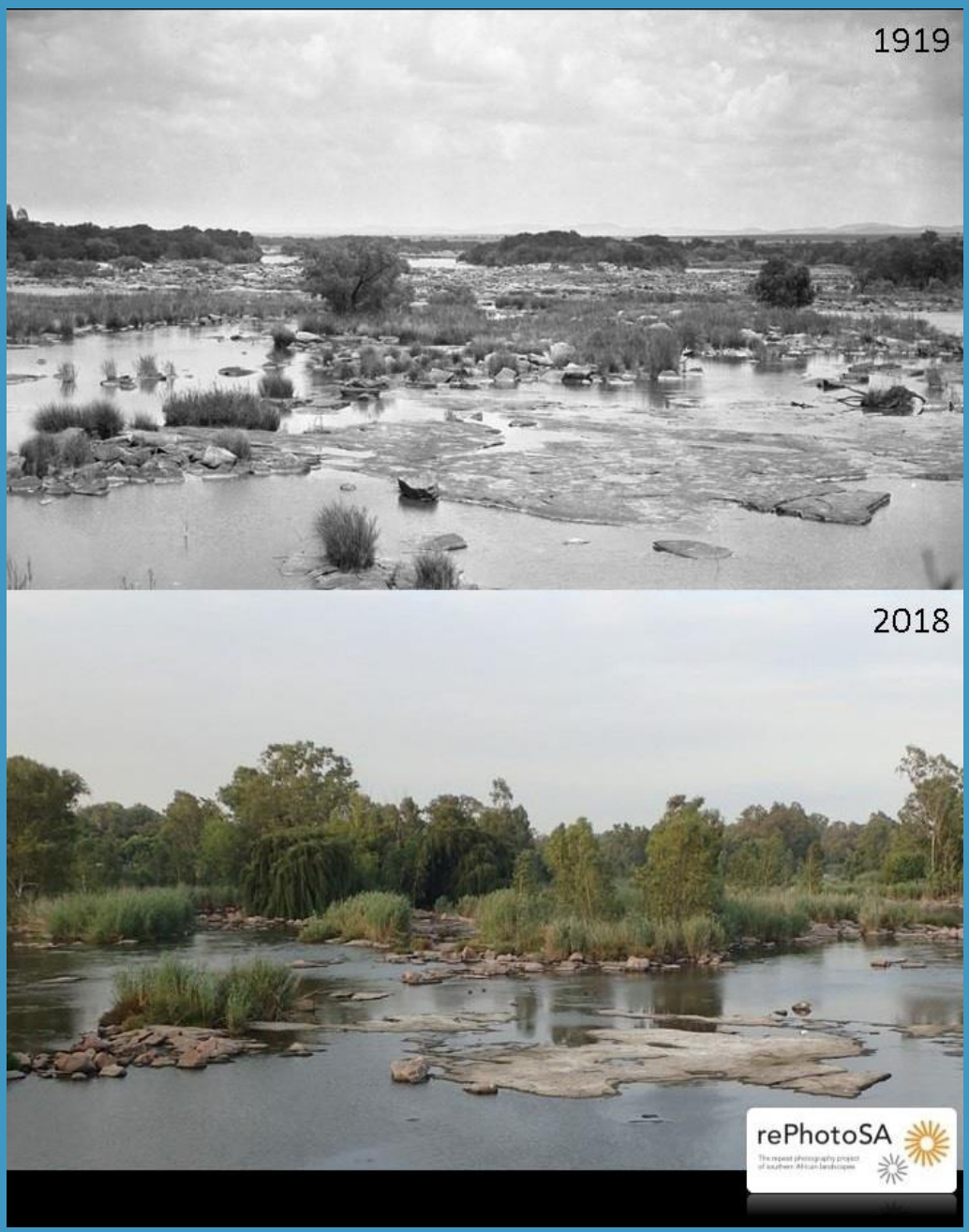
** Statistics simplified from information provided by Dr Leon Barkhuizen (FS DESTEA); overlap in species occurs on some farms, while six Sharptooth Catfish spp. farms are currently inactive and not included above.*

Interbasin transfers of water also result in translocation of animal and plant species from the donor to the recipient system, often with negative effects for the recipient system. A well-studied example is the IBT from the Orange River to the naturally seasonal Fish River in the Eastern Cape Province. The transfer of large amounts of water to meet growing irrigation demand in the Fish River catchment resulted in several fish species successfully colonising the Fish River, which prior to the IBT had very low fish diversity. The change in the Fish River from a naturally seasonal to a perennial state carrying a continuous high volume of water also changed the composition of the aquatic invertebrate fauna (Laurenson & Hocutt 1986). Hybridisation is also a major concern if the donor and recipient systems have fish species which can readily hybridise. Often the introduction of these species is accompanied by associated parasites which also exacerbate the impact on indigenous species (Du Preez & Smit 2013).

Box 4.6. Increase of invasive species in the Vaal River near Parys, South Africa

Contribution copied from the Facebook page of the Plant Conservation Unit, Animal Demography Unit and University of Cape Town. Throwback Thursday posted 12 July 2018.

This #ThrowbackThursday features historical photograph #927 of the, 'Vaal River. Parys.' in the Free State province of South Africa (QDS 2627CD) taken by IB Pole Evans in 1919 and its fantastic repeat taken by Lisa de Speville in January 2018 (http://rephotosa.adu.org.za/Search_photos.php…). Pole Evans noted *Acacia* (*Vachellia*) *horrida* and potentially a *Phragmites* sp. in the river. De Speville noted an overall significant increase in vegetation growth in the river, particularly Blue Gum (*Eucalyptus* spp.) trees (alien invasive spp.) on the rocky islands in the river. She also noted a considerable increase in vegetation growth on the banks. 'The hills in the original photo are not currently visible because of the height of the trees.'



4.1.5 Over-exploitation of species

Utilisation of freshwater species associated with river and inland wetland ecosystems is mostly limited but can be extensive in some cases, although, direct use pressures have not contributed to an increase in the vulnerability of these species. Most of the species known to be utilized are currently assessed as Least Concern, widespread species and direct-use impacts are generally localized. In South Africa, animals are primarily harvested for food and/or traditional and medicinal purposes. Some animals are also persecuted as damage causing individuals closer to farm areas where they may hunt cattle or raid crops. The country has an abundance of national and provincial legislation that affords protection to many species and any direct use activity involving living specimens usually requires a permit from some or other authority. Illegal use and trade in species is more difficult to assess and control. Species that are impacted by global trade or could potentially become impacted by global trade, are listed on one of three Appendices of the Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES). The majority of our South African species in trade are listed on CITES Appendix II which means that even though a species may not necessarily be threatened with extinction, trade in the species must be controlled in order to avoid overutilization that would compromise its survival in the wild (CITES website). South African freshwater species listed on Appendix II of CITES includes all three of South Africa's iconic crane species Wattled Crane (*Bugeranus carunculatus* – CR), Grey Crowned Crane (*Balearica regulorum* – EN) and Blue Crane (*Anthropoides paradiseus* – NT). These birds are potentially vulnerable to trade in their eggs and chicks for the pet and zoo trade. Servals (*Leptailurus serval* – LC) are also traded internationally, primarily as hunting trophies, but also as live animals for keeping in zoos and as pets. The species is also popular in the local traditional medicine trade. International trade in the species is legal and regulated in accordance with CITES and whilst there are provisions for national utilisation and trade, the majority of the offtake remains illegal at this time. Both South African otter species, the Spotted Necked Otter (*Hydrictis maculicollis* – VU) and Cape Clawless Otter (*Aonyx capensis* – NT) as well as the Nile Crocodile (*Crocodylus niloticus* – VU) are listed on CITES as all three species are traded as hunting trophies as well as for their skins. They are also harvested locally as a source of food and medicine. Freshwater species are primarily threatened by an ongoing decline in the size and condition of available habitat and for the few species that are known to be utilised, exploitation is not at levels that threaten their existence. Nevertheless, ongoing monitoring of use and trade should be conducted to detect any change in current trends.

Many freshwater fish species may face over-exploitation due to angling and local fisheries and several species are due to be listed in terms of the national Threatened or Protected Species Regulations (TOPS). South Africa has many species of saltwater fish that have been fished to the point of commercial extinction (e.g. White Steenbras, Red Steenbras, but as yet our indigenous freshwater fish stocks have not been affected by over-utilisation beyond a local scale. A prime reason for this positive state of affairs has been the ban on using nets to harvest fishes in public waters (public dams, rivers) without a permit. Sustainable fish harvesting has taken place using angling, but there is growing pressure from various sectors to allow nets to be used, especially in impoundments (Britz *et al*. 2015). There are increasing incidences of illegal use of nets as well as conflict between recreational and subsistence anglers over how fish stocks should be used (Britz *et al*. 2015). South Africa has very little capacity to manage inland fisheries at present, following the demise of the Inland Fisheries sections at the provincial conservation authorities in the 1970s and 1980's (Impson 2016).

4.1.6 Climate change

Changes in climate, particularly rise in temperature and changes to the amount, intensity and season of precipitation, are expected to exacerbate the impacts of current pressures on inland aquatic ecosystems. Global temperatures have increased by almost 1°C over the past 50 years and could increase another 1–2°C by 2050. Increasing temperature will impact the hydrological cycle, and consequently the functioning of rivers and inland wetlands. Significant reductions in amphibians' range sizes are likely early impacts. In southern Africa, large lakes have shown increases in aquatic temperature, while the tropical cyclones which bring rain to the Maputaland Coastal Plain may move eastward, away from the African continent. Climate change is widely considered as a multiplier of other pressures on biodiversity, both exacerbating the effects of these pressures and altering the frequency, intensity and timing of events. Many of these shifts are predicted to benefit the survival of invasive species over native species and increase the outbreak potential and spread of disease. Considering that many freshwater species are range-restricted and that the fragmented state of ecosystems may prohibit range shift migrations, increasing the connectedness and size of the protected area network, including Ramsar sites, are key components of climate change adaptation strategies. In the inland aquatic realm, human responses to climate change are likely to further increase some pressures, for example, reduced rainfall due to climate change (compounded by biological invasions in catchment areas) drives an increase in water abstraction (for human settlements and agriculture) which compounds the pressure on the aquatic ecosystem and species. (This paragraph is a summary of information obtained from both Chapters 3, 7 and 8. Please refer to these specific chapters for the details and references).

As an example, the combination of increased water abstraction and drought has resulted in the the loss of a quarter of the 428 trees in the riparian Lowveld Riverine Forest, situated along the Limpopo River, between 1990 and 2000 (Kotzé 2015). Consequently, the ability of the riparian flora to secure the bank results in an increase of bank erosion and an increase in the sediment load in the rivers. The 17 peatlands that are either desiccated or have been burning since 1996 (Section 4.3.1 and Figure 4.3) also show the result of and increase in water abstraction with the severe drought conditions that South Africa has experienced in 2015/2016.

4.2 Summary of emerging and intensifying pressures in the inland aquatics

- **Changes to the hydrological regime**:
    - **Increasing water abstraction** is an intensifying pressure with a growing demand for water and intensifying droughts under climate change, is of major concern. The next section will elaborate on the interactions between existing pressures and climate change to expand on this problem.
    - **WWTW** — an increase in demand result in an increase of water released from WWTW; additional water released, impact rivers and wetlands, particularly if asynchronous to hydrological regime and flood pulses.
    - **Fracking of the Karoo aquifer is an emerging pressure.** The proposed exploration and exploitation of shale gas fields in the Karoo and elsewhere in South Africa are emerging pressures on inland aquatic ecosystems. The expected impacts range through pollution of groundwater, release of methane, drawdown of groundwater impacting on ephemeral aquatic ecosystems, seismic activity during exploration, large-scale removal of indigenous

biota, and the cumulative impacts relating to infrastructure development (Holness *et al*. 2016).

- **Water quality**:
  - **Micro-plastics** (see Section 4.3.2) **and Pharmaceuticals** are considered emerging pressures in the inland aquatic ecosystems.
  - **WWTW** — 30% of WWTW have purple status of systems and 46 are under critical review since January 2019 (DWS 2018; News24 2019).
- **Loss of natural habitat**:
  - Illegal sand mining is emerging as a pressure on vulnerable seasonal and ephemeral river ecosystems in South Africa and is difficult to monitor. An evaluation of the cumulative impact of illegal sand mining should inform permitting decisions.
- **Invasive species:**
  - **Aquaculture for economic benefits:** Growth in particularly Tilapia and Marron crayfish has been observed in the past ten years.

4.3 Interactions, combinations and synergies between pressures and climate change

Multiple land uses in a catchment result in multiple pressures which can vary in severity and duration. The majority of South Africa's land area is used for grazing purposes, as it is an arid to semi-arid country (Skowno *et al*. 2019). Different stock types and densities exist and it is often difficult to know where overgrazing is taking place although soil erosion and vegetation changes are obvious signs of severe overgrazing. Grazing in general, although more extensive in the landscape, has less intense impacts compared to the other land uses such as agriculture, mining, plantations and urban areas. Irrigation agriculture demands water from river ecosystems and boreholes, and can have a drastic impact on the hydrological regime. In addition, fertilisers, herbicides and pesticides are added to maximise crop production which cause land and water pollution. Agricultural land that is abandoned or left fallow allows for invasive species to colonise, and if not managed, will establish dominance. Plantations have impacts that are similar to those of agriculture, but because of the high levels of water use of most plantation species, impacts on surface and ground water are more severe (Appendix C and Appendix D). However, less fertilizers and pesticides are used in plantations compared to agriculture. Mining is an intense but not extensive land use, covering only 0.2% of South Africa's surface. Mining severely modifies the terrain geomorphology and uses large quantities of water from rivers or groundwater. Mining waste and acid mine drainage is usually localised, though with some run-off impact up to 40 km from the source (Oberholster *et al*. 2013a) depending on the substrate and surface volume run-off. Urban development, including transport and sewerage infrastructure, results in the complete loss of inland wetlands or drastic changes to the water quality and connectivity of rivers and wetlands. As a result, surface run-off increases owing to hardened surfaces which can cause severe erosion of river banks. Air pollution can be a major problem in big cities and air pollution from coal power stations is a major problem in several towns of the Mpumalanga Province. Towns and cities are new sources of invasive plant species, with garden plants spreading into parks and adjacent countryside. Impermeable transport corridors are physical barriers that can cause habitat fragmentation and inhibit natural species migratory patterns.

Cumulative impacts of multiple pressures have been demonstrated in a number of studies. Durand (2012), for example, discussed the combined impact of water abstraction, water pollution, and loss of natural habitat around the mining operations of the Witwatersrand in Gauteng. The cumulative impacts of WWTWs are also demonstrated through the work of Van Heerden (2014) for an arid inland wetland near Prince Albert. With the increase of the population in Prince Albert, the facility is not able to cope with the increasing volume, and sewage spills into the adjacent wetland. The hydrological regime changes, causing root rot in the succulents and allowing invasive species to dominate in the area which has now turned to a permanently saturated zone. Phosphates, potassium and acidity are higher within 25 m to 50 m from the stream, declining further away from the source of pollution.

The combined and interactive influences of the key pressures to inland aquatic biodiversity are exacerbated further by global-scale environmental change (Dudgeon *et al.* 2006). Climate change impacts are expected to exacerbate the impacts of the existing pressures on inland aquatic ecosystems and are therefore considered a multiplier. The frequency, duration and intensity of extreme weather events, such as floods and droughts, have been increasing. The impact of the most recent drought in Cape Town, and now in the Eastern Cape, is evidence to the emerging pressures to be faced in future.

Water availability, is a major component of inland aquatic systems such as wetlands and rivers, and the decline in its quantity and quality is hugely concerning. An increasing human population with higher standards of living, combined with increasing chances of drought, have put a tremendous pressure on inland aquatic ecosystems. Reducing pressures on our water resources through wise water use and penalties for water wasters should therefore be a top priority. Determining the correct pricing of water for the different water users should be a top priority in each major water management area, and this should factor in ecological infrastructure costs.

The declining quantity of water also impacts the ability of inland aquatic ecosystems to dilute contaminants. Because of climate change, it is predicted that temperatures will increase by an average 2°C, including in Africa, and rainfall will generally decline, and these conditions are likely to favour some invasive alien plants that have superior competitive capabilities over indigenous species, thus further depleting the water resources. This is particularly devastating for countries like South Africa, that are classified was water scarce. The rapid spread of reed species, including the invasive Spanish reed, in the riparian zones of many rivers (e.g. Breede, Western Cape) is an obvious sign of rivers under major pressure – too little flow due to over abstraction, damaged riparian zones due to previous plant invasions and excessive levels of nutrients in the water.

Effective responses to these synergistic and cumulative pressures are further discussed in Chapter 9.

4.4 Change in pressures

4.4.1 Changes to river extent and condition

For the purposes of the NBA 2018 the NFEPA rivers network layer with river ecosystem types was used to represent the diversity of river ecosystems across the country (Nel *et al*. 2011a; 2011b; Nel & Driver 2012). This layer was also used in the freshwater component of the NBA 2011 assessment. Minor river arc editing resulted in a rivers data set representing 200 955 km of river length of which 164 018 km (82%) is located within South Africa. Mainstem rivers constitute 76 830 km (47%) of the total length of the South African rivers, and tributaries 87 188 km (53%). River extent changes are insignificant with the NFEPA total river

length within South Africa being only 242 km (0.1%) more than the NBA 2018 rivers (Smith-Adao *et al*. 2018).

A comparison between the river ecosystem condition results of the NBA 2011 and NBA 2018 are not possible without investigating back casting as the methods used in these two assessments differ considerably (see Section 5.2.1). The major difference being that the NBA 2011 assessment included modelling of the tributary condition using natural land cover as an indicator of condition (Nel *et al*. 2011b; 2011b; Nel & Driver 2012). Furthermore, the desktop PES database must be systematically updated with higher confidence data as it becomes available. The data is based largely on expert opinion. A confidence rating (e.g. mean rating per ecosystem type) could be applied to improve the accuracy of the data in the future.

4.4.2 Changes to inland wetland extent and condition

Since the inland wetlands dataset or base layer requires continuous update before it is considered to be a full representation of the extent of inland wetlands (National Wetland Map version 5 [NWM5], see Van Deventer *et al*. 2018), comparison to previous extents are not possible. Furthermore, the datasets and methods used for the modelling of ecological condition in NFEPA differs from the one used in this assessment (NBA 2018). However, the percentage of natural land cover found within inland wetlands, as mapped in NWM5, of 1990 and 2014, were compared to assess differences. For most of the inland wetland hydrogeomorphic units, a loss of natural land cover was observed since 1990 at a rate of 0.3% per annum (Table 4.8). Depressions are less affected, owing to little development or land conversion taking place in these units.

Table 4.10. Natural land cover (NLC) remaining within inland wetlands for 1990 and 2014.

Hydrogeomorphic unit (down) / Land cover dataset (across)	NLC1990	NLC2014	Percentage change (percentile points)
Depressions	94.6	93.4	-1.2
Floodplains	77.0	73.3	-3.7
Seeps	72.0	68.2	-3.8
Valley-bottoms	80.4	76.7	-3.7

In general, however, land cover is a poor surrogate for land degradation that can take place in wetlands, and is not representative of the wider range of pressures on inland aquatic ecosystems including water pollution, fragmentation, invasive species and climate change.

At a provincial scale, development applications in Mpumalanga show an increasing trend for mining, constituting a large land use change that requires proper administration otherwise the impacts can be devastating on freshwater resources (Box 4.5). Similar statistics was not available for other provinces.

4.5 Conclusion

This chapter has reviewed information available on the internationally recognised pressures on rivers and inland wetlands, namely changes to the hydrological regime, water quality, loss of natural habitat, invasive alien species and the over-exploitation of species. Although this chapter did not provide a thorough or extensive review of these pressures, several facts came to the fore:

- Water availability is the primary limiting factor to the formation of inland aquatic ecosystems. Reduction of water availability results in potential collapse of rivers and inland wetlands;
- A multitude of variables are associated with each category of pressure, providing ample surrogates for the quantification and monitoring of river and inland wetland ecosystems;
- Variables for monitoring water quality is diverse and already in use to categorise and monitor the ecological condition of rivers, while fewer variables are able to quantify water availability which will allow the hydrological regime to persist, as well as variables related to the loss of natural habitat, processes as well as climate change;
- Land degradation, ecological processes and illegal sand mining are difficult to quantify and monitoring;
- Pressures co-exist as a result of succession of degradation in systems. The presence of one pressure in a system may indicate the presence of multiple pressures which eventually act as multipliers of degradation;
- Climate change is a multiplier of existing pressures, exacerbating the impact on rivers and inland wetlands;
- Various methods can be used for monitoring, including in situ, modelling or remote sensing;
- Not all variables need to be monitored consistently over time and therefore a critical selection of indicators from different pressure types should be used to inform the status of rivers and inland wetlands. The EcoClassification and EcoStatus Determination approach (or Present Ecological State / PES model) serves as an excellent example of such a combination of indicators. A unique selection of indicators needs to be developed for inland wetlands (see Chapter 9 for further discussion);
- Improvements to the South African Inventory of Inland Aquatic Ecosystems (SAIIAE) should focus on both the extent of ecosystems as well as pressures, while further research is required to understand how cumulative impact of pressures should be categories within the PES model as well as the resilience of species.

Box 4.7. Patterns in land use development pressure in Mpumalanga, September 2000 to March 2018

Contribution received from Dr Mervyn Lötter

Biodiversity Planning; Scientific Services
Mpumalanga Tourism & Parks Agency (MTPA)
2 April 2018

Patterns in land use change and the risk of these impacting on natural resources was assessed by mapping all land use change applications received for comment by the Mpumalanga Tourism & Parks Agency (MTPA) over a 17 year period, from September 2000 to March 2018. These applications were mapped at the finest possible scale (i.e. individual farm or farm portion). Figure 1 clearly shows that in the last 17+ years, the greatest pressure for land use change has come from prospecting (58.3% of the land surface area of Mpumalanga) and mining applications (27.8% of land surface area), together accounting for 64.5% of the surface area of the Province with the balance of applications related to built infrastructure (12.1%), urban/residential development (4.9%) and cultivation (0.9%).

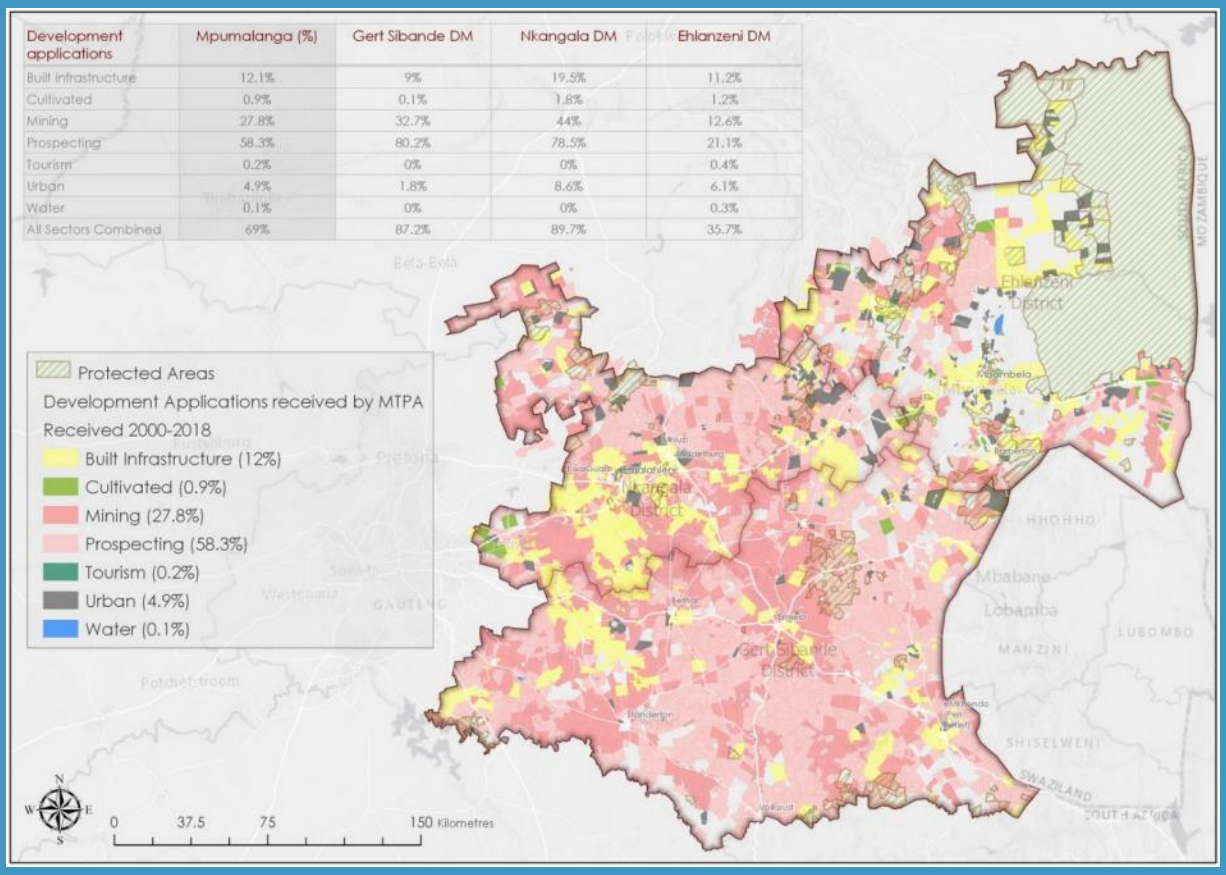


Figure 1: Map showing applications for land use change received between September 2000 and March 2018.

When these applications are expressed as a proportion of the land-surface area for each of the three district municipalities, the general trend is somewhat similar for the Province as a whole, but the extent of impact differs markedly from one district to the next. A far smaller proportion of the land surface area of Ehlanzeni District Municipality has been affected by applications for prospecting and mining, whilst Nkangala and Gert Sibande Districts have been subject to much higher levels of pressure for all types of land use change, but particularly for prospecting and mining. As much as 44% of Nkangala District's cadastres have received mining applications over the last 17 years.

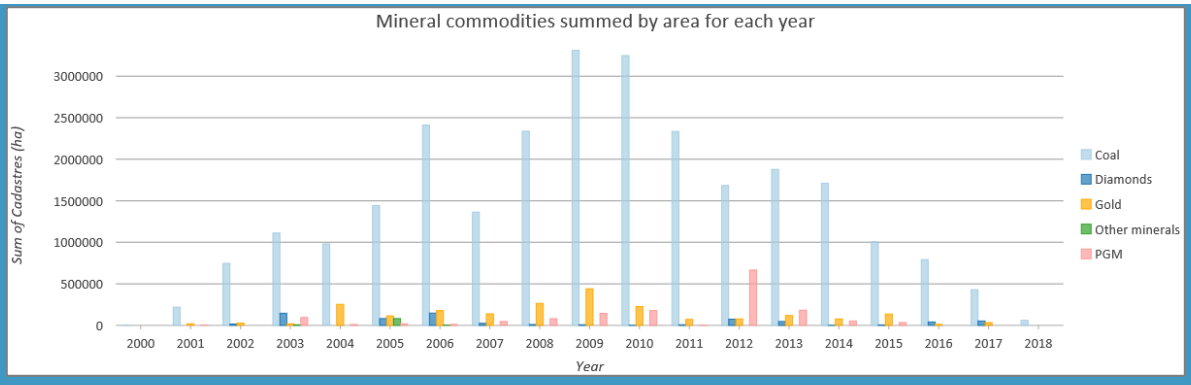


Figure 2: Bar chart showing the extent of development applications received per main commodity group for Mpumalanga over a 17+ year period, expressed as a sum of all the cadastres in the applications. Coal related applications amounted to 73% of all mining and prospecting applications.

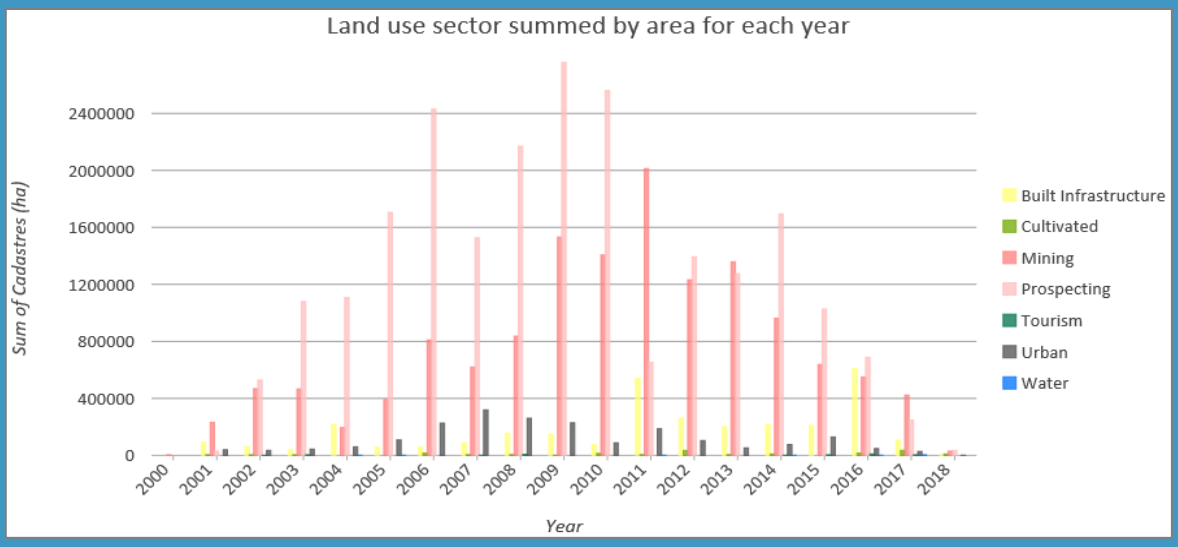


Figure 3: Bar chart showing the extent of development applications received per land use sector over a 17+ year period, expressed as a sum of the cadastre areas applied for.

There is visibly (Figure 3) a more recent decline in development applications received. The decline in prospecting and mining related applications is probably also related to the uncertainty of implementing the One Environmental System in 2015. The MTPA may also not be receiving all the new applications given changes in the processing of applications. The MTPA is no longer a commenting authority but an Interested and Affected Party. There are also very few areas still available where prospecting can still occur given that 58.3% of the cadastres have received some form of prospecting applications – this may therefore contribute to the decline (Figure 4).

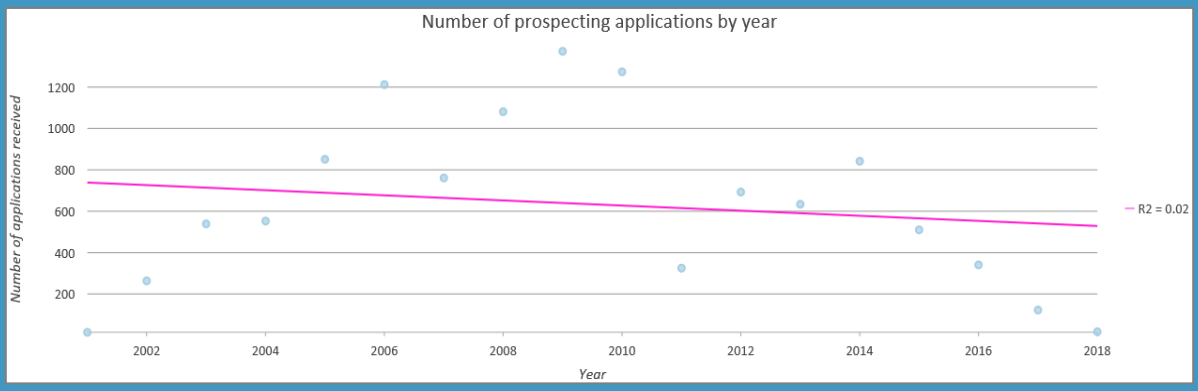


Figure 4: Scatter Plot with trend line showing number of prospecting applications received over 17+ years. Number reflects the number of cadastres.

The assessment of the trend in prospecting applications over the 17+ year period (Figure 4) shows a slight decline (R=0.02) while an assessment of mining applications (Figure 5) shows a slight increase as many prospecting applications are now being converted to mining applications. With a stronger economy the anticipated number of mining applications is expected to grow.

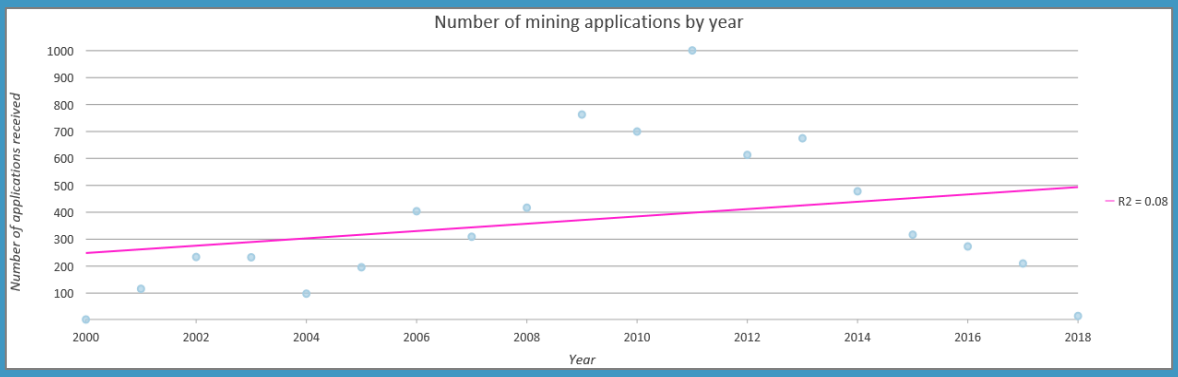


Figure 5: Scatter Plot with trend line showing number of prospecting applications received over 17+ years. Number reflects the number of cadastres.

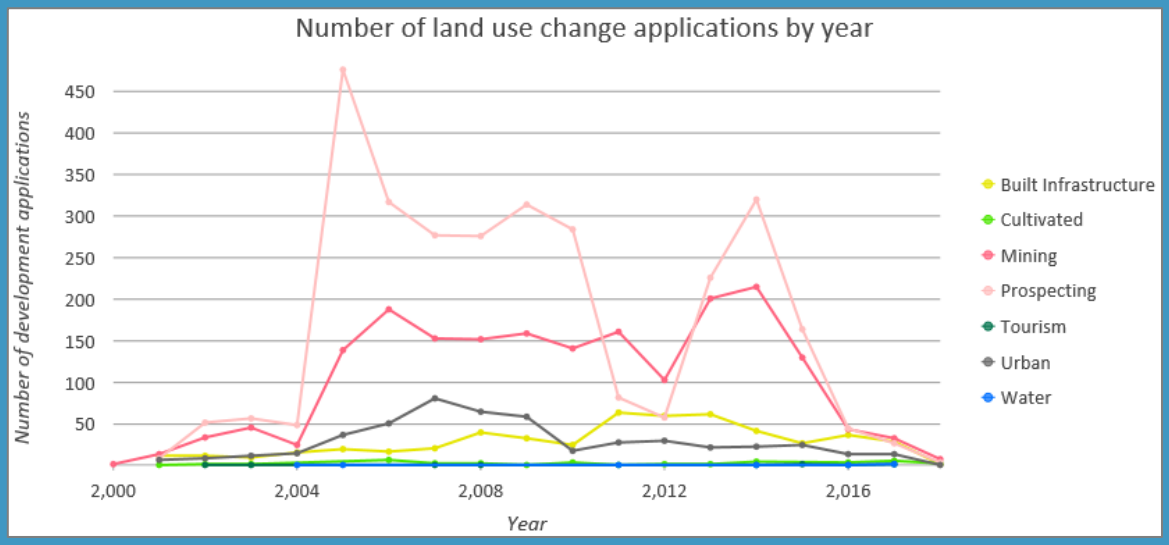


Figure 6: Number of land use applications received by sector per year.

The institutional and human capital investment required to assess applications for a change in land use in Mpumalanga is immense. Over the 17+ year period, the MTPA received 5792 development applications. The majority of these were for prospecting licenses (n=3020) and mining (n=1807). As the MTPA's mandate relates to biodiversity issues, we seldom receive applications to comment on within urban areas. The MTPA objected to 11% of the applications received.

With 64.5% of the parent farms or farm portions receiving mining or prospecting applications, and 20% of Mpumalanga is gazetted as protected areas and an additional 18% identified at Critical Biodiversity Areas (CBA) in the Mpumalanga Biodiversity Sector Plan (MBSP), it is inevitable that there will be some conflict around some of the applications for a change in land use where these applications are in sensitive areas. Mitigating mining related impacts, by avoiding CBAs, may reduce some of this conflict but it should be realised that there will simply be occasions where mining applications are proposed in very sensitive areas that these would need to be objected to. It is inevitable given the vast extent of these applications.

There is a risk that the mining related applications are on an increase and that these may be boosted by the improving economy. This is very good for South Africa's growth and economy and welcomed by the MTPA, but care should be exercised to ensure that sensitive areas are not lost and some form of compromise will be required from all parties concerned. Our precious water resources are also at risk as well as the Strategic Water Source Areas that receive and

provide the majority of rainfall within the province. Mpumalanga will need to be very strategic regarding its decision making.

Strategic relief to the administrative conflict that may arise can be reduced by: (1) declaring very sensitive areas as Nature Reserves and in so doing prevent these areas from being developed; (2) support the development of Section 49 areas as areas in terms of the Mineral and Petroleum Resource Development Act where prospecting and mining are restricted or prohibited; (3) encourage the development of a Strategic Environmental Assessment to guide coal mining in the Mpumalanga Highveld regions where the bulk of the mining related applications occur; and (4) consider other legal frameworks or amendments to protect very sensitive areas. A combination of these is currently being proposed for implementation.

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5. INPUT DATA USED FOR THE ASSESSMENTS

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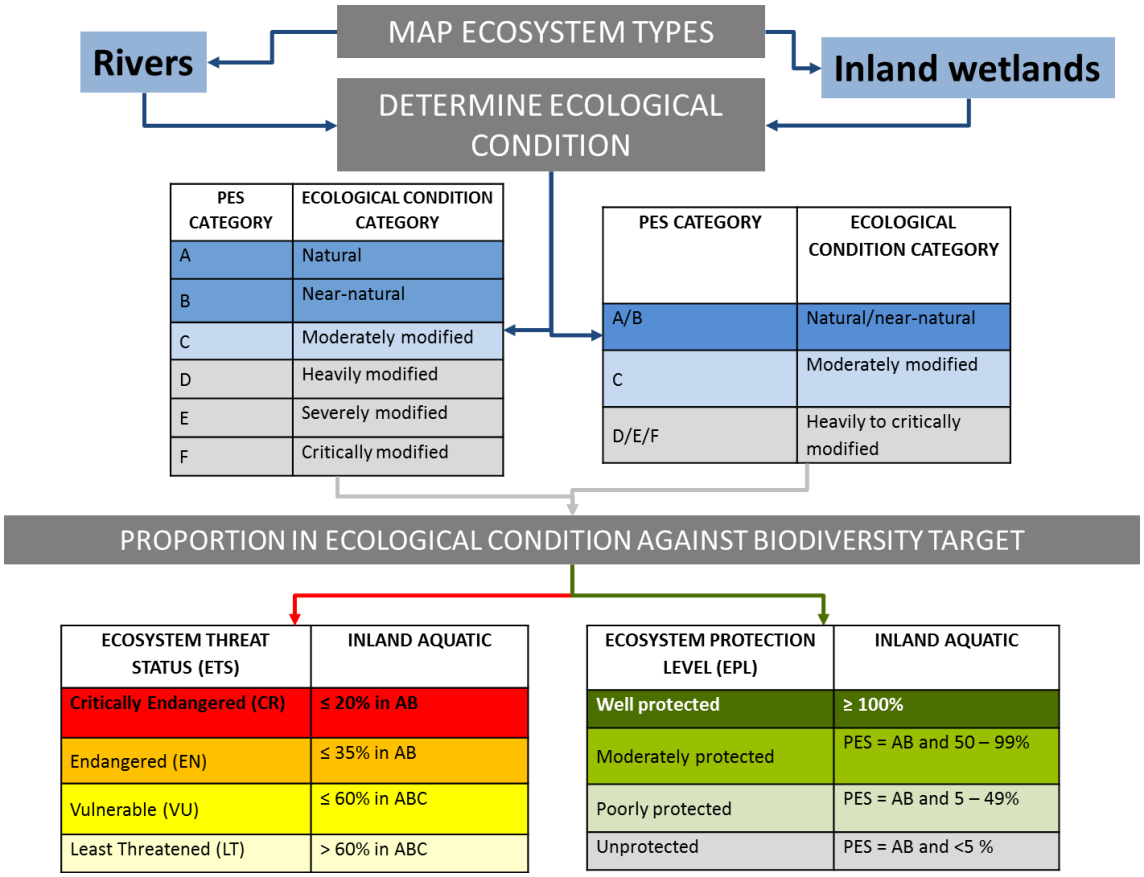
5.1 Overview of steps in calculating the headline indicators

This chapter discuss the approach, data and methods used for determining the headline indicators for ecosystems, including the Ecosystem Threat Status (ETS) and Ecosystem Protection Level (EPL). The ETS and EPL were calculated separately for the river ecosystem types and inland wetland ecosystem types, while the changes to the free-flowing rivers and their ecological condition were assessed. The ecosystems assessment is dependent on (i) mapping and classifying ecosystem types across the country; and (ii) mapping ecosystem condition across the country (Nel & Driver 2012). For rivers and inland wetlands, the biodiversity target was set at 20% (Table 5.1) whereas a target of 100% was used for the freshwater lakes. The biodiversity target for these systems were set at 20% for the NBA 2018, similar to the NBA 2011 (Table 5.1; see also Chapter 1, Section 1.3 for more information). Categories for the ETS and EPL are derived based on the ecological condition of the ecosystem type against the set of thresholds as illustrated in Figure 5.1 and Table 5.1).

In addition to the two headline indicators, ETS and EPL, this chapter also provides the methods and data used for the update of the 62 free-flowing and 19 flagship rivers of the National Freshwater Ecosystems Priority Areas (NFEPA) project (Nel *et al*. 2011a; 2011b). Ecosystem types that are at risk of collapse (see Bland *et al.* 2017 for the definition and description of collapse) are identified as those which are Threatened and Not Protected or Poorly Protected (**highly threatened and unprotected types**). In Chapter 6 the results of these methods and approaches are discussed.

Table 5.1. Thresholds used in determining the Ecosystem Threat Status (ETS) and Ecosystem Protection Level (EPL) of rivers and inland wetlands. *CR = Critically Endangered; EN = Endangered; VU = Vulnerable and PES = Present Ecological State.*

	CR	EN	VU
Thresholds applied to river ecosystems	Where the length of river ecosystem type in a natural or near-natural ecological condition (PES = A or B) is ≤ 20% of the total length for that ecosystem type.	Where the length of river ecosystem type in a natural or near-natural ecological condition (PES = A or B) is ≤ 35% of the total length for that ecosystem type.	Where the length of river ecosystem type in a natural or near-natural ecological condition (PES = A or B) is ≤ 60% of the total length for that ecosystem type.
Thresholds applied to inland wetland ecosystems	Where the extent (area) of each inland wetland modelled in a natural or near-natural ecological condition is ≤ 20% of the total extent for that ecosystem type.	Where the extent (area) of each inland wetland modelled in a natural or near-natural ecological condition is ≤ 35% of the total extent for that ecosystem type.	Where the extent (area) of each inland wetland modelled in a natural or near-natural ecological condition is ≤ 60% of the total extent for that ecosystem type.



PES CATEGORY	ECOLOGICAL CONDITION CATEGORY
A	Natural
B	Near-natural
C	Moderately modified
D	Heavily modified
E	Severely modified
F	Critically modified

PES CATEGORY	ECOLOGICAL CONDITION CATEGORY
A/B	Natural/near-natural
C	Moderately modified
D/E/F	Heavily to critically modified

ECOSYSTEM THREAT STATUS (ETS)	INLAND AQUATIC
Critically Endangered (CR)	≤ 20% in AB
Endangered (EN)	≤ 35% in AB
Vulnerable (VU)	≤ 60% in ABC
Least Threatened (LT)	> 60% in ABC

ECOSYSTEM PROTECTION LEVEL (EPL)	INLAND AQUATIC
Well protected	≥ 100%
Moderately protected	PES = AB and 50 – 99%
Poorly protected	PES = AB and 5 – 49%
Unprotected	PES = AB and <5 %

Figure 5.1. Steps in assessing the headline indicators of Ecosystem Threat Status (ETS) and Ecosystem Protection Level (EPL) categories for inland aquatics in relation to a set of thresholds.

Ecological condition is estimated using a range of different approaches across the realms, but essentially depends on the ability to spatially represent the various pressures exerted on biodiversity. Condition in the terrestrial realm relies primarily on land cover change data; cumulative pressure mapping is used in the marine realm; and a multi criteria ecological condition framework is used in the estuarine and inland aquatic realms. The different systems were aligned as far as possible in the NBA, including the International Union for Conservation of Nature (IUCN) Red List approach, to allow for cross realm comparisons and unified terminology (Table 5.2).

Section 5.2 of this chapter discusses the ecosystem classification of rivers and inland wetlands, followed by the ecosystem condition assessments in Section 5.3. The ecosystem targets are then discussed in Section 5.3, followed by the methodology for calculation EPL. Methods used in assessing and updating the free flowing and flagship rivers follows in Section 5.5, whereas Section 5.6 discuss methods used for the freshwater species assessments.

Table 5.2. The ecological condition categories used in the National Biodiversity Assessment (NBA), showing the original Department of Water and Sanitation (DWS) framework (Present Ecological State [PES] categories using the letters A to F) applied to rivers, inland wetlands and estuaries and the International Union for Conservation of Nature (IUCN) Red List of Ecosystems approach of percentage degradation of ecosystems or percentage disruption of biotic processes.

Department of Water and Sanitation (DWS) ecological condition	A	B	C	D	E	F
	Natural	Largely natural	Moderately modified	Largely modified	Highly degraded	Extremely degraded
IUCN RLE ecosystem degradation categories	Natural or near-natural (<50% degr.)		Moderately degraded (50–70% degr.)	Severely degraded (70–90% degr.)		Very severely degraded (>90% degr.)
NBA ecological condition categories	Natural	Near-natural	Moderately modified	Heavily modified	Severely modified	Critically modified
	Decreasing ecosystem function & increasing ecosystem restoration cost					

5.2 Ecosystem classification and mapping

In the inland aquatic realm, river and inland wetland ecosystems are presented, assessed and reported separately. The sections below provide information on the compilation of the ecosystem types.

5.2.1 River ecosystem types

River ecosystem types were developed by the NFEPA project (Nel *et al*. 2011a; 2011b) and also used in the NBA 2011 (Nel & Driver 2012). The NFEPA river network GIS layer was classified using 31 Level 1 ecoregions, flow variability and geomorphological zones to produce 223 distinct combinations of subtypes (Figure 5.2 and Table 5.3). Level 1 ecoregions classify the landscape based on physiography, climate, geology, soils and potential natural vegetation. Ecoregions broadly characterise the landscape through which a river flows, such that rivers in the same ecoregion share similar broad ecological characteristics compared to those in different ecoregions (Kleynhans *et al*. 2005). River flow variability was described as permanent and not permanent. Permanent included both perennial and seasonal rivers while not permanent included ephemeral rivers (Nel *et al*. 2011a; 2011b; Nel & Driver 2012). Updates should include a revision and adding more river flow categories.

Geomorphological zones were based on the slope categories of Rowntree & Wadeson (1999) and Rowntree *et al*. (2000) which characterise the ability of river reaches to store or transport sediment. Each zone represents a different physical template available for the biota. They were made spatial by Moolman *et al.* (2002) and Moolman (2008) using the 1:500 000 river network coverage and grouped into four zones (mountain stream, upper foothill, lower foothill and lowland river) to depict ecological characteristics at a national level. River ecosystem types are components of rivers that drain through the same ecoregion and have similar flow and geomorphological characteristics, which essentially represent coarse-filter biodiversity surrogates. Under natural conditions, river ecosystem types are expected to share similar biological response potential

NBA 2018 uses 222 river ecosystem types

(Nel *et al*. 2011a; Nel & Driver, 2012). In the NBA 2018 minor editing (i.e. deletion of a subtype located outside South Africa) resulted in 222 river ecosystem types. Updates should include for example new approaches to landscape classification and validation of the river ecosystem types with species data.

Table 5.3. Processing steps used in mapping river ecosystem types and determining the ecological condition of river ecosystems.

Step	Key references	Scientific rigour / credibility	Data deficiency
Delineation of Level 1 river ecoregions	Kleynhans *et al*. 2005.	Expert driven, not peer reviewed journal article.	Less detailed than the Level 2 ecoregions.
Flow type classification	DLA–CDSM 2006; Nel *et al*. 2011a; 2011b; Nel & Driver 2012.	Not peer reviewed journal article.	Broadly described using two categories. Additional river flow categories required.
Geomorphological zonation or classification	Rowntree & Wadeson 1999; Rowndtree *et al*. 2000; Moolman *et al*. 2002; Moolman 2008.	Peer-reviewed journal article.	Further refinement and testing required.
Present Ecological State (PES) category method	DWS 2014.	Mostly expert driven, not peer reviewed journal article.	A desktop assessment, confidence is low.

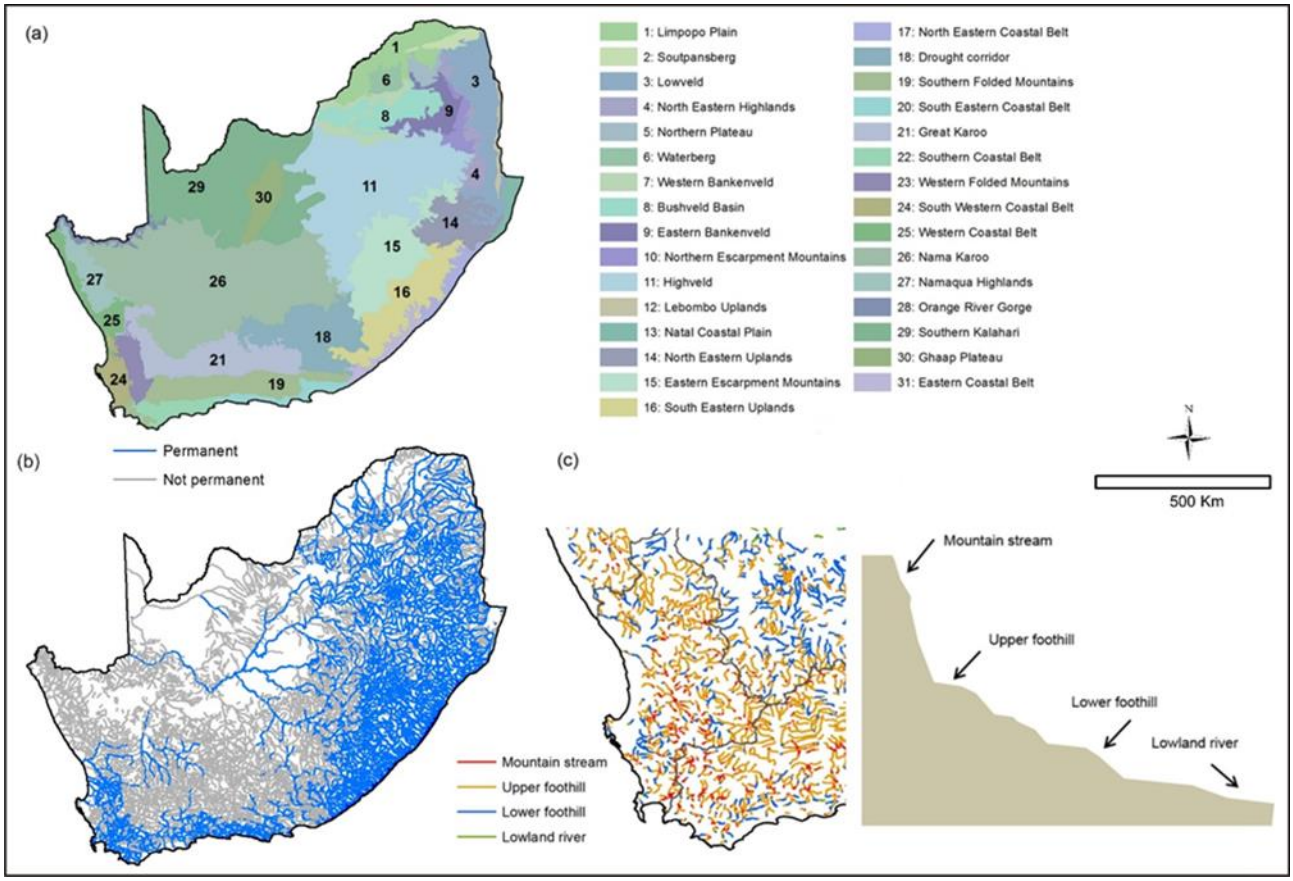


Figure 5.2. Geographical Information Systems (GIS) layers that were combined to derive river ecosystem types: *(a) Level 1 ecoregions (after Kleynhans* et al*. 2005), (b) flow variability (DLA-CDSM 2006), and (c) slope categories (Rowntree & Wadeson 1999; Rowntree et al. 2000; Moolman 2008).*

In South Africa water resources are managed at regional or catchment level in nine redefined Water Management Areas (WMAs) (Figure 5.3) within which Catchment Management Agencies (CMAs) will operate. These WMAs are not aligned with provincial or local government boundaries. Each CMA will be responsible for the development of a catchment management strategy for the water resources within its WMA (DWA 2013). Currently, only two fully operational CMAs have been established, the Inkomati-Usuthu CMA in Mpumalanga and the Breede-Gouritz CMA which largely fall within the Western Cape Province. Figure 5.3 shows the number of river ecosystem types in each WMA. The Limpopo WMA displays the highest diversity, with almost 20% of the total number of river ecosystem types occurring in this area. Relatively moderate river diversity (13%) are displayed in the Orange and Olifants WMAs, while the Vaal (6%) and Breede-Gouritz (8%) WMAs have relatively low river ecosystem diversity. In future, descriptions and lists of dominant species should be developed for each river ecosystem type, and ideally published in a way similar to the vegetation map of South Africa, Lesotho and Swaziland (Mucina & Rutherford 2006).

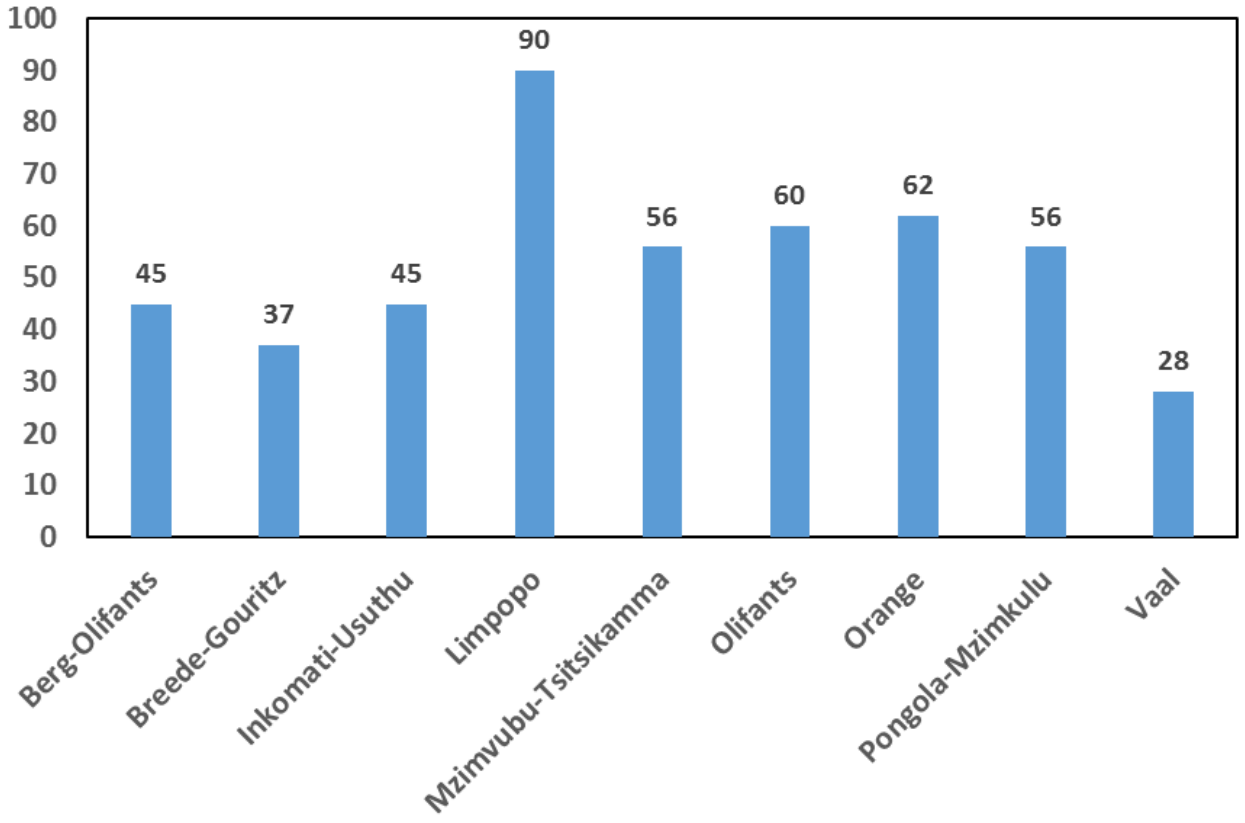


Figure 5.3. Number of river types in each Water Management Area (WMA). *Note that the data exclude Lesotho and Swaziland.*

5.2.2 Inland wetland ecosystem types

Inland wetland ecosystem types constitute a combination of diversity in ecological and functional characteristics across the country. Ecological diversity is represented by broad bioclimatic regions, called the 'regional setting' at Level 2 of the *Classification System for Wetlands and other Aquatic Ecosystems in South Africa* (Ollis *et al*. 2013), whereas functional diversity is represented at Level 4A using hydrogeomorphic (HGM) units. The National Wetland Map version 5 (NWM5) update provided the base layer which implements the conceptual framework of the *Classification System for Wetlands and other Aquatic Ecosystems in South Africa* into inland wetland ecosystem types (Van Deventer *et al*. 2018a). The NWM5 increased the extent of natural inland wetlands mapped by 123%, removed all artificial wetlands from the layer and reduced commission errors by an estimated 20 percentile points (from 30% to 10%). HGM units were assigned from either reference data or through desktop interpretation, which had reduced the error of modelling some HGM units in the NFEPA wetlands, used for the National Biodiversity Assessment of 2011 (NBA 2011) (Nel *et al*. 2011a; 2011b; Nel & Driver 2012; Van Deventer *et al.* 2014; Van Deventer *et al*. 2016).

Uncertainties in the distinct differences between wetland ecosystem types across wetland vegetation groups, as used in the NBA 2011, resulted in the consideration of the bioregions[9] from the National Vegetation Map (NVM) of 2018 (Daryaram *et al.* in review) for the spatial representation of the regional setting at Level 2 of the *Classification System for Wetlands and other Aquatic Ecosystems in South Africa*. The NVM 2018 included updates to vegetation types in the Fynbos and Albany Thicker Biomes (Daryaram *et al*. in review). Aquatic categories in the NVM 2018 were subsumed into adjacent vegetation types and the updated estuaries functional zones were excluded. Several other bioregions were also subsumed into adjacent bioregions, similar to the wetland vegetation types (Nel *et al*. 2011a; 2011b). These included the 'Alluvial Vegetation', 'Azonal Forests', 'Inland Saline Vegetation' and 'Zonal & Intrazonal Forests'. The outcome resulted in **37 vegetation bioregions** for the regional setting at Level 2 (Figure 5.4a). The majority of these bioregions match those published in Mucina & Rutherford (2006), except for the Eastern Strandveld (23 polygons extending over 1 375 ha where no wetland polygones have been mapped) and Seashore Vegetation (877 polygons extending over 42 067 ha containing 37 wetland polygons of 787 ha) which are both thinly distributed on the coast.

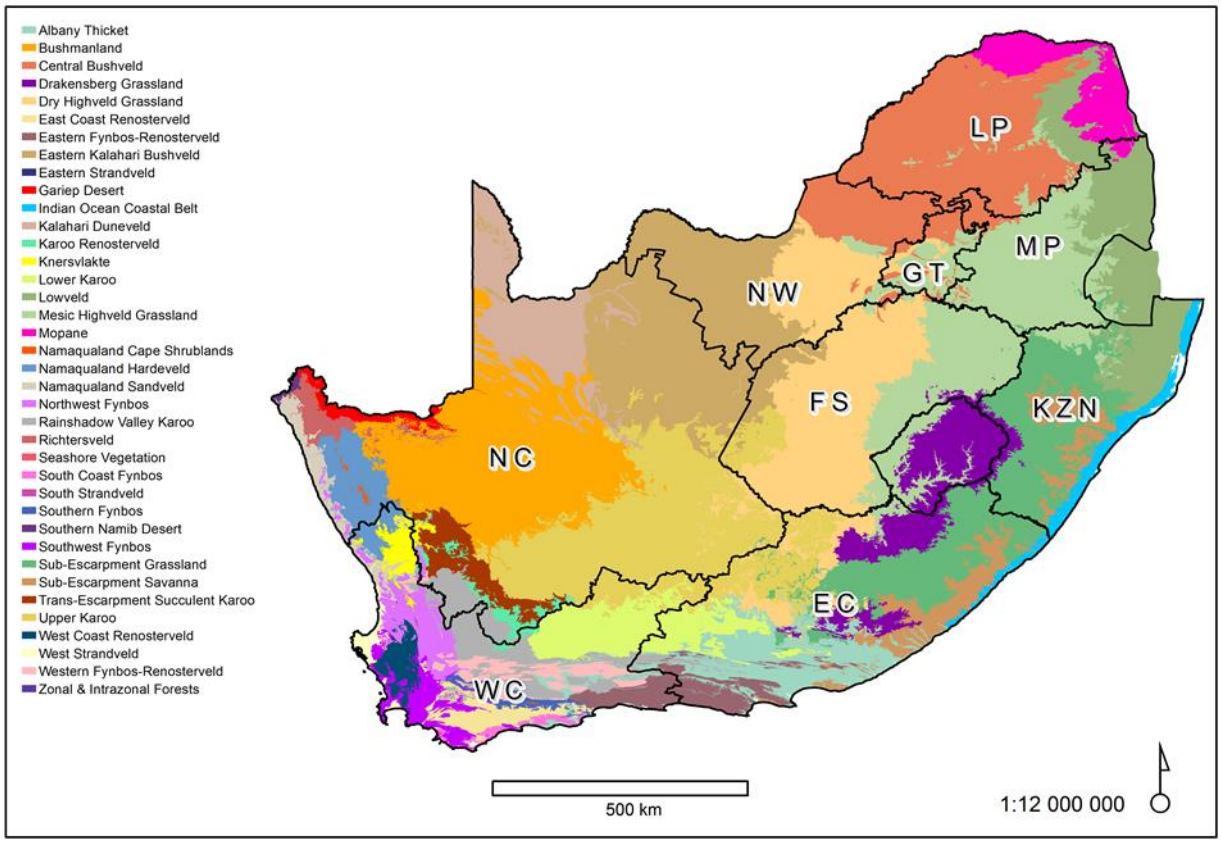
Only four HGM units have been used for the NBA 2018 compared to the seven used in the NBA 2011. Subsequent to the NBA 2011, the hillslope seep category was amalgamated with the seep category in the latest update of the *Classification System for Wetlands and other Aquatic Ecosystems in South Africa* (Ollis *et al*. 2013). In addition, it was recognised that several categories were poorly separable at desktop level, and only in-field visits would be able to identify in hydrological source of water to distinguish wetland flats and depressions. In addition, channelled and unchannelled valley-bottom wetlands are also poorly separable at a desktop level: river channels may be obscured by vegetation or the channel may be an erosion feature and not naturally a channelled valley-bottom wetland. As a result, **this assessment used only four HGM units, namely depressions, floodplains, seeps and valley-bottom wetlands**.

The combination of 37 vegetation bioregions and the four amalgamated HGM units results in a maximum of 148 potential inland wetland ecosystem types. All four HGM units were, however, not present in all vegetation bioregions. The Eastern Strandveld bioregion, for example, with a spatial extent of 1 375 ha and maximum width of < 1 km along the KwaZulu-Natal coastline, had no inland wetlands mapped. Vegetation

[9] In this case, 'bioregions' refer to the second level of division on the National Vegetation Map of Mucina & Rutherford (2006) and updated versions and not to term 'bioregions' in the Biodiversity Act.

bioregions with extensive extents (> 8 000 ha) showed an above-average percentage (> 2.2%) of inland wetlands (Figure 5.4b; Table 5.4). Of these extensive extent bioregions, the Bushmanland Bioregion recorded the highest percentage of inland wetlands (4.2%) followed by the Mesic Highveld Grassland Bioregion (3.8%)[10]. The South Strandveld Bioregion, a small bioregion on the south coast of the Western Cape, recorded the highest spatial extent of wetlands (10.6%) of all bioregions (Table 5.4). Of the smaller-extent bioregions (<1 300 ha), a number of bioregions showed above-average percentage of inland wetland extents, including the East Coast Renosterveld Bioregion in the Western Cape (7.1%), the Southern Fynbos Bioregion (WC; 5.5%), the Indian Ocean Coastal Belt (4.8%), Gariep Desert (NC, 4.3%) and the Namaqualand Cape Shrublands (NC, 3.5%) Bioregions (Table 5.4). The high percentage of inland wetlands in some vegetation bioregions are therefore not only representative of wide arid systems, but also of improved mapping in other, non-arid parts of South Africa (Van Deventer *et al*. 2018a).

(a)



[10] Significant edits have been done in this area by both Dr Mervyn Lötter and Mr Hannes Marais from the Mpumalanga Tourism and Park Agency (MTPA), particularly to the wetlands data set of the Mpumalanga Highveld project generated by Mbona *et al*. (2015).

(b)

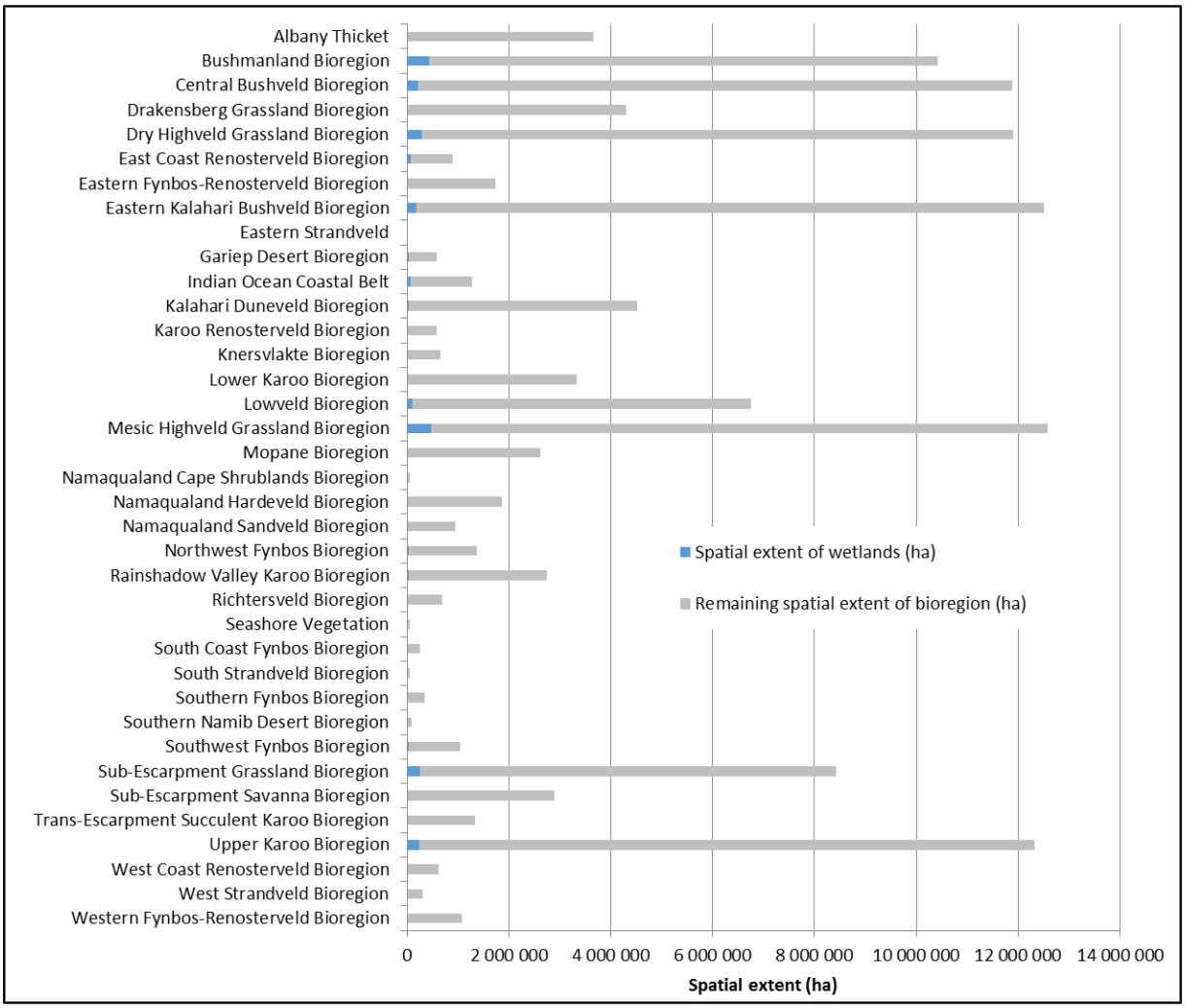


Figure 5.4. The spatial distribution of vegetation bioregions in South Africa (a), as well as the extent of wetlands in each of these bioregions shown in hectares (b).

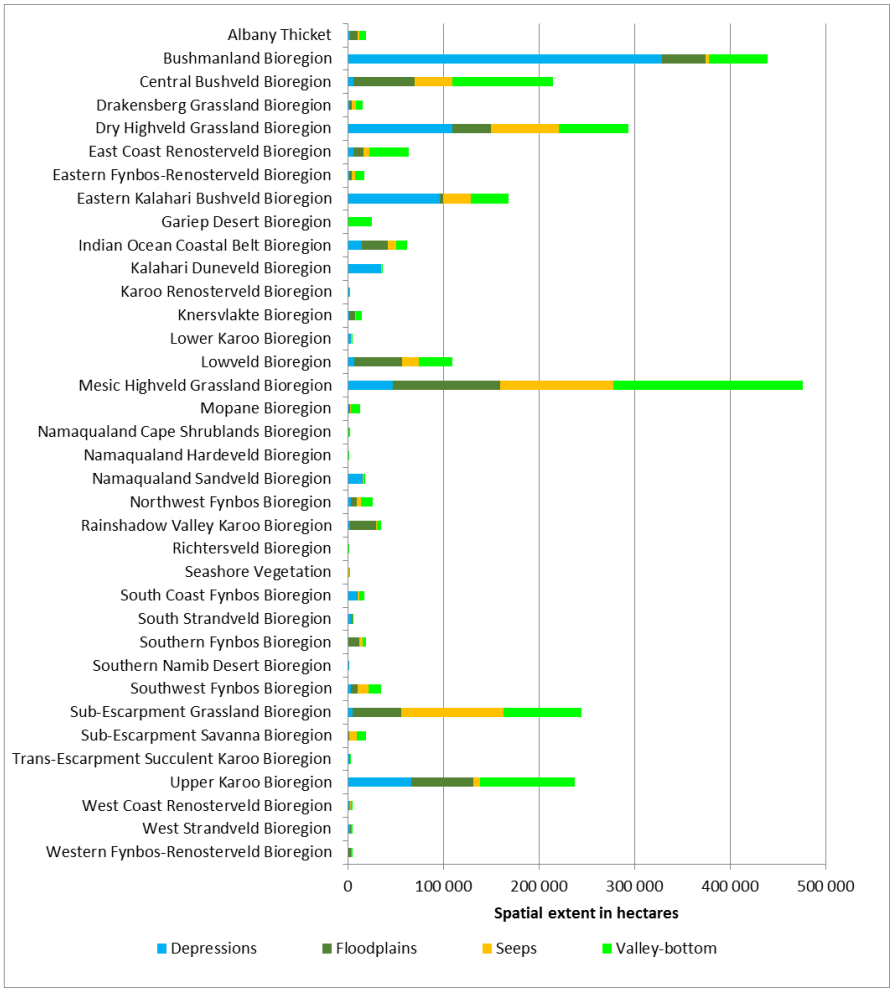
The combination of the four HGM units with the 37 vegetation bioregions in the digital map resulted in 135 wetland ecosystem types which had been used in the NBA 2018. The Mesic Highveld Grassland Bioregion showed the largest of extent of all four HGM units compared to the other vegetation bioregions (Figure 5.5a). In general, most vegetation bioregions varied in extent of HGM units (Figure 5.5b). The majority of the vegetation bioregions are dominated (> 37% of spatial extent of all inland wetlands in a bioregion) by either depressions or valley-bottom systems (28 of the 37), with fewer dominated by floodplains (6) and in the case of the Sub-Escarpment Grassland Bioregion, seeps (Table 5.5).

NBA 2018 used 135 inland wetland ecosystem types

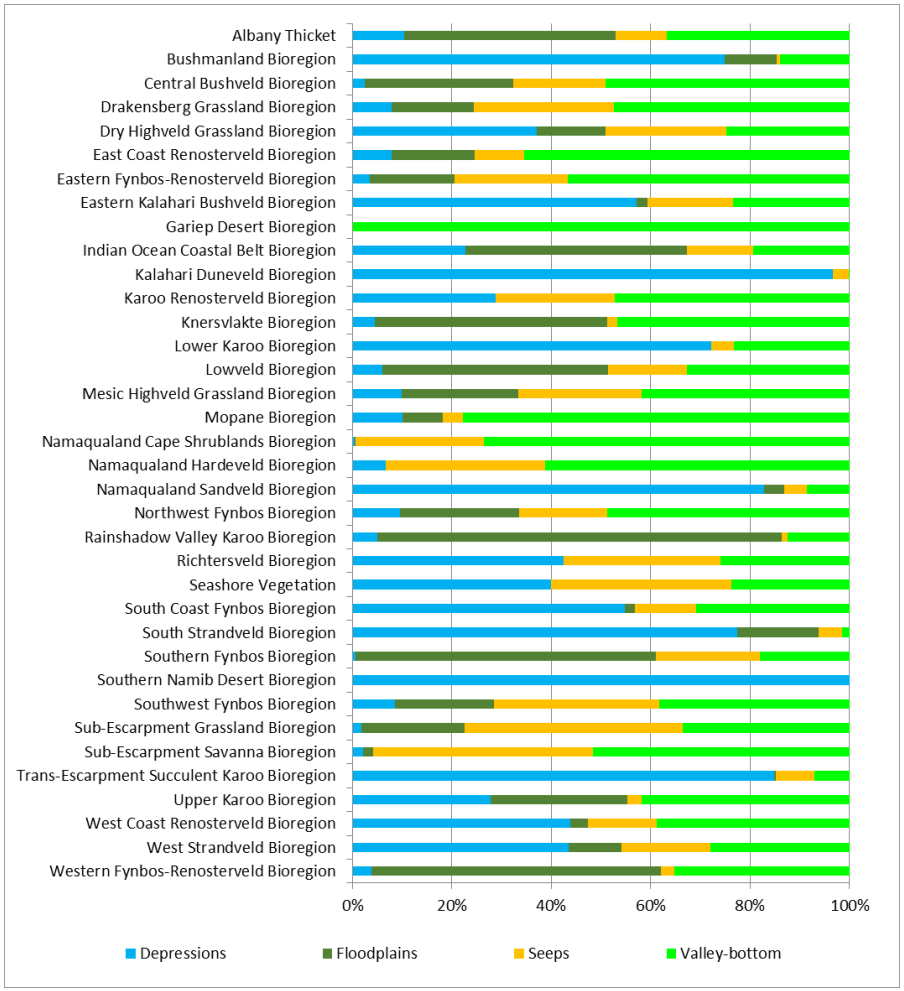
Table 5.4. Percentage of the spatial extent of inland wetlands per wetland bioregion.

Wetland bioregion	Extent of bioregion	Spatial extent of wetlands (ha)	Percentage of area represented by wetlands
Albany Thicket	3 652 579.1	18 760.0	0.5
Bushmanland Bioregion	10 418 121.6	438 327.3	4.2
Central Bushveld Bioregion	11 881 131.0	213 874.6	1.8
Drakensberg Grassland Bioregion	4 297 538.7	14 875.6	0.3
Dry Highveld Grassland Bioregion	11 906 072.9	293 395.6	2.5
East Coast Renosterveld Bioregion	890 634.8	63 228.4	7.1
Eastern Fynbos-Renosterveld Bioregion	1 734 398.4	16 975.0	1.0
Eastern Kalahari Bushveld Bioregion	12 504 589.6	167 806.0	1.3
Eastern Strandveld	1 375.3	-	-
Gariep Desert Bioregion	578 124.6	24 855.5	4.3
Indian Ocean Coastal Belt	1 273 332.4	61 749.1	4.8
Kalahari Duneveld Bioregion	4 510 605.2	35 478.4	0.8
Karoo Renosterveld Bioregion	575 075.1	2 080.3	0.4
Knersvlakte Bioregion	647 605.4	14 287.6	2.2
Lower Karoo Bioregion	3 320 749.7	4 244.4	0.1
Lowveld Bioregion	6 751 912.2	109 069.0	1.6
Mesic Highveld Grassland Bioregion	12 589 272.6	475 386.8	3.8
Mopane Bioregion	2 615 097.4	12 422.0	0.5
Namaqualand Cape Shrublands Bioregion	41 933.1	1 462.6	3.5
Namaqualand Hardeveld Bioregion	1 861 224.5	1 347.7	0.1
Namaqualand Sandveld Bioregion	938 504.0	17 797.4	1.9
Northwest Fynbos Bioregion	1 360 346.5	25 449.9	1.9
Rainshadow Valley Karoo Bioregion	2 750 571.1	34 086.2	1.2
Richtersveld Bioregion	694 644.3	560.6	0.1
Seashore Vegetation*	42 067.0	787.2	1.9
South Coast Fynbos Bioregion	248 928.4	16 467.0	6.6
South Strandveld Bioregion	46 885.4	4 969.7	10.6
Southern Fynbos Bioregion	336 236.1	18 557.7	5.5
Southern Namib Desert Bioregion	79 108.2	16.3	0.0
Southwest Fynbos Bioregion	1 037 345.1	34 287.4	3.3
Sub-Escarpment Grassland Bioregion	8 427 401.2	244 410.1	2.9
Sub-Escarpment Savanna Bioregion	2 893 842.3	18 367.2	0.6
Trans-Escarpment Succulent Karoo Bioregion	1 334 156.6	2 022.7	0.2
Upper Karoo Bioregion	12 332 362.3	236 551.5	1.9
West Coast Renosterveld Bioregion	610 182.4	4 111.8	0.7
West Strandveld Bioregion	304 629.8	4 354.9	1.4
Western Fynbos-Renosterveld Bioregion	1 078 542.9	4 796.1	0.4

**Wetlands mapped within the Seashore Vegetation zone should be investigated to assess whether these are inland wetlands or estuarine in nature.*



(a)



(b)

Figure 5.5. Wetland ecosystem types used for the National Biodiversity Assessment 2018: (a) spatial extent (ha) of hydrogeomorphic (HGM) wetland type across bioregion and (b) percentage of HGM wetland type across bioregion.

Table 5.5. Percentage of each hydrogeomorphic (HGM) unit calculated as a total of the extent of inland wetlands found in each wetland bioregion.

Bioregion (down) // HGM units (across):	Depressions	Floodplains	Seeps	Valley-bottom
Albany Thicket	10.4	42.6	10.3	36.7
Bushmanland Bioregion	74.9	10.3	0.8	13.9
Central Bushveld Bioregion	2.4	29.9	18.6	49.1
Drakensberg Grassland Bioregion	7.9	16.5	28.2	47.4
Dry Highveld Grassland Bioregion	37.1	13.9	24.2	24.8
East Coast Renosterveld Bioregion	7.9	16.8	9.9	65.4
Eastern Fynbos-Renosterveld Bioregion	3.5	17.1	22.9	56.6
Eastern Kalahari Bushveld Bioregion	57.1	2.2	17.2	23.5
Gariep Desert Bioregion	0.1	-	0.1	99.9
Indian Ocean Coastal Belt Bioregion	22.8	44.5	13.3	19.4
Kalahari Duneveld Bioregion	96.7	-	3.2	0.1
Karoo Renosterveld Bioregion	28.8	-	23.9	47.3
Knersvlakte Bioregion	4.5	46.8	1.9	46.8
Lower Karoo Bioregion	72.3	-	4.4	23.3
Lowveld Bioregion	6.1	45.4	15.9	32.7
Mesic Highveld Grassland Bioregion	9.9	23.5	24.9	41.8
Mopane Bioregion	10.1	8.0	4.1	77.8
Namaqualand Cape Shrublands Bioregion	0.5	0.1	25.8	73.6
Namaqualand Hardeveld Bioregion	6.8	-	32.0	61.3
Namaqualand Sandveld Bioregion	82.8	4.1	4.7	8.5
Northwest Fynbos Bioregion	9.6	24.0	17.7	48.7
Rainshadow Valley Karoo Bioregion	5.1	81.3	1.1	12.5
Richtersveld Bioregion	42.5	-	31.6	25.9
Seashore Vegetation	40.0	0.0	36.2	23.8
South Coast Fynbos Bioregion	54.8	2.1	12.3	30.8
South Strandveld Bioregion	77.5	16.3	4.8	1.5
Southern Fynbos Bioregion	0.7	60.3	21.0	18.0
Southern Namib Desert Bioregion	100.0	-	-	-
Southwest Fynbos Bioregion	8.7	19.9	33.2	38.3
Sub-Escarpment Grassland Bioregion	1.9	20.7	44.0	33.5
Sub-Escarpment Savanna Bioregion	2.1	2.1	44.2	51.7
Trans-Escarpment Succulent Karoo Bioregion	84.9	0.3	7.8	7.0
Upper Karoo Bioregion	27.9	27.5	2.8	41.8
West Coast Renosterveld Bioregion	43.8	3.6	13.9	38.7
West Strandveld Bioregion	43.5	10.6	18.0	27.9
Western Fynbos-Renosterveld Bioregion	3.8	58.3	2.7	5.2

5.2. Ecosystem condition

The condition of rivers and inland wetlands have been assessed using the six ecological categories ranging from A to F, where an A and B category is regarded as a natural or near-natural ecological condition, and an F category a system which has been heavilty to severely or critically modified. Ideally, those inland aquatic ecosystems that are currently considered to be of high integrity or in natural to near-natural ecological condition should be selected for the purposes of conserving biodiversity. These natural ecosystems tend to be more self-sustaining, thus requiring less conservation management. The cost of rehabilitating rivers or inland wetlands in good condition is also lower than the cost of rehabilitating modified systems, and the likelihood of success is greater.

The following two subsections discuss the methods used for assessing the ecological condition of the river and inland wetland ecosystem types, as well as the outcomes which were used for the headline indicators (see Chapter 6).

5.2.3 Estimating the ecological condition of river ecosystems

Ideally, those freshwater ecosystems that are currently considered to be of high integrity or in a natural or near-natural ecological condition should be selected for the purposes of conserving biodiversity. River condition describes the extent to which a river has been modified by human activity. In the NBA 2018 the 2011 output of the Present Ecological State/Ecological Importance/Ecological Sensitivity (PES/EI/ES) dataset (DWS 2014) (i.e. aggregated ecological condition categories) was used to assess the degradation of rivers across the country[11]. Specifically, EI refers to biophysical aspects in a sub-quaternary reach (SQR) that relates to its capacity to function sustainably while ES considers SQR attributes that relates to the sensitivity of biophysical components to general environmental changes such as flow modifications. The EI and ES of SQRs are therefore assessed to obtain an indication of vulnerability to environmental modification within the context of the PES. The aggregated ecological condition category reflects the degree of modification from natural (A) to critically modified (F) (Table 5.6). This national desktop dataset was based on expert assessment of a set of six underlying indicators (flow modification, physico-chemical modification, instream habitat and habitat continuity modification, riparian/wetland zone habitat and habitat continuity modification) and was developed by the Department of Water and Sanitation (DWS 2014).

[11] The objective of the Present Ecological State/Ecological Importance/Ecological Sensitivity (PES/EI/ES) dataset is to provide first level desktop level information on ecological issues as it relates to the protection and management of sub-quaternary reaches (SQRs). This refers specifically to Ecological Reserve determination, water use licensing and the determination of priorities for monitoring (e.g. Ecological Water Resource Monitoring [EWRM]). This dataset replaces the 1999 PESEIS assessment of DWA and other desktop approaches that were followed for ecological reserve purposes and the National Aquatic Ecosystem Health Monitoring Programme (NAEHMP). Moreover, it relates explicitly to rivers (instream and riparian aspects) and limited aspects of valley-bottom wetlands (DWS 2014).

Table 5.6: Translation of the ecological categories used by the Department of Water and Sanitation (DWS) to describe the condition of river ecosystem types in South Africa, to the ecological condition categories used in this assessment (adopted from Kleynhans & Louw 2007). *For this assessment, rivers in an A and B ecological category were regarded as being in 'a natural or near-natural ecological condition', with the ability to contribute towards biodiversity targets. Rivers with a C ecological category were considered to be moderately modified. NBA 2018 = National Biodiversity Assessment of 2018.*

DWS ecological category	Description of the DWS ecological category	NBA 2018 Ecological condition category
A	Unmodified, natural	Natural
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.	Near-natural
C	Moderately-modified. A loss and change of natural habitat and biota have occurred but the basic ecosystem functions are still predominantly unchanged.	Moderately modified
D	Largely-modified. A large loss of natural habitat, biota and basic ecosystem functions have occurred.	Heavily modified
E	Seriously-modified. The loss of natural habitat, biota and basic ecosystem functions are extensive.	Severely modified
F	Critically/Extremely-modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.	Critically modified

River condition was used in this assessment to inform:

1. ***ETS of river ecosystem types***: this was based on the extent to which each river ecosystem type had been altered from its natural condition (Section 6.1).
2. ***EPL of river ecosystem types***: river ecosystem types in protected areas needed to be in good condition rivers (A or B ecological category) to be considered as protected (Section 6.2).

For the NBA 2011 the process involved combining PES categories for quaternary mainstems (Kleynhans 2000) whereas the PES categories were modelled for the smaller tributaries. Lack of PES categories for the tributaries necessitated the modelling of the ecological condition using natural land cover as an indicator of condition. This first version of river condition was updated with existing quantitative data during 2008 to derive the second river condition version, as a Geographical Information System (GIS) layer, during the National Freshwater Ecosystems Priority Areas (NFEPA) project (Figure 5.6). The latter was then reviewed and updated where necessary by river health experts across the country during 2009 before used for the ETS of the river ecosystem types in the NBA 2011 (Nel *et al*. 2011a; 2011b; Nel & Driver 2012).

For the NBA 2018 the process involved using DWS (2014) PES/EI/ES (also referred to as PES/EIS) data, which included mainstems and tributaries at a sub-quaternary level. These desktop data were updated with data that became available between 2011 and 2017 from Reserve or Ecological Water Requirement (EWR) and Water Resource Classification System (WRCS) studies. Some discrepancies occurred between the desktop PES data and the ecological reserve data, e.g. where the PES data showed the river to be in an 'A/B' category, while the reserve data showed a 'C' category. The ecological category was either updated or remained unchanged depending on which assessment was most recent.

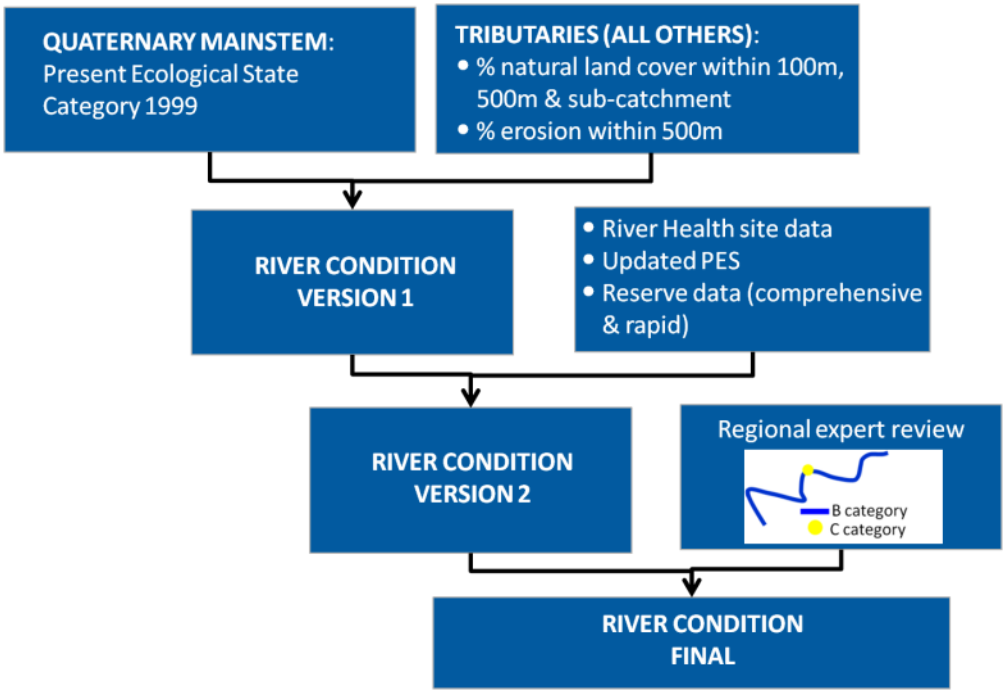


Figure 5.6: Steps and data used to collate river condition for NBA 2011 (after Nel & Driver 2012).

The data and process used to collate the river condition data for the NBA 2011 (Figure 5.6) and NBA 2018 assessments (Table 5.7) therefore differed. This has an important implication in that the ETS and EPL results derived for these two assessments are also not directly comparable. Back casting of the methods in NBA 2018 to that of NBA 2011 would also not be possible, since many of the PES and reserve studies were not available for the NBA 2011 assessments. Back casting between river reaches would only be possible where similar methods were used to determine the ecological categories. The latter would require a separate study outside the NBA 2018.

The refinement of the PES categories for the NBA 2018 showed that 90% of the length of the river ecosystem types within South Africa had PES categories assigned by DWS up to 2017, whereas 10% were data deficient. These refinements resulted in the final version of river condition used in this assessment (Figure 5.7). The majority of near-natural and natural river reaches are located in the Breede–Gouritz and Berg–Olifants WMAs with heavily modified river reaches also dominating. In contact, moderately modified river reaches occur in most of the WMAs while critically modified river reaches are scattered across the country.

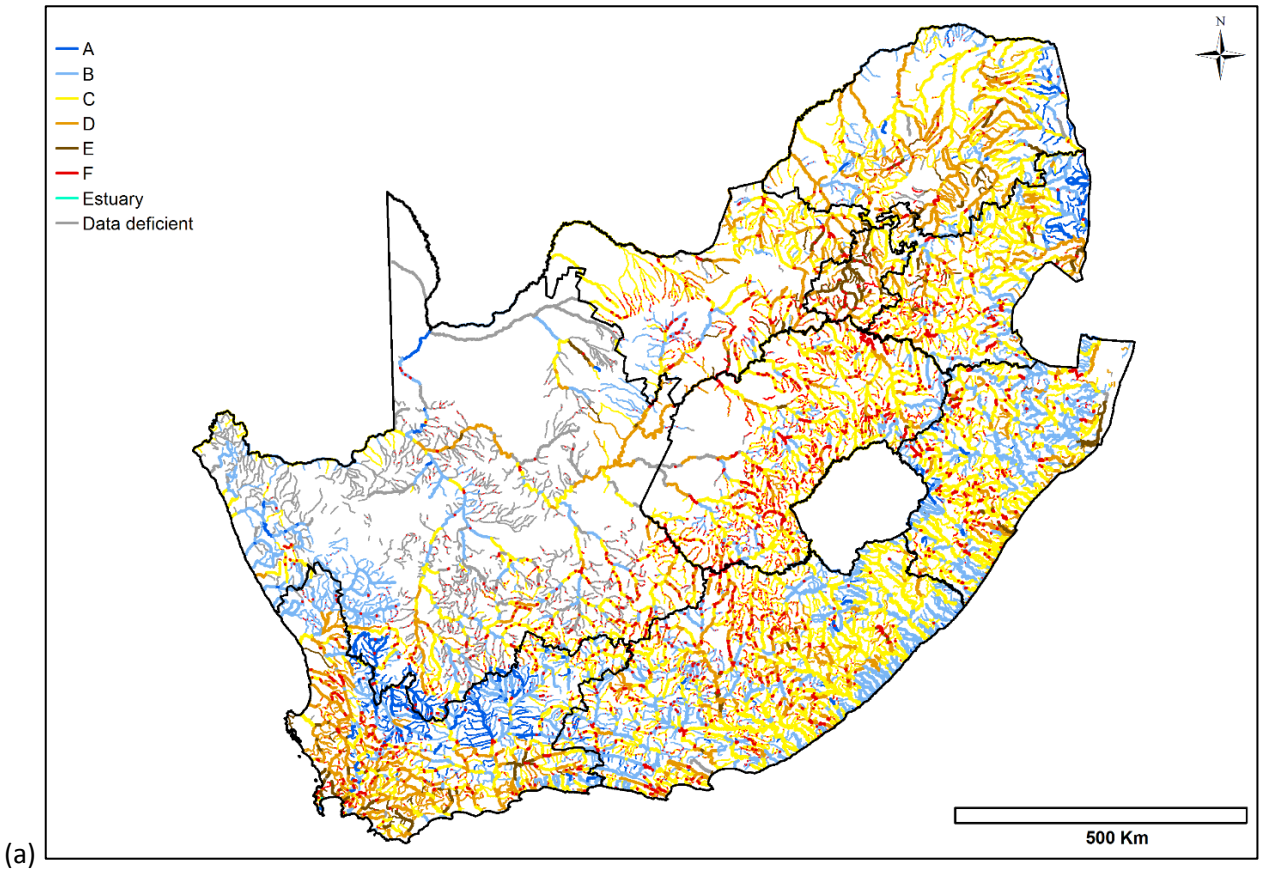
A third of the total length of the river ecosystems (33%) are in a natural or near-natural condition, including both main rivers and tributaries (Figure 5.8). The majority of the total length of rivers (67%) is therefore degraded (Figure 5.8). This assessment showed that tributaries are generally less heavily impacted than main rivers with 38% of the tributary length in a good condition compared to 28% of the mainstems (Figure 5.8). This emphasises the important role that healthy tributaries play in keeping heavily impacted main rivers functioning.

Even though NBA 2018 could not be directly compared to the NBA 2011 for several reasons (Table 5.7), the outcome of both assessments showed similar trends, with the majority of the river length no longer natural and with tributaries in a better condition compared to mainstem rivers. Healthy tributaries are vital for keeping the degraded main rivers in the lowland areas functioning. These rivers are subject to intense land and water use pressure.

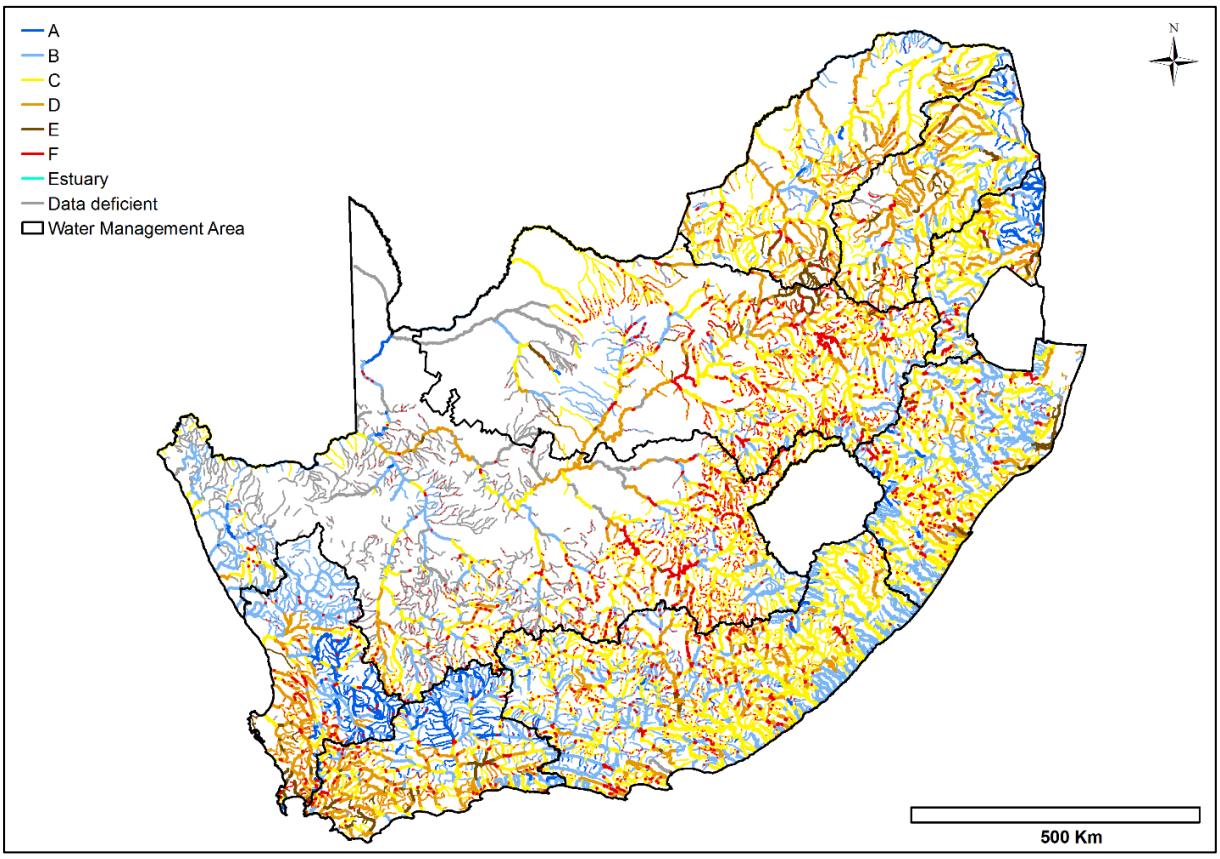
Table 5.7. Differences between river ecosystem types in the National Biodiversity Assessment (NBA) of 2011 and NBA 2018.

NBA 2011	NBA 2018
Ecological condition categories were derived from DWS ecological categories, modelled data and expert review.	PES categories were updated from the NBA 2011 with the DWS (2014) PES/EIS data and additional data from Reserve or Ecological Water Requirements (EWR) and Water Resource Classification System (WRCS) studies done in 2017.
Ecological categories for some tributaries were modelled using the land cover data from 2009.	Tributaries without ecological categories were reclassified according to several rules. *Some of these tributaries were identified as 'data deficient' as per Bland *et al*. 2017.
Ecological categories were lumped as AB, C, D, EF and Z.	Ecological categories were not lumped but left as A, B, C, D, E or F.
River sections / reaches within large dams were not excluded from the assessment.	River sections within large dams were given an 'F' ecological category.
River sections / reaches within estuaries were not excluded from the assessment.	River sections / reaches within estuaries were excluded from the assessment.
Erosion information was used in modelling PES categories.	Erosion datasets do not distinguish between natural and induced erosion and were therefore not used.
Used 223 river ecosystem types.	Used 222 river ecosystem types. One of the NBA 2011 river ecosystem types were found to be outside South Africa's boundaries.

** These river reaches were not assessed in the NBA 2018. They included arid systems typed as 'ephemeral' or 'episodic' or where no channel was present, or the reach was completely within a dam or estuary.*



(a)



(b)

Figure 5.7. River ecological condition shown with (a) provincial boundaries and (b) the Water Management Areas (WMAs). *Mainstem rivers are drawn thicker than tributaries. The ecological condition categories are those defined in Table 5.3.*

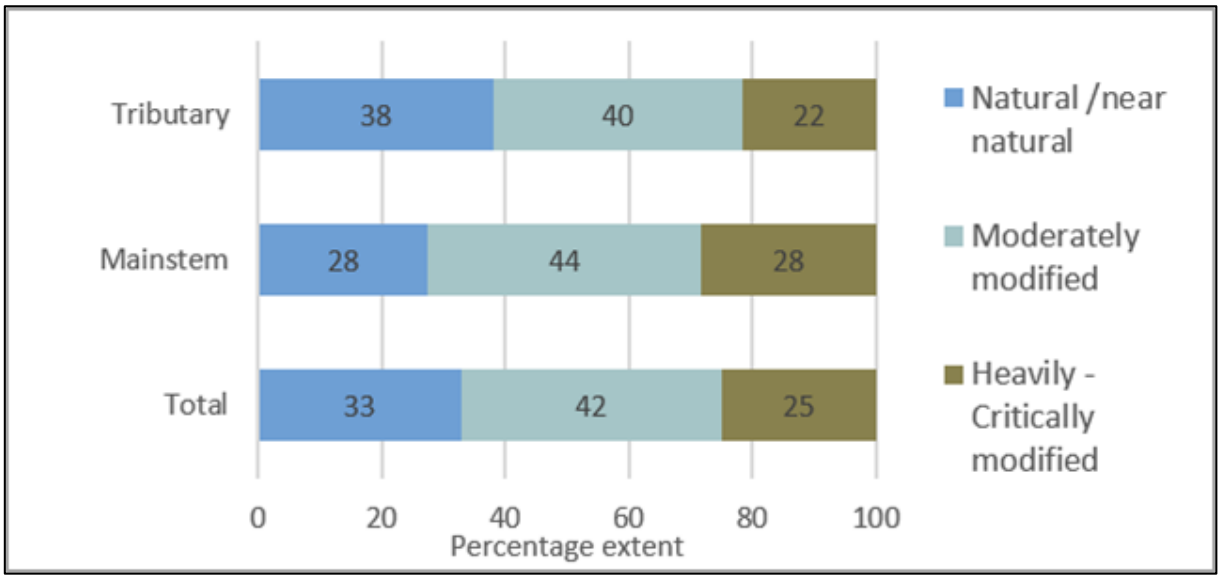


Figure 5.8. Proportion of main rivers and tributaries in a natural or near-natural ecological condition (equivalent to A or B ecological category) relative to the full length of rivers. *Tributaries are in a much better condition than mainstem rivers and play a crucial role in keeping downstream heavily impacted main rivers functioning.*

5.2.4 Estimating the ecological condition of inland wetland ecosystem types

The ecological condition of inland wetlands describes the degree to which a wetland has been modified from its natural condition (ecological category 'A') by humans (Nel & Driver 2012). In the absence of field survey data for inland wetlands, the ecological condition of inland wetlands had to be modelled, similar to the NBA 2011 (Nel & Driver 2012). Owing to the high level of uncertainty in the modelling of the ecological condition of inland wetlands at a desktop level and country-wide scale, a number of the PES categories were lumped together, leaving three main categories 'A/B', 'C' and 'D/E/F' (Table 5.8). These refer to the three associated ecological conditions, namely 'Natural or near-natural', 'Moderately modified', and 'Heavily to severely/critically modified'. **Associations between pressures and the assigned ecological category were made based on literature, however it is noted that the severity, persistence and spatial extent of impact can only be verified in the field. Impacts may vary as a result of the type, magnitude, and duration of the pressure, as well as the ability of a system to recover from the impact** (see Chapter 4 for the review of pressures on inland wetlands). Owing to the diverse setting of South Africa's inland wetlands, alternative methods of modelling should be researched to improve the associations between the diverse ranges of pressures and impacts across regions or wetland ecosystem types.[12]

Table 5.8. Description of ecological categories and associated ecological conditions for inland wetlands. DWS = Department of Water and Sanitation.

[12] The weighted scoring of land cover as a method to modelling ecological condition was also considered by the project. This method was in development by a Water Research Commission project K5/2549 'Developing a refined suite of tools for assessing the Present Ecological State of wetland ecosystems' at the time of writing of this report. Initial tests done by Heidi van Deventer at the CSIR revealed that the method would be cumbersome to implement at a national scale, which the NBA 2018 budget and time frame could not accommodate.

DWS ecological category	Description of ecological condition	Examples
A/B	Natural or near-natural state with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.	Low levels of grazing and infrequent subsistence use of ecosystem services by a small group of people.
C	Moderately-modified. A loss and change of natural habitat and biota have occurred but the basic ecosystem functions are still predominantly unchanged.	Historical ploughing (secondary natural); grazing, water abstraction; land uses which has limited impact on dominant water supply; artificial wetlands, transport infrastructure (connecting communities or cities) or weirs in large systems (hypothetically > 500 Ha). Water quality impacts in large systems. Persistent use of ecosystem services.
D/E/F	Heavily to severely/critically modified. A large loss of natural habitat, biota and basic ecosystem functions have occurred and may have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.	Waste Water Treatment Works (WWTWs), within 500 m from active or abandoned mine, large dams (up or downstream), canals, overgrazing, invasive species, peatlands burnt, medium to high water abstraction, land uses which impacts the water supply; artificial wetlands, transport infrastructure or weirs in small (hypothetically ≤ 500 Ha) systems. Water quality has been severely affected, particularly in small systems, fragmented isolated systems which had previously been part of clusters or linear systems

The use of the minimum percentage natural land cover within the wetland itself, as well as a series of buffers outside the wetland (50, 100 and 500 m), was developed in the NBA 2011. This method was adopted in the NBA 2018 too, however, additional ancillary datasets were used to model the ecological condition of inland wetlands. The ancillary data was first used to determine the PES categories of wetlands prior to the assignment of PES categories based on the minimum percentage land cover within the four zones (Table 5.6). The South African National Biodiversity Institute (SANBI) captured secondary fields (old cropfields which were left to recover from historical topographical maps (Skowno *et al*. 2019). The extent of secondary fields was combined with the 30 m, 2014 land cover dataset developed by GeoTerraImage Pty Ltd (GTI 2015) and reclassified to natural (including 'Natural' and 'Open water – natural'; code 1) or transformed (code 2) classes. The percentage natural land cover was then calculated as a percentage of the total natural + transformed pixels for each zone. The zone with the minimum percentage land cover was used to determine the PES categories, similar to NBA 2011 (Nel & Driver 2012; Table 5.7).

The number of inland wetland polygons which were affected by various pressure datasets are indicated in Table 5.9 as a total of the maximum number of inland wetlands mapped in National Wetland Map version 5 (NWM5) = 147 029 or 2 650 509 ha. Of these, the ecological confition for the majority of the extent of wetlands (> 2 million ha or 79% of the extent) have been modelled through ancillary data, whereas the only 21% of the extent had ecological categories assigned based on the minimum percentage of land cover.

The eight freshwater lakes were assessed using the same methodology for determining the ecological condition, but are reported separately. The freshwater lakes have been identified in South Africa (Van Deventer *et al*. 2018a) based on peer-reviewed and internet literature. The freshwater lakes or limnetic wetlands are permanently inundated wetlands which are > 2 m deep at the annual average low-water mark, and are equivalent to what is internationally referred to as 'lakes' (Ollis *et al*. 2013).

Table 5.9. Selected pressures and associated spatial data and thresholds used to model the ecological categories of inland wetlands. *PES = Present Ecological State; WWTW = Waste Water Treatment Work.*

Pressure dataset	Motivation and selection criteria	Number (and percentage of total number) of inland wetlands affected	Modelled ecological category
Rivers in a poor condition	The condition of an inland wetland is influenced by the hydrological regime and water quality of the river feeding the inland wetland. Select inland wetlands which intersect rivers with a PES scored of D, E or F.	3 306 (2.2%) 990 042.8 ha (37.4%)	D/E/F
Active and abandoned mines	Inland wetlands within 500 m from an active or abandoned mine would have experienced chemical and sediment pollution through air, surface run-off, interflow and groundwater sources. The land cover 2014 dataset includes some mines however adjacent fields and wetlands/water bodies were coded as natural from the land cover dataset, but may be situated within 500 m from adjacent mine infrastructure. Ancillary data is therefore important to supplement the land cover dataset. This excludes salt mines in the arid regions since these were not properly represented by the dataset.	1 846 (1.3%) 438 378.7 ha (16.5%)	D/E/F
WWTW	The condition of an inland wetland is affected by both the volume of water effluent of the WWTW as well as the water quality of the WWTW. Where an inland wetland is within 500 m downstream of a WWTW.	284 (0.2%) 134 531.4 ha (5.1%)	D/E/F
Aquaculture facilities	Inland wetlands within 500 m of aquaculture facilities were assumed to be at risk of nutrient pollution, chemical pollution, parasites or escapees. Inland wetlands up and downstream of such facilities were therefore selected and assigned a PES score.	37 (0.03%) 4 740.1 ha (0.2%)	D/E/F
Roads and railways	Roads and railways affect both the hydrological regime of inland wetlands as well as water quality. Often highways have sufficient culverts to minimise the impact on hydrology, however other roads will still impact the water quality of inland wetlands. All roads which intersected inland wetlands, is expected to modify the natural condition of inland wetlands. In wetlands > 500 ha the impacts were assumed to be less compared to smaller wetlands.	> 500 Ha; 536 (0.4%) 1 279 005.6 ha (48.3%)	C
Artificial wetlands or dams	Where a wetland was ≤ 500 ha, the impact was assumed to be severe. Natural vegetation is removed for an extent up to 60 m for road access, construction and the reserve. This amounts to at least 1/3 (0.36%) of a wetland of 100 ha to be impacted, and up to 10% for a wetland of 500 ha.	≤ 500 Ha; 16 136 (11%) 634 581.8 ha (23.9%)	D/E/F
	Instream dams modify the flow of inland wetlands. The impact is dependent on the height and type of structure of a dam wall. An assumption was made that large dams with concrete structures, as listed in the dams register, affect rivers more than wetlands, and that farm dams are more often found instream of inland wetlands, both valley-bottom, floodplains, seeps and depressions. These dam walls, can however, be easily breached and therefore their impact is more minimal, compared to the dams built in rivers.	16 413 (11.2%) 1 627 861.2 ha (61.4%)	C
Inland wetlands which have been burning or became desiccated since 1996	A total of 17 inland wetlands, identified by wetland experts (see for example Appendix C and D), have become desiccated or have been burning since 1996 (Appendix C; D). The hydrological regime of these systems has been altered to such a degree, that both the substrate and above-ground biomass has been destroyed and therefore altered severely from its original state. Of the 17 sites, two were located within an EFZ and two sites were only added after the condition, ecosystem threat and protection level assessments have been completed. These include sections of the Lajuma wetland in the Limpopo Province, where the ecological condition was modelled to be in an A/B ecological category at the time of the assessment, and a section of the Onrus peatland, caused by the Betty's Bay fire in January 2019, where the ecological condition was modelled in a D/E/F ecological category.	8 (0.005%) 13 354.1 ha (0.5%)	D/E/F
Percentage remaining land cover	If the minimum percentage land cover within the wetland or within the 50, 100 or 500m buffer zones of an inland wetlands is predominantly natural (≥ 75%), the inland wetland is presumed to be in a good condition.		A/B
	If the minimum percentage land cover within the wetland or within the 50, 100 or 500m buffer zones of an inland wetland is mostly natural (> 25% and < 75%), the inland wetland is presumed to be in a fair condition.	117 990 (80%) 544 668 ha (20.6%)	C
	If the minimum percentage land cover within the wetland or within the 50, 100 or 500m buffer zones of an inland wetlands is predominantly transformed (≤ 25%) of the remaining area is natural), the inland wetland is presumed to be in a poor condition.		D/E/F

Ecological condition of inland wetlands (excluding limnetic wetlands)

The majority of inland wetlands are in a poor ecological condition with 68% of the total spatial extent categorised as an ecological category 'D/E/F', meaning heavily to severely/critically modified (Table 5.10). Less than 15% of the inland wetlands are in a natural to near-natural ecological condition ('A/B') whereas 18% of the inland wetlands show their ecological condition to be moderately modified ('C').

A comparison between HGM units shows that depressions have the highest percentage of systems in a natural to near-natural ecological condition (35%). The other HGM units showed that < 15% of their extent was in a natural to near-natural ecological condition. In fact, > 64% of all the HGM units was largely to critically modified, except depressions (41%). Floodplains show the lowest percentage of inland wetland ecosystems in a natural to near-natural condition (1.7%) and were the most transformed (91%).

Table 5.10. Percentage of the ecological condition and associated Department of Water and Sanitation (DWS) ecological categories in brackets, as a total of the spatial extent of each hydrogeomorphic (HGM) unit and of all inland wetlands.

HGM unit (down) / DWS ecological category (across):	Natural or near-natural ('A/B')	Moderately modified ('C')	Heavily to severely/critically modified ('D/E/F')
Channelled valley-bottom	4.2	17.9	78.0
Depression	35.3	24.2	40.5
Flat	11.6	7.8	80.6
Floodplain	1.7	7.3	91.0
Seep	15.1	21.2	63.7
Unchannelled valley-bottom	7.3	16.0	76.7
Total	14.7	17.9	67.5

Geographically, the ecological condition of inland wetlands within and around the metropoles are largely transformed ('D/E/F'), as well as those regions where crops are cultivated (irrigated and dryland) in the Gauteng, KwaZulu-Natal, Mpumalanga, North West and Western Cape provinces (Figure 5.9). Inland wetlands in the more arid Eastern Cape, Free State, Limpopo and Northern Cape provinces show less density of inland wetlands, probably a result of underrepresentation of inland wetlands in these areas (low confidence that the extent of inland wetlands have been mapped). The western part of the Free State as well as the Northern Cape provinces tends to show a higher percentage of the extent of wetlands in a natural to near-natural condition, considering that the ancillary data and land cover data reflects little pressures and transformed land in these Provinces.

The result of the ecological condition modelled for inland wetlands in the KwaZulu-Natal Province supports the findings of Begg (1988) where 58% of the inland wetlands in the uMfolozi secondary catchment (KwaZulu-Natal Province) were found to be highly modified and 'lost'. Historically the uMfolozi catchment hosted 50 244 ha of inland wetlands, comprising 5% of the catchment, but according to Begg (1988), 21 244 ha (2.1%) remained unmodified. The NWM5 (Van Deventer *et al*. 2018a; 2018b; in review) mapped the extent of 42 347 ha inland wetlands for the uMfolozi catchment, of which 12.4% were now modelled to be in a natural or near-natural ecological condition (this report). The ecological condition in the arid Northern Cape Province is however difficult to model, since pressures in these arid areas are related to overgrazing or invasive species around the riparian zones (Kotze *et al*. 2019). These pressures are poorly represented in the data used to model ecological condition of the inland wetlands in the arid systems.

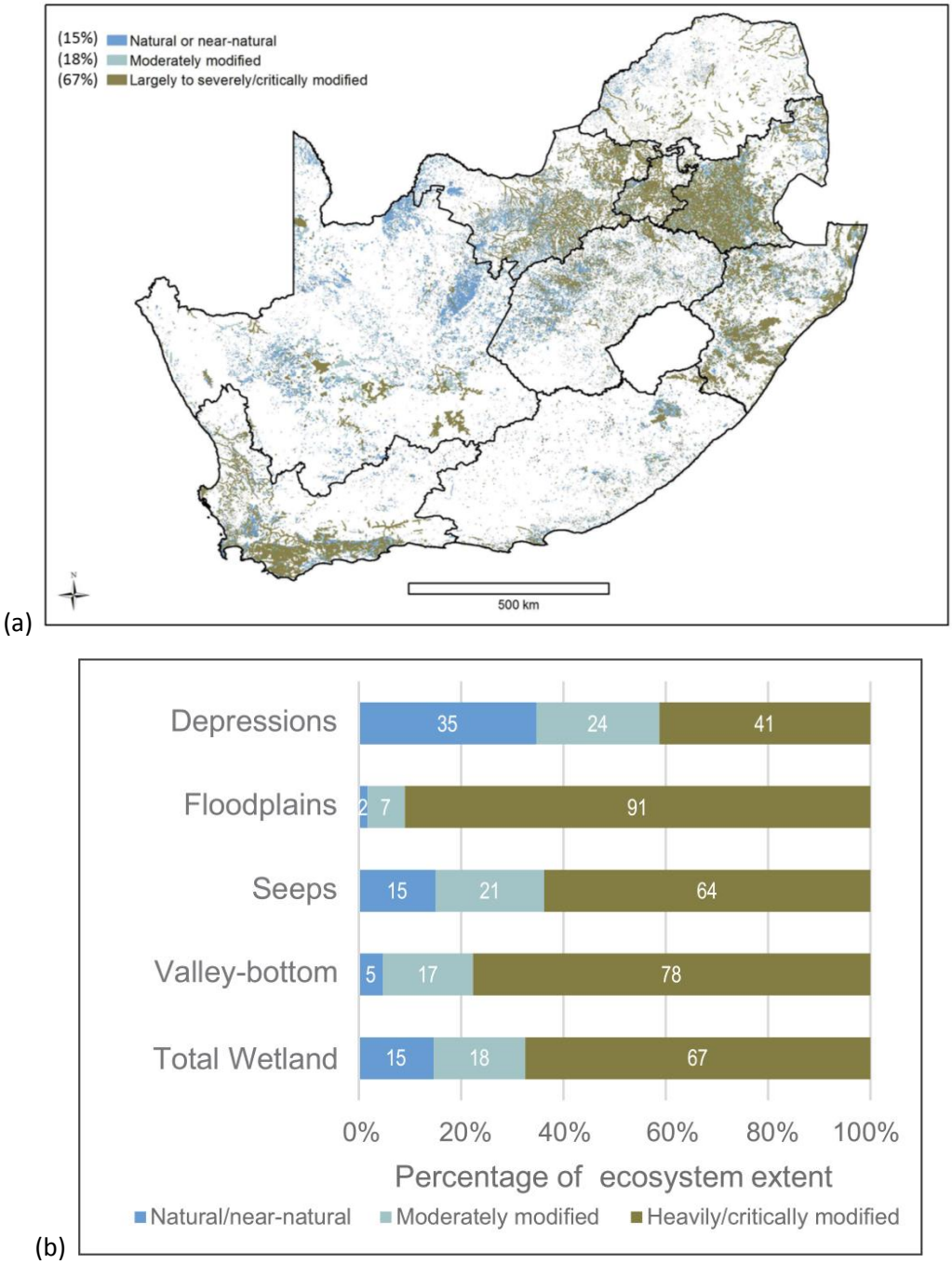


Figure 5.9. Ecological condition for inland wetlands of South Africa. *(a) The extent of inland wetlands within each ecological condition class with outlines around the polygons of inland wetlands accentuation (0.5 pnts) for visual purposes; (b) The extent of each hydrogeomorphic unit is also shown within each ecological condition class (expressed as a percentage of total extent).*

When the ecological condition of inland wetland ecosystem types is compared between the vegetation bioregions, the majority of the ecosystem types (79%) having more than a third of the extent largely to critically modified from natural condition (Table 5.11). Only 30% of the inland wetland ecosystem types have more than a third of their spatial extent still in a good ecological condition. Five ecosystem types show no modification from natural condition (extent is 100% in natural or near-natural ecological condition, DWS ecological category A/B). These are all located in the arid regions where some level of grazing is possible. In 49 of the 135 inland wetland ecosystem types, > 80% of the extent was largely to critically modified from natural condition, dispersed across the country.

Table 5.11. Percentage of inland wetland (spatial) extent per ecological condition summarised by vegetation bioregion. *The Department of Water and Sanitation (DWS) ecological categories are given in brackets.*

Inland wetland ecosystem type unit / DWS ecological category (across):	Natural or near-natural ('A/B')	Moderately modified ('C')	Heavily to severely/critically modified ('D/E/F')
Albany Thicket (Depression)	33.2	8.0	58.8
Albany Thicket (Floodplain)	3.8	10.6	85.7
Albany Thicket (Seep)	43.9	14.5	41.6
Albany Thicket (Valley-bottom)	14.6	7.7	77.7
Bushmanland Bioregion (Depression)	16.0	33.6	50.4
Bushmanland Bioregion (Floodplain)	1.9	29.4	68.7
Bushmanland Bioregion (Seep)	38.0	18.7	43.2
Bushmanland Bioregion (Valley-bottom)	1.5	62.6	35.9
Central Bushveld Bioregion (Depression)	67.5	11.4	21.1
Central Bushveld Bioregion (Floodplain)	0.5	0.0	99.4
Central Bushveld Bioregion (Seep)	5.0	16.1	78.9
Central Bushveld Bioregion (Valley-bottom)	3.5	4.3	92.2
Drakensberg Grassland Bioregion (Depression)	54.8	33.8	11.4
Drakensberg Grassland Bioregion (Floodplain)	6.3	38.8	54.9
Drakensberg Grassland Bioregion (Seep)	61.7	15.4	22.8
Drakensberg Grassland Bioregion (Valley-bottom)	23.7	16.0	60.2
Dry Highveld Grassland Bioregion (Depression)	46.3	18.9	34.8
Dry Highveld Grassland Bioregion (Floodplain)	2.7	8.5	88.8
Dry Highveld Grassland Bioregion (Seep)	3.9	7.4	88.8
Dry Highveld Grassland Bioregion (Valley-bottom)	2.9	3.2	94.0
East Coast Renosterveld Bioregion (Depression)	2.8	31.9	65.3
East Coast Renosterveld Bioregion (Floodplain)	2.1	2.7	95.2
East Coast Renosterveld Bioregion (Seep)	13.5	24.7	61.8
East Coast Renosterveld Bioregion (Valley-bottom)	2.3	6.8	90.9
Eastern Fynbos-Renosterveld Bioregion (Depression)	42.7	8.4	48.9
Eastern Fynbos-Renosterveld Bioregion (Floodplain)	-	0.8	99.2
Eastern Fynbos-Renosterveld Bioregion (Seep)	39.0	19.3	41.7
Eastern Fynbos-Renosterveld Bioregion (Valley-bottom)	16.0	17.3	66.7
Eastern Kalahari Bushveld Bioregion (Depression)	70.5	5.7	23.8
Eastern Kalahari Bushveld Bioregion (Floodplain)	0.6	48.8	50.5
Eastern Kalahari Bushveld Bioregion (Seep)	10.0	15.1	75.0
Eastern Kalahari Bushveld Bioregion (Valley-bottom)	0.9	29.6	69.5
Gariep Desert Bioregion (Depression)	100.0	-	-
Gariep Desert Bioregion (Seep)	-	-	100.0
Gariep Desert Bioregion (Valley-bottom)	0.2	-	99.8
Indian Ocean Coastal Belt Bioregion (Depression)	50.3	4.7	44.9
Indian Ocean Coastal Belt Bioregion (Floodplain)	1.8	21.1	77.1
Indian Ocean Coastal Belt Bioregion (Seep)	6.8	11.4	81.8
Indian Ocean Coastal Belt Bioregion (Valley-bottom)	11.3	5.7	83.0
Kalahari Duneveld Bioregion (Depression)	45.8	29.9	24.3
Kalahari Duneveld Bioregion (Seep)	100.0	-	0.0
Kalahari Duneveld Bioregion (Valley-bottom)	100.0	-	-
Karoo Renosterveld Bioregion (Depression)	89.4	1.5	9.1
Karoo Renosterveld Bioregion (Seep)	52.4	14.4	33.3
Karoo Renosterveld Bioregion (Valley-bottom)	0.2	0.3	99.5
Knersvlakte Bioregion (Depression)	63.8	2.9	33.3
Knersvlakte Bioregion (Floodplain)	0.1	-	99.9
Knersvlakte Bioregion (Seep)	13.6	2.8	83.6
Knersvlakte Bioregion (Valley-bottom)	1.8	0.8	97.4
Lower Karoo Bioregion (Depression)	62.5	18.0	19.5
Lower Karoo Bioregion (Seep)	84.1	12.7	3.2
Lower Karoo Bioregion (Valley-bottom)	62.9	11.7	25.3
Lowveld Bioregion (Depression)	44.1	6.0	49.9
Lowveld Bioregion (Floodplain)	3.7	10.3	86.0
Lowveld Bioregion (Seep)	21.5	19.9	58.6
Lowveld Bioregion (Valley-bottom)	5.7	33.6	60.7
Mesic Highveld Grassland Bioregion (Depression)	45.7	19.2	35.1
Mesic Highveld Grassland Bioregion (Floodplain)	2.0	3.7	94.2
Mesic Highveld Grassland Bioregion (Seep)	18.7	31.7	49.5
Mesic Highveld Grassland Bioregion (Valley-bottom)	4.1	12.4	83.5
Mopane Bioregion (Depression)	47.3	8.0	44.8
Mopane Bioregion (Floodplain)	0.2	87.1	12.7
Mopane Bioregion (Seep)	26.0	10.6	63.4
Mopane Bioregion (Valley-bottom)	2.1	23.8	74.1
Namaqualand Cape Shrublands Bioregion (Depression)	9.9	2.0	88.1
Namaqualand Cape Shrublands Bioregion (Floodplain)	100.0	-	-

Namaqualand Cape Shrublands Bioregion (Seep)	66.7	9.4	23.9
Namaqualand Cape Shrublands Bioregion (Valley-bottom)	8.3	5.6	86.1
Namaqualand Hardeveld Bioregion (Depression)	59.1	9.6	31.4
Namaqualand Hardeveld Bioregion (Seep)	10.2	1.5	88.3
Namaqualand Hardeveld Bioregion (Valley-bottom)	13.5	-	86.5
Namaqualand Sandveld Bioregion (Depression)	16.9	60.7	22.4
Namaqualand Sandveld Bioregion (Floodplain)	-	-	100.0
Namaqualand Sandveld Bioregion (Seep)	96.9	-	3.1
Namaqualand Sandveld Bioregion (Valley-bottom)	1.6	0.2	98.2
Northwest Fynbos Bioregion (Depression)	31.0	28.6	40.4
Northwest Fynbos Bioregion (Floodplain)	1.8	8.5	89.7
Northwest Fynbos Bioregion (Seep)	43.3	10.4	46.3
Northwest Fynbos Bioregion (Valley-bottom)	10.7	7.7	81.6
Rainshadow Valley Karoo Bioregion (Depression)	30.4	17.6	51.9
Rainshadow Valley Karoo Bioregion (Floodplain)	0.0	-	100.0
Rainshadow Valley Karoo Bioregion (Seep)	20.0	13.6	66.4
Rainshadow Valley Karoo Bioregion (Valley-bottom)	15.8	7.8	76.4
Richtersveld Bioregion (Depression)	94.1	-	5.9
Richtersveld Bioregion (Seep)	100.0	-	-
Richtersveld Bioregion (Valley-bottom)	47.9	-	52.1
Seashore Vegetation (Depression)	1.7	-	98.3
Seashore Vegetation (Floodplain)	-	100.0	-
Seashore Vegetation (Seep)	16.0	0.2	83.8
Seashore Vegetation (Valley-bottom)	-	-	100.0
South Coast Fynbos Bioregion (Depression)	11.1	15.6	73.3
South Coast Fynbos Bioregion (Floodplain)	32.8	0.1	67.1
South Coast Fynbos Bioregion (Seep)	17.2	10.3	72.5
South Coast Fynbos Bioregion (Valley-bottom)	2.4	17.0	80.6
South Strandveld Bioregion (Depression)	0.8	0.0	99.2
South Strandveld Bioregion (Floodplain)	1.3	0.1	98.6
South Strandveld Bioregion (Seep)	1.8	1.2	97.0
South Strandveld Bioregion (Valley-bottom)	24.5	-	75.5
Southern Fynbos Bioregion (Depression)	17.0	32.5	50.5
Southern Fynbos Bioregion (Floodplain)	0.1	-	99.9
Southern Fynbos Bioregion (Seep)	63.1	11.1	25.8
Southern Fynbos Bioregion (Valley-bottom)	11.8	23.0	65.2
Southern Namib Desert Bioregion (Depression)	82.0	-	18.0
Southwest Fynbos Bioregion (Depression)	23.7	15.4	60.8
Southwest Fynbos Bioregion (Floodplain)	4.6	1.5	93.9
Southwest Fynbos Bioregion (Seep)	45.4	11.8	42.8
Southwest Fynbos Bioregion (Valley-bottom)	11.7	8.0	80.2
Sub-Escarpment Grassland Bioregion (Depression)	20.9	60.5	18.6
Sub-Escarpment Grassland Bioregion (Floodplain)	1.5	3.1	95.4
Sub-Escarpment Grassland Bioregion (Seep)	11.5	23.1	65.4
Sub-Escarpment Grassland Bioregion (Valley-bottom)	7.5	11.1	81.3
Sub-Escarpment Savanna Bioregion (Depression)	27.9	31.0	41.1
Sub-Escarpment Savanna Bioregion (Floodplain)	0.8	6.4	92.8
Sub-Escarpment Savanna Bioregion (Seep)	11.4	20.2	68.4
Sub-Escarpment Savanna Bioregion (Valley-bottom)	7.1	10.3	82.6
Trans-Escarpment Succulent Karoo Bioregion (Depression)	54.9	6.2	38.9
Trans-Escarpment Succulent Karoo Bioregion (Floodplain)	100.0	-	-
Trans-Escarpment Succulent Karoo Bioregion (Seep)	70.2	29.8	-
Trans-Escarpment Succulent Karoo Bioregion (Valley-bottom)	-	-	100.0
Upper Karoo Bioregion (Depression)	49.0	10.6	40.4
Upper Karoo Bioregion (Floodplain)	0.4	1.7	98.0
Upper Karoo Bioregion (Seep)	11.9	76.2	11.9
Upper Karoo Bioregion (Valley-bottom)	5.5	35.1	59.4
West Coast Renosterveld Bioregion (Depression)	13.9	27.6	58.5
West Coast Renosterveld Bioregion (Floodplain)	20.0	0.9	79.1
West Coast Renosterveld Bioregion (Seep)	15.5	13.7	70.7
West Coast Renosterveld Bioregion (Valley-bottom)	18.9	8.0	73.1
West Strandveld Bioregion (Depression)	18.8	9.1	72.1
West Strandveld Bioregion (Floodplain)	3.3	5.9	90.9
West Strandveld Bioregion (Seep)	9.7	3.7	86.6
West Strandveld Bioregion (Valley-bottom)	0.2	1.2	98.6
Western Fynbos-Renosterveld Bioregion (Depression)	42.1	6.1	51.8
Western Fynbos-Renosterveld Bioregion (Floodplain)	0.5	2.9	96.6
Western Fynbos-Renosterveld Bioregion (Seep)	50.6	17.9	31.5
Western Fynbos-Renosterveld Bioregion (Valley-bottom)	9.1	22.7	68.1

Difference between the extent of wetlands modelled from the land cover methodology NBA 2011 (all) and NBA 2018 (21%) makes the results difficult to compare.

Ecological condition of freshwater lakes (limnetic wetlands)

Four of the freshwater lakes (limnetic wetlands) are completely largely to critically modified (Table 5.12), including Groenvlei, Lake Fundudzi, Barberspan and Lake Sibaya. The De Hoop limnetic depression is classified as moderately modified. Lake Banagher and Chrissiesmeer are classified as largely to critically modified (82% of the Mesic Highveld Grassland Limnetic Depression Ecosystem types), whereas Tevredenpan is in a natural or near-natural ecological condition (18% of ecosystem type).

Table 5.12. Percentage of the extent of the eight freshwater lakes (limnetic wetlands) per ecological condition and associated Department of Water and Sanitation (DWS) ecological categories in brackets. *MLD = Mpumalanga Lakes District.*

Name of depression	Bioregion	Natural or near-natural ('A/B')	Moderately modified ('C')	Heavily to severely/critically modified ('D/E/F')	Total ha
Groenvlei	Albany Thicket			100	357.3
Lake Fundudzi	Central Bushveld Bioregion			100	196.3
Barberspan	Dry Highveld Grassland Bioregion			100	1 727.70
De Hoop	East Coast Renosterveld Bioregion		100		949.3
Lake Sibaya	Indian Ocean Coastal Belt Bioregion			100	8 233.30
Tevredenpan, Lake Banagher and Chrissiesmeer in the MLD	Mesic Highveld Grassland Bioregion	18.3		81.7	1 796.30

Limitations of the data and approach in modelling ecological condition

Specific limitations for rivers, pertaining specifically to the data and approach in modelling ecological condition, include:

- The DWS (2014) PES/EIS dataset employed in NBA 2018, which included main rivers and tributaries at a sub-quaternary level, is a desktop assessment which means the confidence is low in any event. Furthermore, SQR subdivisions for example into various ecoregions or geomorphic zones, are not addressed on a desktop level, and may be required for fine scale assessments. Also, secondary catchments are the level of assessment used in the PES/EIS. This means that certain metrics are assessed relative to attributes of the secondary catchment and these are consequently only relevant to the particular catchment (DWS 2014).
- This national desktop dataset was based on expert assessment. It is important to note that expert-derived data are unreliable for monitoring trends in ecological condition because changes may be based on a change in the understanding or knowledge of experts, rather than actual quantitative changes in condition. Hence, it is crucial for monitoring to use quantitative measures for assessing trends in river condition.
- There are only two points in time (PES 2000 used for the NBA 2011) for mainstems and PES 2011 (being used for the NBA 2018) for mainstem and tributaries, which is only indicative of a change, but not a repetitive pattern to deduce a trend or the rate of change. This was also recognised as a limitation in Nel & Driver (2015) and in order for time series comparison of ecological condition of both main rivers and tributaries, the ecological condition of tributaries in 1999 were retrospectively estimated, based on modelling and expert review, where the estimates of the condition of tributaries in 1999 were used (Nel & Driver 2015).
- There is a possibility of using data from the River EcoStatus Monitoring Programme (REMP) which could increase the confidence level of the PES/EIS data. However, an inadequate ability to map spatially explicit information (e.g. the Rivers Database lacked summarized PES scores or ecological categories and global position points (GPS) co-coordinates recorded in the field of certain sites were incorrect) hampered this process in the past with the River Health Programme (RHP). A data driven repeatable approach is necessary with consistency in datasets and institutional collaboration.
- The desktop PES/EIS data are supposed to be updated with higher confidence data as it becomes available on the DWS website. However, limited capacity at DWS is currently hampering this upload process (i.e. the online PES database can be out dated) as well as a limitation in DWS funding to repeat the national survey such as the PES/EIS 2011 (Christa Thirion, *pers. comm.*).
- Methods for the determination of PES (or ecological) categories may differ. A PES score may have been assigned as A or B but in another assessment may be assigned a C, which may not reflect true change, but rather a change in method or ranking. For instance, the Western Cape is the only office doing full EcoStatus assessments currently while biomonitoring data can lack a review process (Christa Thirion and Andrew Gordon, *pers. comm*.). Another example includes the PES impact fact spreadsheets on the online PES database which are derived using different methods. It is therefore necessary to evaluate the data sources when comparing datasets. Moreover, higher confidence studies should override desktop assessments.
- There is a need for using a higher resolution rivers network, a new national hydrologically-corrected rivers dataset derived from the 1 arc-second (30 m) Shuttle Radar Topography Mission (SRTM) data, or better resolution if available. This include addressing the mismatch of various 1:500 000 rivers with that of the 1:50 000 rivers. Hence, improvement of the spatial accuracy of the rivers layer used for assessments (Smith-Adao *et al*. 2018).
- The DWS has a low confidence in the flow variability attributes (perennial versus non-perennial rivers) attached to the 1:500 000 rivers network categories. The river flow categories should be

revised and more categories must be added, for example those recommended by Uys & O'Keeffe (1997). Also, hydrological indices at a sub-quaternary scale are needed.

- There is a need for endorsed (i.e. the mandate of the DWS) quaternary and sub-quaternary or quinary catchment boundary GIS layers using the latest information and methods. Hence, develop sub-catchment planning units that take into account condition changes and altitudes. According to Nel & Driver (2015), a standard national set of quinary catchment boundaries still has to be agreed on, as different quinary catchment boundaries are useful for different purposes. For climate change modelling, for example, quinary catchments based on altitudinal subdivisions of quaternary catchments are useful whereas for hydrological modelling quinary catchments based on drainage units are required (Nel & Driver 2015).
- Macroinvertebrate and riparian vegetation data are mostly lacking in the assessments of river ecosystem types and planning. There is a need to develop biodiversity indices that speak directly to biodiversity (of which macroinvertebrates would be one, and fish, riparian vegetation, diatoms, etc.) (mandate of the DEFF). This is very important from the NBA perspective as it would be a way of validating the NBA data sets such as river ecological status.
- The land cover and erosion data available for modelling ecological condition (i.e. addressing the data gaps in the PES/EIS dataset) are inadequate as the analysis indicated country wide natural areas. The latter is incorrect, as grazing (not mapped), invasive plant species (e.g. *Prosopis*) and erosion (natural versus human induced) impacts are not accounted for.
- The ecological condition of seeps has incorrectly been modelled through the intersection of rivers with an ecological category of D/E/F. This error constitutes approximately 11% of all seeps, however, since a similar ecological condition of these seeps would also have resulted from other ancillary data, the ecological condition of only 6 893 ha of seeps were incorrectly classified this way, which makes up 1.5% of seeps and 0.3% of all inland wetlands. Future modelling of ecological condition should consider improvement per HGM type.

Specific limitations to the modelling of the ecological condition for inland wetlands include:

- Pressures in the arid regions, such as overgrazing and invasive plant species, are not represented in the base layers used for modelling ecological condition of inland wetlands. As a result, most of the systems in arid inland vegetation bioregions therefore appear as natural or near-natural (PES = A/B), owing to a lack of representation of pressures in these regions (Kotze *et al*. 2019).
- The size of land cover pixels (900 m²) is larger than > 99% of the size of inland wetlands.
- The most extensive pressure, grazing (Skowno *et al*. 2019) is not at all represented in any dataset used for modelling the ecological condition of inland wetlands. Skowno *et al*. (2019) indicated that approximately 70% for the country is grazed, yet no information is available on stock types and levels to determine possible areas of overgrazing and resultant impacts.
- Land cover is a poor discriminator of degradation. A visual inspection of some inland wetlands near active and abandoned mining points showed that the underlying land cover was natural. Therefore, old mines showed up as natural land cover, owing to the reflectance of grass cover used for the classification. Ancillary datasets therefore proved tremendously valuable in detecting formerly transformed and degraded areas. Open water bodies in the land cover is also classified as natural, and the minimum percentage natural land cover method within the four zones would result in a PES = A/B category. In one example the open water body was classified as natural or near-natural (PES = A/B) being predominantly natural, however it was situated within 500 m of a tailings impoundment, receiving run-off from mining waste. Multiple layers, therefore a combination of land cover data and ancillary data, as well as proximity thresholds are therefore crucial to use in

modelling ecological condition, to ensure a more accurate representation of the integrity of an inland wetland.

- The correspondence and accuracy of the ecological condition of inland wetlands to in-field assessments have not been assessed. Although we would attribute a 50% confidence level to the accurate representation of the land cover data of the land cover type, the severity, magnitude, duration and rate of land degradation for the inland wetland ecosystem types are however unknown, and therefore the confidence of the Present Ecological State (PES) categories are unresolved.
- The spatial accuracy and representation accuracy of ancillary datasets (Table 5.6) is unknown. Random visual inspection was used to assess some of the points and line datasets, and errors in representation and location accuracy have been found. Where observed, the PES was corrected for affected inland wetlands.
- Several pressures are unrepresented in the base dataset layers that have been used for modelling the ecological condition of inland wetlands. A wish list has been set up for future assessments to consider.
- The next NBA would probably have more information from the National Wetland Monitoring Programme to infer ecological condition from. In the NBA 2011 (Nel & Driver 2012), a strategic assessment of inland wetland health and congruency assessments with desktop models was recommended, however little in-field data was freely available to do this for the NBA 2018.

A Water Research Commission project (WRC K5/2549) was in development between 2016 and 2019 titles 'Developing a refined suite of tools for assessing the Present Ecological State of wetland ecosystems.' This project investigated the health assessment of inland wetlands at various scales, using the approach where land cover types are weighted according to their associated impacts on difference HGM units. The automation of the procedure was in development during the time of the NBA 2018, and may be a feasible alternative for future NBAs.

5.3 Ecosystem targets

Owing to insufficient data in determining ecologically differentiated targets, a wide range of stakeholders from related sectors agreed to a biodiversity target of 20% for inland aquatic ecosystems at a workshop held in 2006 (Roux *et al*. 2006; Nel & Driver 2012). The NBA 2018 follows this biodiversity target of 20% (Table 5.1). This means that ecosystems with < 20% of their spatial extent in a natural or near-natural ecological condition (where the ecological condition = A and B for rivers or A/B for inland wetlands), was considered Critically Endangered. Thresholds of 35% and 60% were used for Endangered (EN) and Vulnerable (VU) categories, whereas ecosystems with > 60% in a natural or near-natural ecological condition, was considered of Least Concern (LC). These thresholds were applied to the river ecosystem types as well as inland wetland ecosystem types.

The threshold of the **freshwater lakes or limnetic wetlands** (**lakes**, Table 5.13), of which only eight exist in South Africa to our knowledge, were set at **100% of the biodiversity target**, as agreed to in a reference committee meeting for the inland aquatic ecosystems (Appendix A). For the limnetic wetlands qualify under the Red List of Ecosystem (RLE) criteria B (*Restricted distribution*) as well as C (*Degradation*).

Table 5.13: The spatial extent of eight freshwater lakes (limnetic wetlands) of South Africa (Van Deventer *et al*. 2018a:xix).

Name	Extent (ha)	Percentage of the total extent of the freshwater lakes (limnetic wetlands)
Barberspan	1 720.6	12.9
Chrissiesmeer	1 282.6	9.6
De Hoop	949.3	7.1
Groenvlei	357.3	2.7
Lake Banagher	184.5	1.4
Lake Fundzudzi	192.3	1.4
Lake Sibaya	8 360.1	62.5
Tevredenpan	329.2	2.5
Total extent	**13 375.9**	**100**

5.4 Protection level building blocks

The NBA 2018 follows the headline indicator of EPL, introduced in the NSBA 2004 and NBA 2011. Owing to insufficient data to determine ecologically differentiated targets, and a high level of uncertainty related to the effectiveness of protection against the pressures and impacts on both ecosystems and biota, the target was set at 20%, similar to the ETS. Figure 1.8 illustrates the process of mapping ecosystem types and assigning or modelling the associated ecological condition, followed by the assessment of the two headline indicators against a set of thresholds. SANBI has integrated various datasets from the Department of Environmental Affairs (DEA) and provincial organisations into a single dataset of protected areas (Figure 5.11). The DEA in-house dataset called 'Protected Areas and Conservation Areas' (PACA) and the publicly available South African Protected Areas Database (SAPAD) version 2017Q3 and more recent updates of 2018Q2 included gazetted reserves, whereas *de facto* reserves where private land has been managed by provincial conservation authorities (for example those from Ezemvelo KwaZulu-Natal Wildlife and CapeNature), has been integrated (Skowno *et al*. 2019). The resultant database includes several types of protected areas and subtypes (Table 5.14). The targets and thresholds for the EPL are discussed in Section 6.2 in more detail.

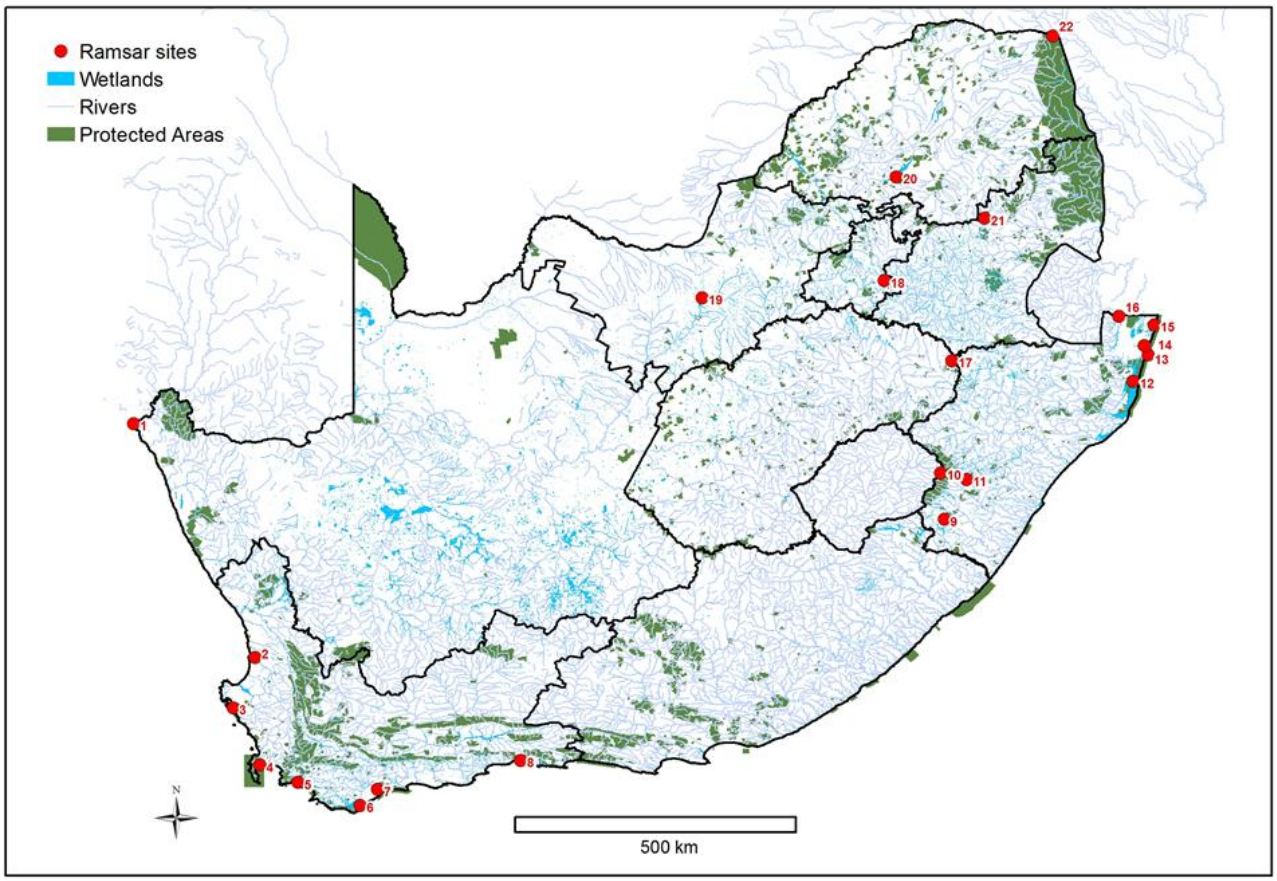


Figure 5.10. Protected areas and Ramsar sites used in the NBA 2018 for the assessment of the Ecosystem Protection Levels (EPLs). *See Table 5.15 for the names and extents of the Ramsar sites. The Prince Edward Islands Ramsar site is not included in the map for reasons of scale.*

Table 5.14. List of main protected area types and subtypes for the National Biodiversity Assessment of 2018.

Main type	Subtype
Forest Nature Reserve	FNR - Forest Nature Reserve
Forest Wilderness Area	FWA - Forest Wilderness Area
Marine Protected Area	MPA - Marine Protected Area
Mountain Catchment Area	MCA - Mountain Catchment Area
National Park	NP - Agreement Park
	NP - Contractual Agreement
	NP - Contractual Park
	NP - National Park
Nature Reserve	NR - Bird Sanctuary
	NR - Development Areas Reserve
	NR - Local Nature Reserve
	NR - Nature Reserve Stewardship Programme
	NR - Not Assigned
	NR - Private Nature Reserve
	NR - Provincial Nature Reserve or Nature Reserve
Protected Environment	PE - Protected Environment
	PE - Stewardship Programme
Special Nature Reserve	SNR - Special Nature Reserve
World Heritage Site	WHS - Buffer
	WHS - Core
	WHS - Not Assigned

In addition to the protected areas, South Africa has 23 wetlands of international importance (Table 5.15), also referred to as Ramsar sites, which totals 554 028 ha in extent (Ramsar 2018). Ramsar sites provide some level of protection to the wetlands in South Africa in that these require management plans. Some overlap exists between the protected areas and the Ramsar sites (Figure 5.11). For the EPL, only the formal protected areas have been considered, however we also report the extent of Ramsar sites that do not overlap with the formal protected areas and what contribution they make to the EPL for inland wetlands (Section 6.2). The protected area network and Ramsar sites were used together, to evaluate whether South Africa has met Aichi target 11, which states that '… by 2020, at least 17 per cent of terrestrial and inland water areas and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscape and seascape.' (CBD no date).

Table 5.15. List of South Africa's 23 Ramsar sites (Ramsar 2018), their primary ecosystem type for which they were nominated, their extent (ha) and map label number. *Sites in red text are currently listed on the Montreux record.*

Name	Primary ecosystem type	Extent (ha)	Map label no. (Figure 5.10)
Barberspan	Inland wetland	3 118.0	19
Blesbokspruit	Inland wetland	1 858.0	18
Bot - Kleinmond Estuarine System	Estuarine	1 349.8	5
De Hoop Vlei	Inland wetland	750.0	7
De Mond	Estuarine	918.0	6
False Bay Nature Reserve	Estuarine	1 542.0	4
Kosi Bay	Estuarine	10 982.0	15
Lake Sibaya	Inland wetland	7 750.0	14
Langebaan	Estuarine	6 000.0	3
Makuleke Wetlands	Inland wetland	7 757.0	22
Natal Drakensberg Park	Inland wetland	242 813.0	10
Ndumo Game Reserve	Inland wetland	10 117.0	16
Ntsikeni Nature Reserve	Inland wetland	9 200.0	9
Nylsvley Nature Reserve	Inland wetland	3 970.0	20
Orange River Mouth	Estuarine	2 000.0	1
Prince Edward Islands	Island	37 500.0	23
Seekoeivlei Nature Reserve	Inland wetland	4 754.0	17
St. Lucia System	Estuarine	155 500.0	12
Turtle Beaches/Coral Reefs of Tongaland	Coastal	39 500.0	13
Umgeni Vlei Nature reserve	Inland wetland	958.0	11
Verloren Valei Nature Reserve	Inland wetland	2 891.0	21
Verlorenvlei	Estuarine	1 500.0	2
Wilderness Lakes	Estuarine	1 300.0	8

In addition, we have evaluated how much NFEPA has contributed to the trend in securing extent of rivers and inland wetlands within the protected area network over the past seven years.

5.5 Detecting changes to the free-flowing and flagship rivers

The 62 free-flowing rivers, which had been identified by the NFEPA project, were assessed in two ways. Firstly, we assessed whether any changes took place to these rivers since 2011 when they were identified. The DWS dams register of 2016 was linked to the updated artificial wetlands layer (Van Deventer *et al.* 2018a; 2018b). Where any medium to large dam intersected a free-flowing river, we determined the date of the building of the dam, verified this on Google Earth historical imagery and assessed the location of the dam relative to the river. If the dam was built on a tributary of the free-flowing river, the river was still considered to be free flowing in status. However, if the dam was built on the main-stem part of the river, and split the river into < 100 km segments, the river would no longer qualify under the criteria for a free-flowing river.

Secondly, changes in the ecological condition of the free-flowing rivers were considered. The PES data of 2011 were compared to those of the most recent update (2017) (Smith-Adao *et al*. 2018) and the extent of the change in condition presented. All flagship rivers remained as such but there were some changes in the free-flowing rivers post-review.

5.6 Species data needed for threat assessments

Accurate species occurrence data is required to support both threat and protection level assessments. For each taxon group the following data preparation is required:

I. **Collation of information on species occurrences:**
   Historic and current occurrence records are sourced from:
   a. Digitised specimens from collections institutions (museums or herbaria);
   b. Citizen science records collected during targeted atlasing projects and online virtual museums;
   c. Provincial conservation agencies and South African National Parks monitoring records; and
   d. Additional observation data from species experts not already captured in any of the above datasets.

II. **Georeferencing of occurrence records and spatial verification:**
   a. For all taxonomic groups, with the exception of birds, historical occurrence records from museums or herbaria provide much of the available data on species occurrences. These records often do not have spatial co-ordinates associated with them. Thus, for each group, a process was undertaken to accurately georeference records based on locality descriptions. Uncertainty of accuracy of the co-ordinates captured in correspondence with the level of detail provided in the locality description was included; and
   b. As georeferencing is typically undertaken by contract staff who are not species experts, an important step to ensure accuracy of species input data was to run a process whereby experts checked the validity of occurrence records and identified both errors of incorrectly georeferenced occurrence records as well as incorrect identification of records from collections institutions.

III. **Species life-history and ecological information:**
   In order to determine key parameters required for IUCN Red List assessments of threat status and to set the conservation targets to determine protection level, information such as habitat,

generation length, life history or growth form, population growth rate etc. was obtained both from the scientific literature and species experts.

IV. Spatial data:

Land cover data was used to determine causes of habitat loss and was used to calculate decline parameters for Red List threat assessments. Changes in land cover between 1990 and 2014 (see Section 3.2.2 of the terrestrial report, Skowno *et al.* 2019) was the main source of information to determine trends in change of status for reptiles, amphibians and plants. South Africa's protected areas layer (see Section 5.4) was intersected with species point occurrence data and habitat suitability models generated for each taxon group to determine the level of representation in the protected area network for each taxon.

Species groups assessed

In order for species assessments to feed into national level indicators such as the IUCN Red List Index (RLI) it is important that full taxonomic groups are assessed. Groups included in this assessment are those groups where the taxonomy is stable enough for there to be sufficient knowledge generated from field studies, and collections to provide the baseline data for each taxon's to be assessed. In addition, only groups that have had extensive investment in mobilisation, collation and cleaning of foundation information can be assessed. To date seven freshwater taxonomic groups have been comprehensively assessed, namely all freshwater vertebrates (birds, mammals, reptiles, amphibians and freshwater fish), all South African plants and one aquatic invertebrate group (dragonflies). Table 5.16 details the data collated and prepared for each taxonomic group.

Table 5.16. Summary of species occurrence and habitat suitability model distribution data used as a primary input data for conducting threat status assessments conducting Red List Indexes used to determine change in trend data (see Section 7.1.2) and to conduct protection level assessments (see Section 7.2.2).

Birds: Occurrence data was sourced from the Southern African Bird Atlas Project (SABAP2) co-ordinated by the University of Cape Town (UCT). SABAP2 started in 2007 and data collection is ongoing. For the Red List Index (RLI) assessment data collected by SABAP2 until mid–2015 were used and changes in abundance and distribution for birds were obtained by comparing data from the SABAP1 conducted between 1987 and 1991 and SABAP2 2007 onwards. For the Species Protection Level analysis SABAP2 data collected until February 2018 were used. SABAP2 coverage of the PA network is sufficient for the vast majority of Bird Species. SABAP2 data were used to calculate relative abundance of birds in each reserve using reporting rates. Other datasets managed and curated by UCT's Animal Demography Unit (ADU) including Birds in Reserve Project (BIRP), Co-ordinated Waterbird Counts (CWAC), or specialised datasets obtained from individuals was used in a handful of cases to augment information available in SABAP.
Mammals: Data collation for the mammal assessment began in June 2013 and ran, in parallel with other processes, to December 2015. Data collation and cleaning was co-ordinated and conducted by the Endangered Wildlife Trust (EWT) with contributions from the ADU at the UCT's MammalMap project. Data contributors included museums, university researchers, statutory conservation agencies, environmental consultancies, private protected areas, landowners and citizen scientists. Overall, 460 931 occurrence records and 41 075 population count records were amassed. In total, there were 104 primary data contributors including 60 institutions and researchers in their private capacity. For details on data contributors see (Child *et al.* 2016).

Reptiles: Occurrence records were first sourced as part of the Reptile Conservation Assessment (SARCA) that was coordinated by the ADU at the UCT between 2004 and 2009 (Bates *et al.* 2014). As part of this project the 135 512 reptile occurrence records from 20 participating institutions were digitised and collated. The project involved extensive field surveys in gap areas and initiated the first virtual museum for the country where members of the public submitted images and coordinates of reptiles. While extensive digitisation took place as part of SARCA, a large proportion of the data was not georeferenced to the scale required for assessment work. The reassessment of South Africa's Reptiles undertaken by the IUCN Southern African Reptile Red List Authority between 2015 and 2018 ensured verification of spatial data by experts and the extrapolation of point data to infer occupied distribution ranges that were used both to calculate the species threat statuses and protection level, also took place as part of this project (Tolley *et al*. 2019).
Amphibians: Occurrence records for South African amphibians are managed by the IUCN's Amphibian Specialist Group, working on southern African amphibians (Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia and Zimbabwe). The group known as the Southern African Frog Re-assessment Group (SA-FRoG), formed in 2009 have collated 133 667 amphibian occurrence records which includes data from all of South Africa's major collection institutions and amphibian monitoring projects. Data from 45 projects and institutions and 21 independent researchers are included. Point occurrence data has been extrapolated by the amphibian experts working on RLI assessments to infer occupied distribution maps. Occupied distribution maps in combination with recent occurrence data were used for both threat and protection level assessments.
Freshwater fish: Occurrence data was obtained from South African Institute for Aquatic Biodiversity (SAIAB 2016), and supplemented by provincial conservation agency data where more recent field records were available. Some species have not been described and records related to these newly described species and lineages were supplied by the researchers and accessions numbers will be provided when records are submitted to the SAIAB database. All distribution records were in the form of point data based on specimen records. As per IUCN requirement freshwater species distribution was mapped to sub-basins or lakes using the HydroBASINS layer (Lehner & Grill 2013). All restricted threatened species and Taxa of Conservation Concern (ToCC) were mapped at the finer resolution of level 10, which is closest in size to the South African sub-quaternary catchments. While for widespread Least Concerned species, the 2007 maps were used and were updated where required using lower resolution of level 6. For the purposes of analysis, the species distributions were converted to sub-quaternary catchments. This data was used for both IUCN redlist assessments as well as assessing species protection level.
Freshwater Plants: Occurrence data were sourced primarily from digitised herbarium specimen data from South Africa's 6 major herbaria which constitute 90% of the country's ca. 3 263 200 plant specimens: the Bolus Herbarium (BOL), the Selmar Schonland Herbarium (GRA), the Compton Herbarium (NBG), The KwaZulu-Natal Herbarium (NH), the BEWS herbarium (NU) and the National Herbarium (PRE). Additional datasets from provincial conservation authorities' plant monitoring datasets, and smaller private herbaria and collections were also included. Recent field occurrence data was obtained from two primary sources, from the data collected by the Custodians of Rare and Endangered Wildflowers Programme (CREW), a SANBI led citizen science project that specifically targets surveying South Africa's rare and threatened plant species and iNaturalist a virtual museum open to all members of the public. A 100 South African plant taxa were selected as part of a random sample to pick up trends on inland aquatic plants taxa.
Odonata (Dragonflies & Damselflies): Odonata species distribution records was obtained from the OdonataMap a Virtual Museum project, managed by the ADU, vetted and curated data was donated by the University of Stellenbosch which was curated by Prof. Michael Samways and Dr John Simaika (Samways & Simaika 2016).

The following chapter (Chapter 6), present the results of the headline indicators for ecosystem types, as well as the additional analysis for non-formal conservation areas.

5.7 References

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6. ECOSYSTEM ASSESSMENTS FOR THE INLAND AQUATIC REALM

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This chapter offers the results of the headline indicators of the National Biodiversity Assessment of 2018 (NBA 2018) for river and inland wetlands. In Section 6.1 the results of the Ecosystem Threat Status (ETS) headline indicators are given, followed by the Ecosystem Protection Level (EPL) results in Section 6.2. The assessment results for freshwater lakes (limnetic wetlands) are discussed in Section 6.3. Changes in the status of free flowing and flagship rivers are provided in Section 6.4, whereas the the highly threatened and unprotected ecosystem types are discussed in Section 6.5. We conclude the chapter with a comparison between the NSBA 2004, NBA 2011 and NBA 2018 results.

Box 6.1. South Africa's freshwater conservation goal as agreed on through an inter-departmental cross-sector policy development process (Roux *et al.* 2006:x)

To conserve a sample of the full variety or diversity of inland water ecosystems that occur in South Africa, including all species as well as the habitats, landscapes, rivers and other water bodies in which they occur, together with the ecosystem processes responsible for generating and maintaining this diversity, for both present and future generations.

6.1 Ecosystem Threat Status (Red List of ecosystems)

Ecosystem Threat Status (ETS) is a key indicator of the degree to which South Africa's ecosystems are still intact, or alternatively losing vital aspects of their structure and functioning. The ETS has been traditionally assessed for species, in the form of national or global Red Lists that draw attention to species threatened with extinction. Ecosystem types are categorised as Critically Endangered (CR), Endangered (EN), Vulnerable (VU) or Least Concern (LC), with CR, EN and VU ecosystem types collectively referred to as 'threatened'. Critically Endangered ecosystems are ecosystem types that have very little of their original extent (measured as area, length or volume) left in natural or near-natural condition. Most of the ecosystem type has been heavily, severely or critically modified from its natural state. Any further loss of natural habitat or deterioration in condition of the remaining healthy examples of these ecosystem types must be avoided, and the remaining healthy examples should be the focus of urgent conservation action (Nel & Driver 2012).

Endangered ecosystems are ecosystem types that are close to becoming Critically Endangered. Any further loss of natural habitat or deterioration of condition in these ecosystem types should be avoided, and the remaining healthy examples should be the focus of conservation action. Vulnerable ecosystems are ecosystem types that still have the majority of their original extent (measured as area, length or volume) left in natural or near-natural condition, but have experienced some loss of habitat or deterioration in

condition. Least concerned ecosystems are ecosystem types that have experienced little or no loss of natural habitat or deterioration in condition (Nel & Driver 2012).

6.1.1 Ecosystem Threat Status calculation method

River ecosystem types (Section 5.1.1) were combined spatially with river condition (Section 5.2.1). The percentage length of each river ecosystem type in good condition (A or B ecological category) and moderate condition (C ecological category) was thus calculated. An ETS category was assigned to each river ecosystem type by applying the thresholds for river ecosystems to these percentages.

Figure 6.1 details the main steps involved in assessing ETS. Once ecosystem types have been mapped and classified, the next step is to map pressures on ecosystems or where ecosystems have been lost. This information supports an assessment of the condition or ecological integrity of ecosystems, which can range from 'natural' or 'near-natural' through to 'extremely or critically-modified'. The proportion of each ecosystem type that remains in good condition is then evaluated against a series of thresholds to determine ETS.

This section reports the results of the ETS and EPL for river ecosystem types (Section 6.1.1.), followed by the results of inland wetland ecosystems (Section 6.1.2.). Subsequently the EPL for the rivers and inland wetlands are discussed in Section 6.2., and then the ETS and EPL for the freshwater lakes (limnetic wetlands) in Section 6.3.

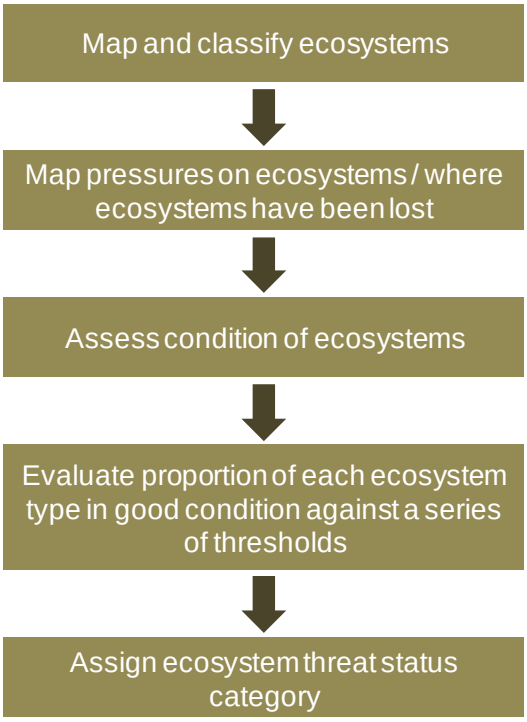


Figure 6.1. Main steps in assessing Ecosystem Threat Status (after Nel & Driver 2012).

The thresholds were customised for rivers and inland wetlands as follows (derived from Nel & Driver 2012):

- **Critically Endangered:** Owing to insufficient data in determining ecologically differentiated targets, the biodiversity target was set to 20% for inland aquatic ecosystems (Nel & Driver 2012). This threshold was recommended in cross-sectoral policy objectives for conserving inland aquatic orfreshwater ecosystems (Roux *et al*. 2006). This cross-sectoral policy process established inter-departmental governmental agreement that at least 20% of each river or inland wetland ecosystem type should remain in a good condition (A or B ecological category). Thus, a river or inland wetland ecosystem type was considered Critically Endangered if less than 20% of its total length or spatial extent is in good condition (A or B ecological category).
- **Endangered:** Set as the Critically Endangered threshold plus an additional buffer of 15% of the spatial extent of that ecosystem type. Thus, river and inland wetland ecosystem types with 20–35% of their total extent in a good condition (A or B ecological category) were classified as Endangered.
- **Vulnerable:** A less stringent threshold was set requiring at least 60% of the total extent of the ecosystem type in a good condition OR in a moderately-modified condition (A, B or C ecological category). This threshold acknowledges that moderately-modified rivers and inland wetlands support some biodiversity pattern and ecological functioning, albeit impaired.
- **Least concern:** An ecosystem type had to have > 60% of its total extent in a good OR moderately modified (A, B or C ecological category) to be classified as least concern.

The threshold of freshwater lakes (limnetic wetlands), of which only eight exist in South Africa to our knowledge, were set at 100% of the biodiversity target, as agreed to in a reference committee meeting for the inland aquatic ecosystems (Appendix A). The degree of transformation, as well as the restricted range criterion B of Bland *et al*. (2017), was used to assess the threat status of the eight freshwater lakes (limnetic wetlands).

6.1.2 Ecosystem Threat Status results

ETS of river ecosystem types

Figure 6.2 shows river ETS across the country. As could be expected, the Critically Endangered and Endangered ecosystems are concentrated mainly around major cities and production landscapes where pressures on water resources are highest. Note that an ecosystem type can have a range of different ecological conditions but only one ETS category. For example, Critically Endangered ecosystem types will by definition have very few examples in natural or near-natural condition (A or B ecological category), while those of least concern will have more. Rivers that contain examples of Critically Endangered or Endangered ecosystem types that are still in a natural or near-natural ecological condition (A or B ecological category) should remain in this condition as they are vital for achievement of South Africa's biodiversity goal (Box 6.1).

The river ETS also varies across Water Management Areas (WMAs) (Figure 6.2b). The Vaal WMA has an alarming proportion of Critically Endangered ecosystems associated with its rivers, far higher than the rest of the country (> 70% of its length contains Critically Endangered ecosystems). Since Critically Endangered ecosystems have dropped below the desired biodiversity target of maintaining at least 20% in a good condition, this WMA will be particularly hard pressed to meet the country's goal for inland aquatic ecosystem conservation (Box 6.1) without a focused effort to rehabilitate some river ecosystems. Of South

Africa's 222 river ecosystem types, 43% are Critically Endangered, 19% are Endangered, 2% are Vulnerable, and 36% are of Least Concern (Figure 6.3a).

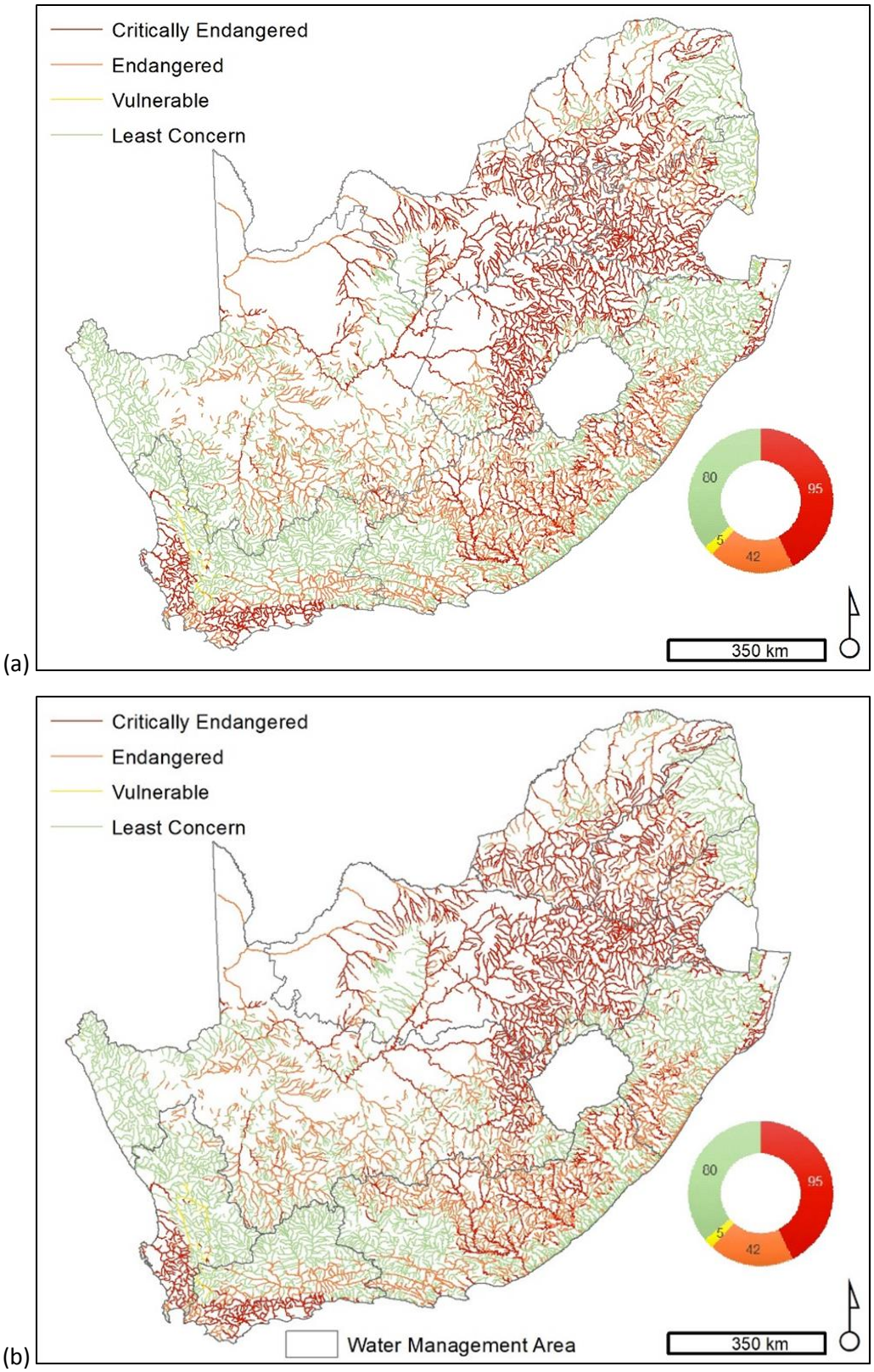


Figure 6.2. Ecosystem Threat Status for river ecosystem types with (a) provincial boundaries and (b) Water Management Areas (WMAs). *Rivers in a good condition (A or B ecological category) which contain Critically Endangered or Endangered ecosystem types are vital for achieving South Africa's goal for freshwater ecosystem conservation (Box 6.1). The inset doughnut shows the number of ecosystem types per threat category.*

ETS also varies across geomorphological zones (i.e. slope categories). For example, 67% of ecosystem types in lowland rivers are Critically Endangered compared to only 25% of ecosystem types in mountain streams (Figure 6.3b). This reflects a global trend where productive lowland areas are often subject to intense land and water use pressure, and are also often the areas that are least conserved (Pressey 1994). In addition, this trend in ETS increases as one proceeds from mountain streams, through foothill streams to lowland rivers (Figure 6.3), which is arguably a reflection of multiple pressures accumulating from river source to sea (Allan 2004).

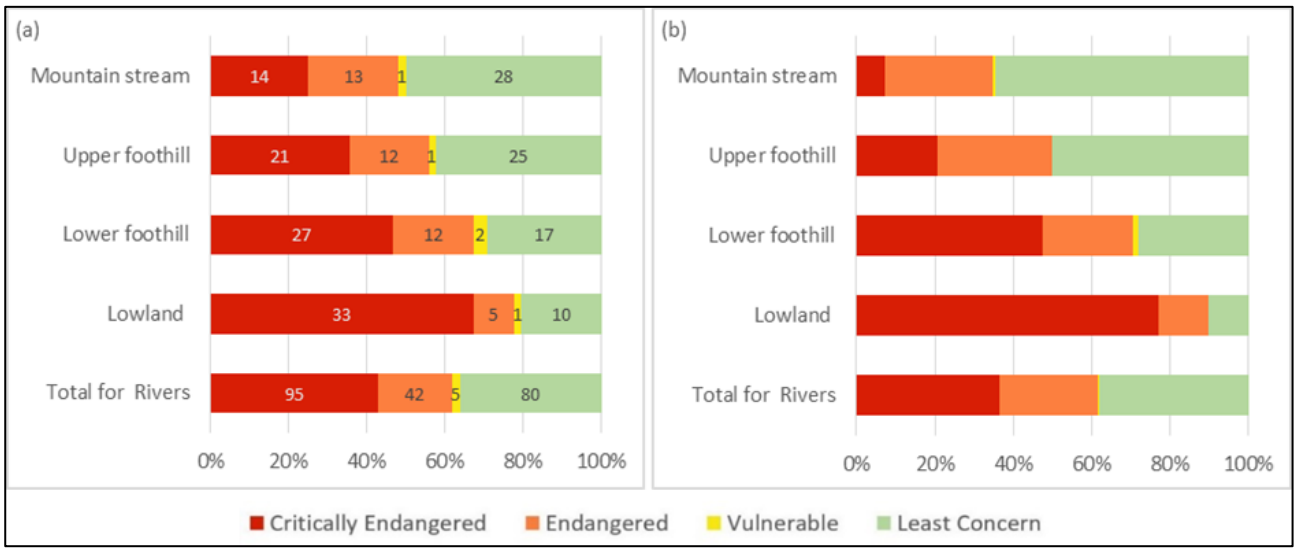
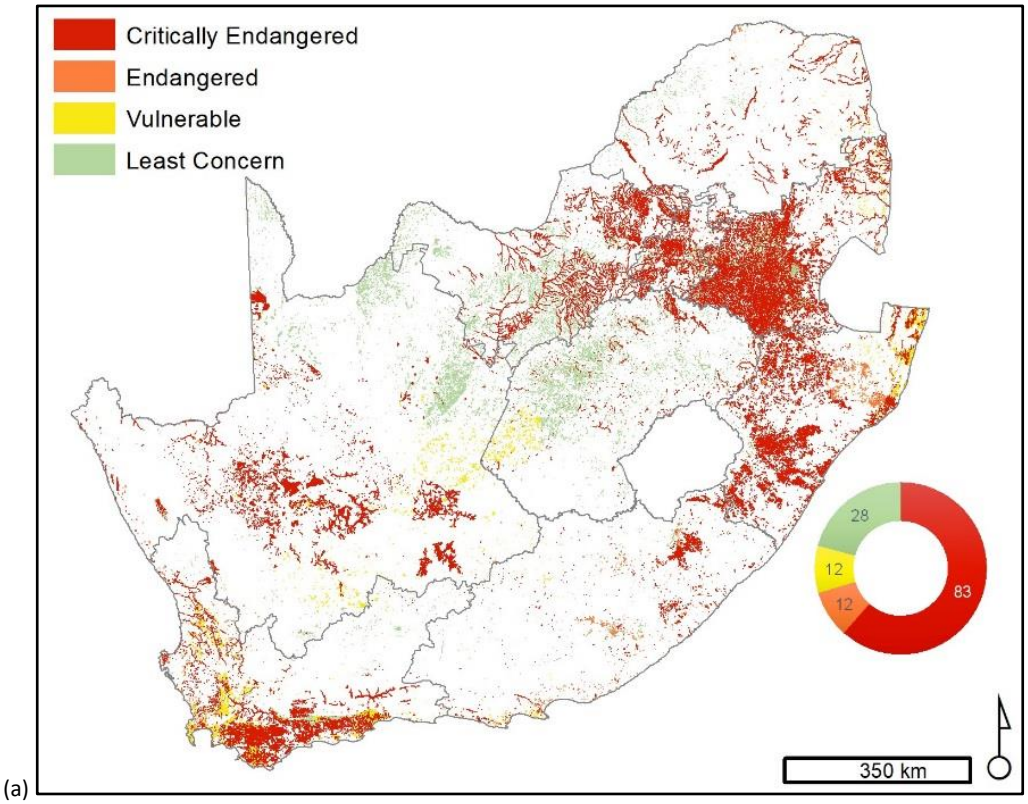


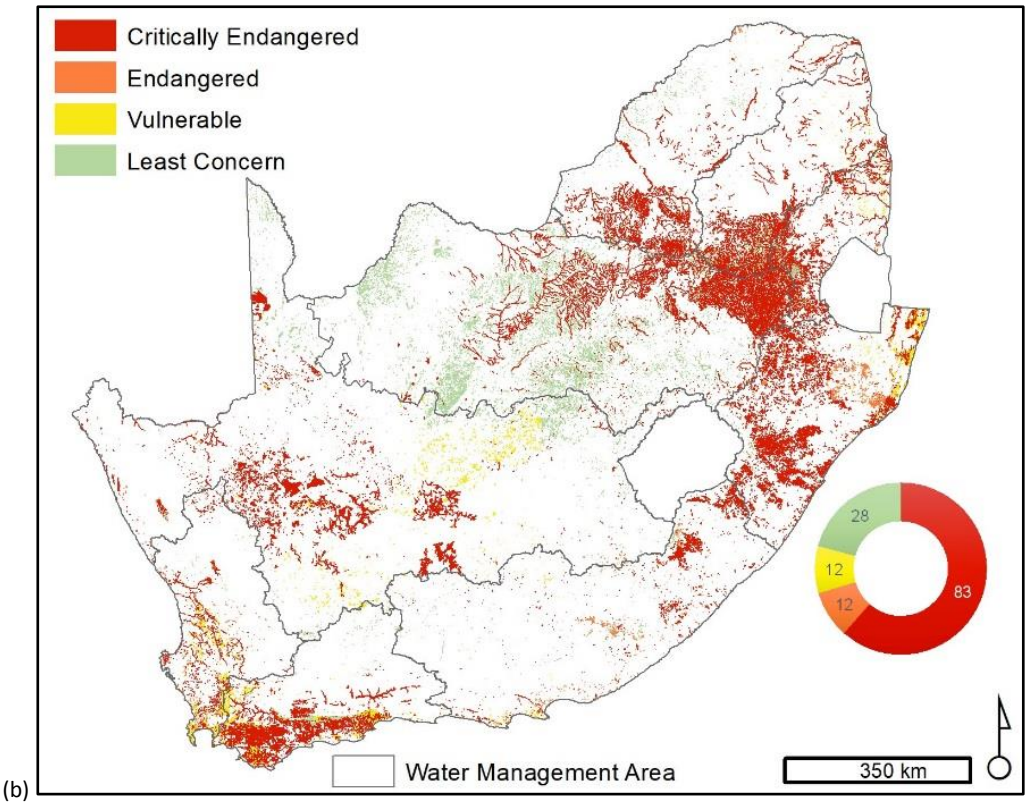
Figure 6.3. Summary of Ecosystem Threat Status (ETS) for river ecosystem types and per geomorphological zone (i.e. slope category). *(a) The percentage of river ecosystem types per threat category (labelled with actual value) with the total for all river ecosystem types (labelled with actual value) at the bottom, where the percentage (%) of river ecosystem types is calculated as the number of ecosystem types in the ETS category expressed as a percentage of the total number of ecosystem types (n = 222). CR, EN, VU and LC refer respectively to Critically Endangered, Endangered, Vulnerable and Least Concern ecosystems. (b) The percentage of river length (km) within each threat category with the total length for all rivers at the bottom – providing an indication of the relative extent of each category.*

ETS of inland wetland ecosystem types

Critically Endangered ecosystems (CR) are primarily distributed in large parts of the Gauteng Province, the western half of the Mpumalanga Province the KwaZulu-Natal Province, the central parts of the Northern Cape Province and the southern part of the Western Cape Province (Figure 6.4). It is important to understand that an inland wetland ecosystem type can include a range of ecological conditions, however, it will have only a single ETS assigned to it. For example, the 'Bushmanland Bioregion Depression' inland wetland ecosystem type, which includes Hakskeenpan in the Kalahari region, has about 16% of the total extent of the wetlands in a natural and near-natural ecological condition (A/B ecological category), almost 34% in a moderately modified condition (C ecological category) and 50% in a heavily to severely/critically modified (D/E/F ecological category) ecological condition. The inland wetland ecosystem type is listed as Critically Endangered (CR) based on the percentage of natural and near-natural extent being below the biodiversity target of 20% of the full spatial extent of this inland wetland ecosystem type.



(a)



(b)

Figure 6.4. Ecosystem Threat Status (ETS) for (a) inland wetland ecosystem types (a) per province and (b) per Water Management Area (WMA). *Inland wetlands in a good condition which contain Critically Endangered or Endangered ecosystem types are vital for achieving South Africa's biodiversity goal. The outlines around wetland polygons in (a) have been accentuated for visual purposes. ETS categories include Critically Endangered (CR), Endangered (EN), Vulnerable (VU) and Least Concern (LC) ecosystems. (The boundaries of the wetlands have been enhanced (0.5) to enable better visualisation.). The inset doughnut shows the number of ecosystem types per threat category.*

It is crucial that ecosystem types which are threatened should maintain their current extent of natural and near-natural ecological condition to meet the South Africa's ecosystem goal for freshwater conservation (Box 6.1).

Vulnerable ecosystems (VU) shows distributions in between CR and EN ecosystems, most noticeably in the eastern parts of the Mpumalanga and KwaZulu-Natal provinces, the western part of the Free State and eastern part of the Northern Cape provinces, as well as in the western part of the Western Cape. Three provinces show wide distributions of LC ecosystems: the north-western part of the Free State Province, the western half of the North West Province and the eastern to northern third of the Northern Cape Province.

A large proportion of the inland wetland ecosystem types (80%) are threatened (Figure 6.5). Of South Africa's 135 inland wetland ecosystem types, 83 (62%) are Critically Endangered, 12 (9%) are Endangered, 12 (9%) are Vulnerable and 28 (21%) of Least Concern. The limitations associated with the input datasets used as well as the modelling of ecological condition are discussed in Section 6.1.2.

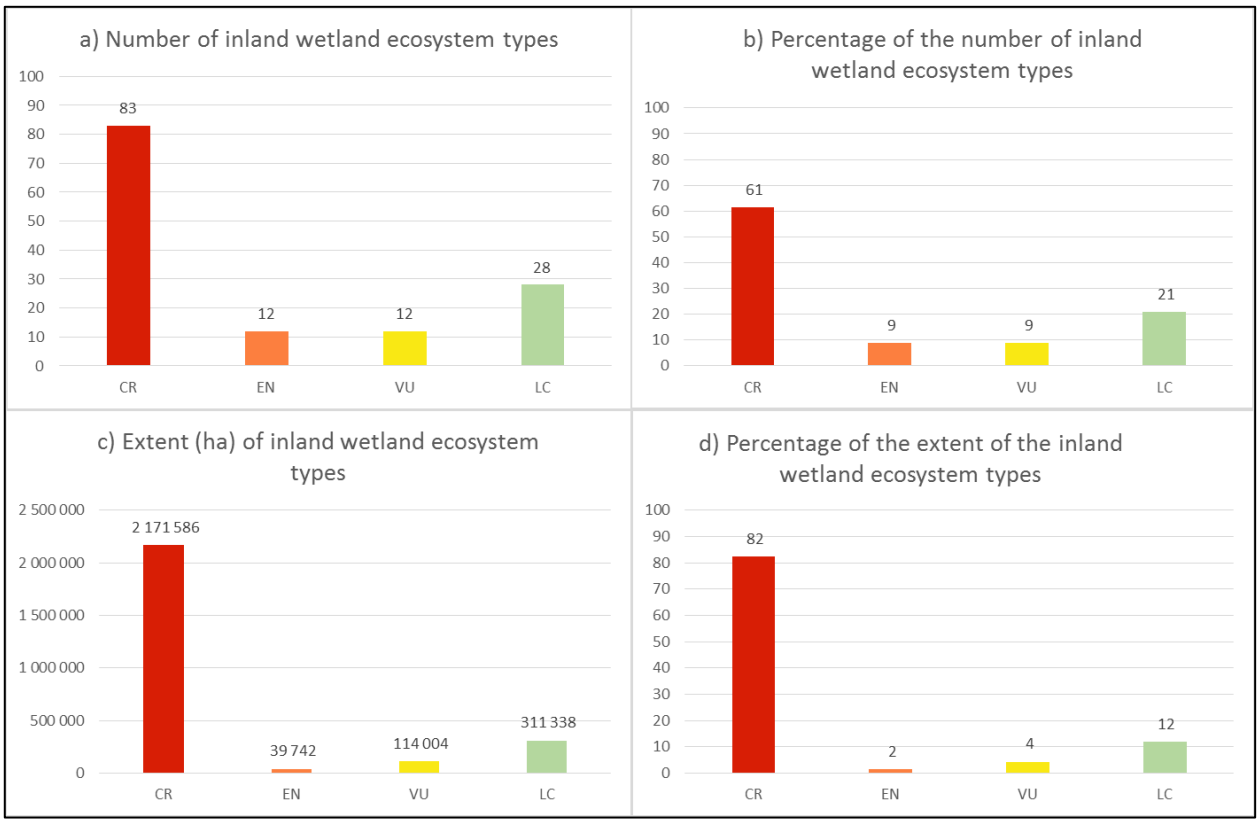


Figure 6.5. Summary of the Ecosystem Threat Status (ETS) for inland wetland ecosystem types: (a) according to the number of ecosystem types threatened and (b) percentage of the number of ecosystem types; the extent in hectares (c) and the percentage of extent (d). *The percentage (%) of ecosystem types was calculated as the number of ecosystem types in the ETS category expressed as a percentage of the total number of ecosystem types (n = 135). Similarly, the percentage (%) of vegetation bioregions was calculated using the number of vegetation bioregions in each category, where total number of vegetation bioregions = 36. ETS categories include Critically Endangered (CR), Endangered (EN), Vulnerable (VU) and Least Concern (LC) ecosystems.*

Inland wetland ecosystem types in at least four vegetation bioregions were found to be 100% Critically Endangered, namely the 'East Coast Renosterveld', 'Seashore vegetation', 'West Coast Renosterveld' and 'West Strandveld Bioregions' (Figure 6.6). Inland aquatic ecosystems in the 'Seashore vegetation' and 'West Strandveld Bioregions' would very likely be aquifer dependent ecosystems, however, these systems needs to be evaluated to assess whether they are indeed different from ecosystem types in adjacent vegetation bioregions or whether they should be evaluated as coastal (not estuarine) ecosystems (see Harris *et al*. 2019). The representation and ecological condition of inland wetlands within the 'East Coast Renosterveld' and 'West Coast Renosterveld' bioregions should be investigated to determine whether they are truly Critically Endangered.

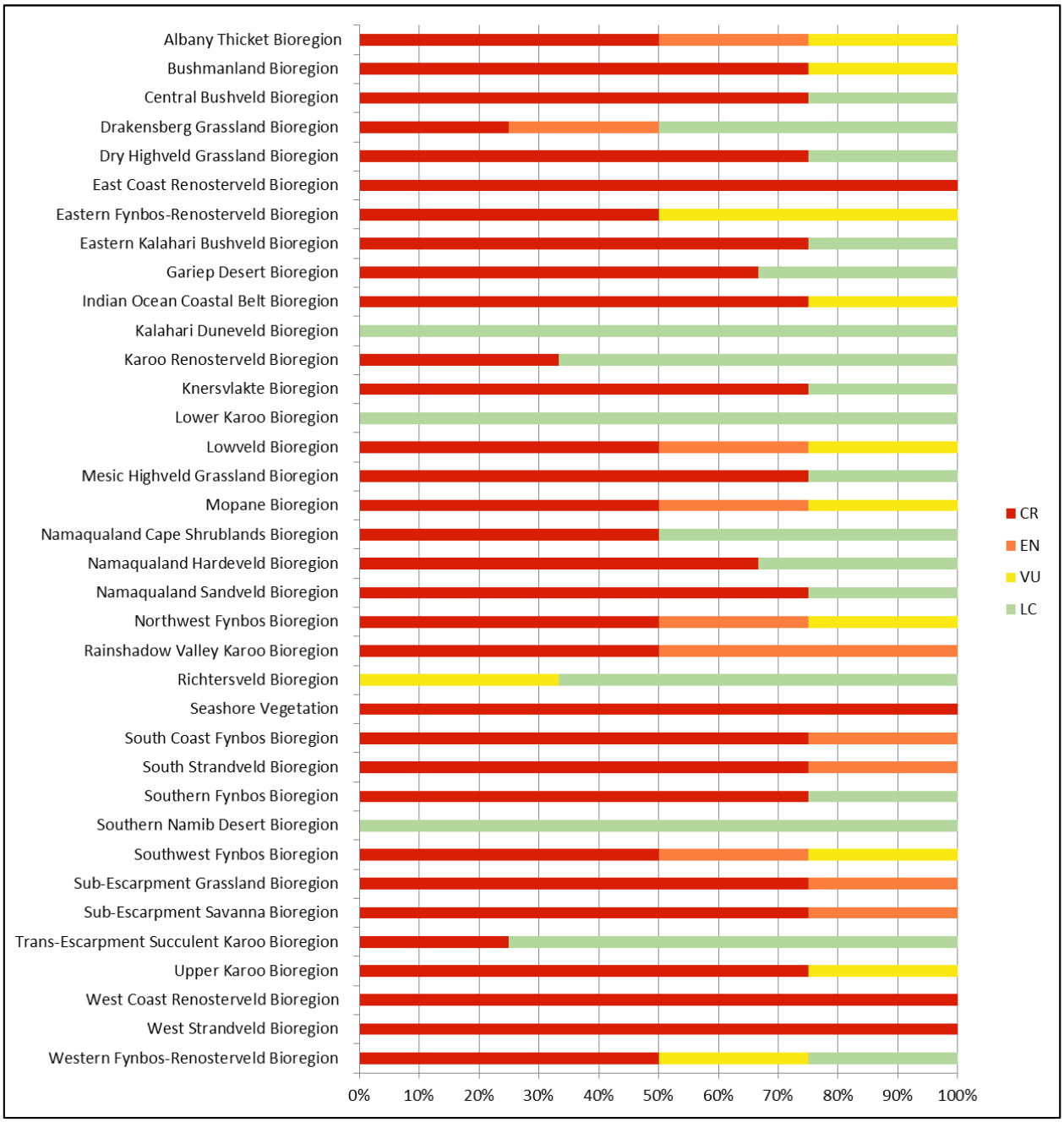


Figure 6.6. Summary of the Ecosystem Threat Status (ETS) within each inland wetland bioregion. *ETS categories include Critically Endangered (CR), Endangered (EN), Vulnerable (VU) and Least Concern (LC) ecosystems.*

In contrast, two vegetation bioregions are classified as least concern (100%), namely the arid Lower Karoo' and 'Southern Namib Desert' Bioregions. For five of the inland vegetation bioregions, a large proportion (≥ 50%) is still of least concern, including the 'Drakensberg Grassland', 'Karoo Renosterveld', 'Namaqualand Cape Shrublands', 'Richtersveld' and 'Trans-Escarpment Succulent Karoo' Bioregions. The majority of inland vegetation bioregions are, however, largely threatened, particularly those in the semi-arid regions, as opposed to the arid regions. Pressures in the arid regions, such as overgrazing and invasive plant species, are not represented in the base layers used for modelling ecological condition of inland wetlands.

More than 93% of the valley-bottom and floodplain HGM units of inland wetlands are threatened, followed by 71% of seeps and 61% of depressions (Figure 6.7). Van Deventer *et al*. (in review) found < 11% of inland wetland types to be naturally inundated, using the land cover data of 2014 as assessment layer. Very often the open water systems are associated with intermittently to seasonally and permanently inundated depressions, whereas the seeps, valley-bottom and floodplains systems were found to be largely vegetated or arid. Land conversion would not take place in permanently or seasonally inundated wetlands, whereas the likelihood to convert or use land increase towards temporary inundated or saturated wetlands. Therefore, using land cover as a surrogate to inform ecological condition, favours HGM units such as valley-bottom, floodplain and to some degree seeps over depressions

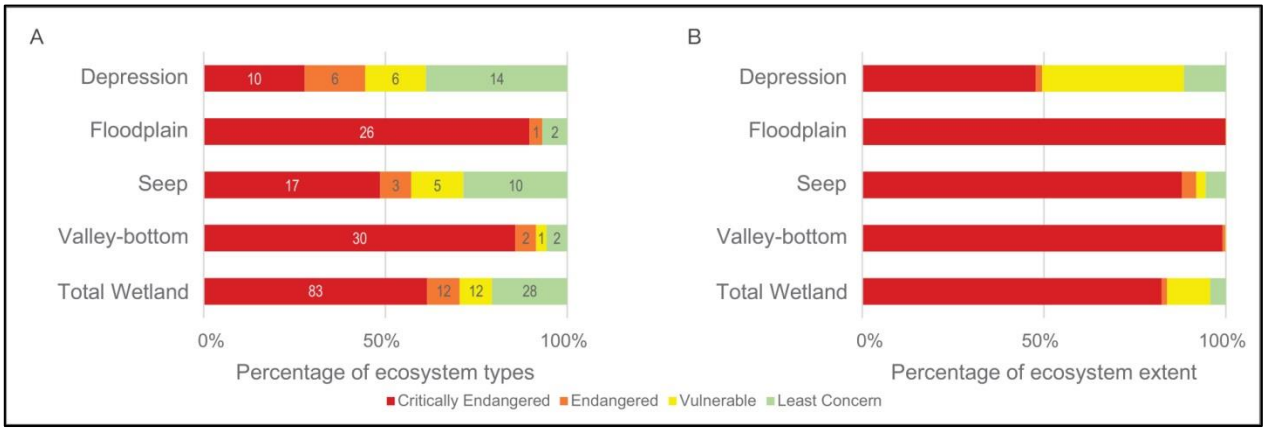


Figure 6.7. Summary of the Ecosystem Threat Status (ETS) within each hydrogeomorphic wetland unit. *(a) The percentgae of ecosystem types per threat category (labelled with actual value) with the total for all inland wetland at the bottom (n = 135); and (b) the percentage of inland wetland area within each threat category with the total for all inland wetlands 2,6 million ha) according to the corresponding hydrogeomorphological unit. ETS categories include Critically Endangered (CR), Endangered (EN), Vulnerable (VU) and Least Concern (LC) ecosystems.*

The extent of either depressions, floodplains, seeps or valley-bottoms mapped for each vegetation bioregion totals at least 100 ha. For eight wetland ecosystem types, however, the wetland extent consists of < 50 ha, resulting in biodiversity targets which totalled < 10 ha (Table 6.1). Although the majority of the vegetation bioregions are located in arid regions, the reason for the small extent range from underrepresentation of ecosystem types, to mapping errors and uncertainty in bioregion boundaries. **The Gariep Desert seeps and the Namaqualand Cape Shrubland depressions, may well be unique, restricted in range, while Critically Endangered and Not Protected. It is also likely that depressions from the Namaqualand Hardeveld Bioregion are also range restricted. Hence, these three ecosystem types should be prioritised for in-field verification to assess whether they can be red listed.** The remaining six of the inland wetland ecosystem types with a small extent are not necessarily range restricted and should therefore receive careful consideration during future conservation planning.

Table 6.1. Recommendations for assessing whether the eight inland wetland ecosystem types with extents <50 ha are unique and range restricted. *Confidence levels were cited from Van Deventer et al. (2018). CR = Critially Endangered; ETS = Ecosystem Threat Status; EPL = Ecosystem Protection Level; LC = Least Concern; NP = Not Protected.*

Ecosystem type	# of polygons	Extent (ha)	ETS	EPL	Confidence of mapping extent and HGM units	Recommendation
Gariep Desert depressions	1	14.2	LC	NP	Low (1)	Undermapping of ecosystem type.
Gariep Desert seeps	1	19.2	CR	NP	Low (1)	Undermapping of ecosystem type.
Kalahari Duneveld valley-bottom wetlands	1	33.9	LC	NP	Low (1)	The bioregion is a narrow corridor along the Molopo River. Verify whether a valley-bottom is formed along these reaches of the river.
Namaqualand Cape Shrublands depressions	11	7.4	CR	NP	Low to Medium (2)	This vegetation bioregion is quite small (696 ha) and is completely surrounded by the Namaqualand Hardeveld Bioregion (hosting 78 depressions with a total extent of 91 ha). These systems are believed to be unique (Dr Sieben, *pers. comm.*) owing to their location on different geological strata and elevations. The completeness of the depressions should be investigated. One of the depression polygons transcends the border between these two vegetation bioregions, and in-field verification is required to ensure confirm its association.
Namaqualand Cape Shrublands floodplains	1	1.5	LC	NP	Medium (3)	In-field verification is required to assess whether this ecosystem type is unique and restricted in range.
Seashore vegetation floodplain	1	0.29	CR	NP	Low to Medium (2)	The boundary of the vegetation bioregion has cut through a floodplain polygon which transcended the Seashore vegetation and Southwest Fynbos Bioregions, resulting in a sliver. It should be decided whether the Seashore vegetation bioregion would host any inland aquatic ecosystems separate from adjacent bioregions.
Southern Namib Desert depressions	3	16.3	LC	NP	Low (1)	Undermapping of ecosystem type.
Trans-escarpment succulent Karoo	1	5.9	LC	NP	Low (1)	A section of this wetland polygon has been split into a floodplain whereas the majority is mapped as a valley-bottom wetland, which therefore appears to be a mapping error.

Of the remaining 127 (of total 135) inland wetland ecosystem types where the biodiversity target is > 10 ha, 80 types (63% of total number of types) have a shortfall of 50% and 72 (57% of total number of types) a shortfall of more than 75% of the biodiversity target extent (Figure 6.8). The **Bushmanland Bioregion Depression** type had the largest shortfall in extent (> 65 000 ha), is Critically Endangered and Not Protected. The second highest shortfall of extent to the biodiversity target is the Valley-bottom wetlands in the Mesic Highveld Grassland Bioregion, totalling nearly 40 000 ha required. The ETS for the **Mesic**

Highveld Grassland Bioregion Valley-bottom type is CR and the EPL is not protected. Another six ecosystem types require approximately 20 000 ha to reach their biodiversity target. These statistics emphasize the huge extent of inland wetland ecosystem types that should be considered for a Protected Areas Expansion Strategy or other means of protection or alternatively rehabilitation. The majority of vegetation bioregions are, however, largely threatened, particularly those in the semi-arid regions, as opposed to the arid regions. A number of ecosystem types showed a large shortfall to the biodiversity target as a result of being situated in extensive vegetation bioregions. These include the Bushmanland Bioregion Depression type (> 65 000 ha) and Valley-bottom wetlands in the Mesic Highveld Grassland Bioregion (nearly 40 000 ha).

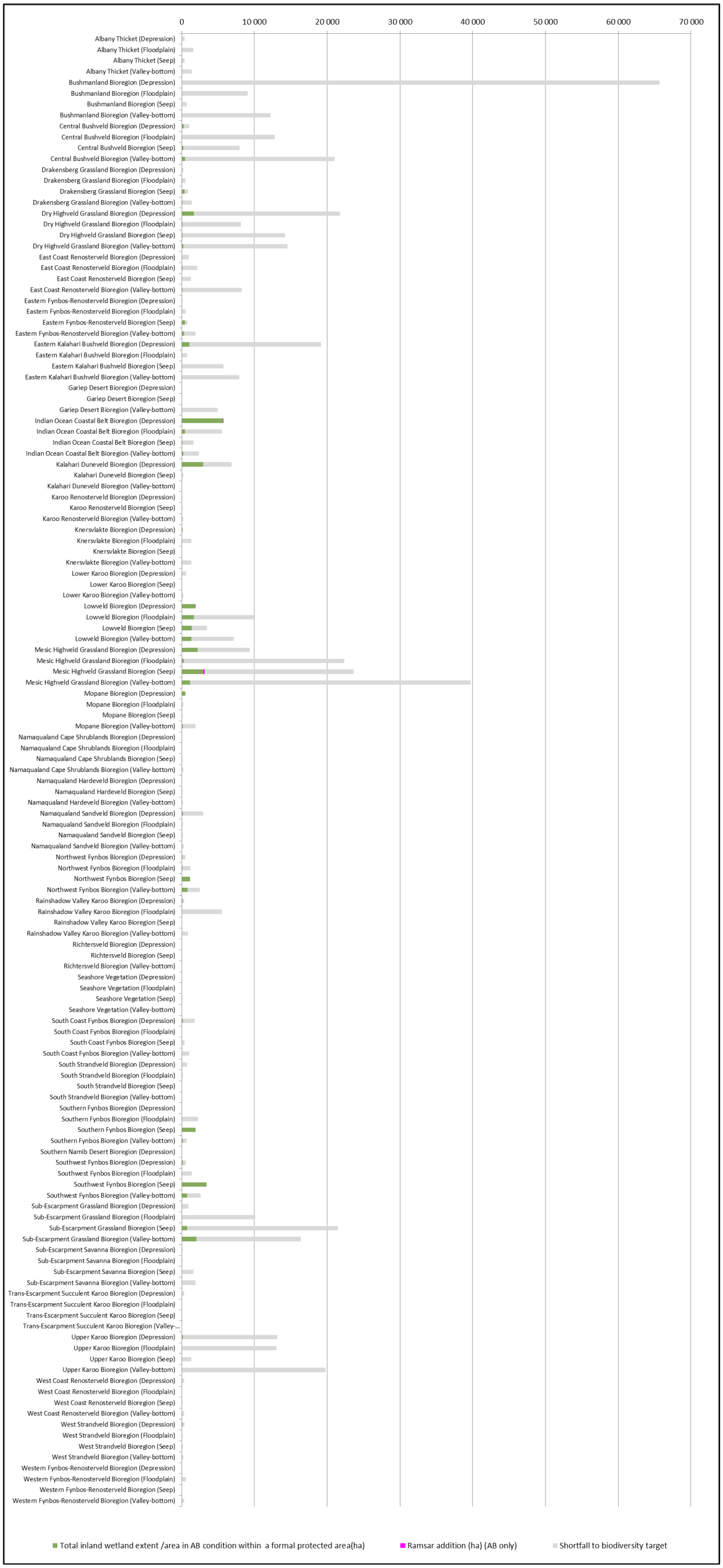


Figure 6.8. Shortfall of each inland wetland ecosystem type in extent (ha) to the 20% biodiversity target.

6.1.3 Ecosystem Threat Status trends

This assessment did not assess trends for inland wetland ecosystems, owing to the limitations in comparability between the former NSBA 2004 and NBA 2011. Differences between these national assessments are discussed in more detail in Section 6.6 of this report.

6.1.4 Ecosystem Threat Status limitations in this environment

- Inland wetland depressions were found to be less threatened compared to the three other hydrogeomorphic (HGM) units. This result stem from the fact that the natural land cover dataset classifies these as natural. Pressures on depression HGM units are also poorly represented and it is likely that these systems are more impacted and threatened than portrayed here.
- For the majority of the country (69%), the extent and HGM unit of inland wetlands were indicated as 'Low', whereas only 24% of the country had a 'medium' confidence score (Van Deventer *et al*. 2018). The implications may be that a lot of inland wetlands have not been properly mapped, which could change the ETS results completely. For example, if more inland wetlands are mapped, and these are found to be in a natural or near-natural ecological condition, it could contribute to the biodiversity target and render some inland wetland ecosystem types not threatened anymore.
- We further concur with the findings and recommendations in the NBA 2011 (Nel & Driver 2012:96): 'There is a range of uncertainty in the setting of thresholds used for devising the different ETS categories. These include issues such as the ability to identify ecological thresholds, the variation in the response of different species or ecosystems to the same disturbances, and the variation in response to thresholds at different scales (Huggett 2005). Empirical data for thresholds of ecosystem status categories (20%, 35% and 60%; Table 3.1) are needed. This research should improve our scientific understanding of river ecology, ecosystem functioning, and the response of ecological variables to disturbances. Additionally, uniform thresholds do not reflect the relative responses of different ecosystems to the same disturbances. Thresholds used in this assessment should therefore be refined as new research becomes available.'

6.2 Ecosystem Protection Level

6.2.1 Ecosystem Protection Level calculation method

Protected areas are crucial for the ecological sustainability of rivers and inland wetlands and provide resilience to species and humans against climate change impacts (Nel & Driver 2012). Protected areas may be considered less effective if excessive water abstraction takes place or the incoming rivers are severely impacted upstream of the protected area (Mancini *et al*. 2005). Protected areas may result in a number of benefits within a catchment, serving as a catalyst for effective integrated catchment management (Nel & Driver 2012).

Ecosystem Protection Levels (EPLs) were assessed by examining the contribution that protected areas make (Section 5.4, Table 5.12) to achieving the biodiversity target of each river ecosystem type. However, it is often argued that partial inclusion of rivers in protected areas does not guarantee protection from impacts outside protected area boundaries that can still have negative consequences for freshwater biodiversity within (Mancini *et al*. 2005). Protected areas were defined as areas of land or sea that are formally

protected in terms of the Protected Areas Act and managed mainly for biodiversity conservation. This includes state-owned protected areas (e.g. national parks and nature reserves) and contract protected areas (e.g. private protected areas through for example formal biodiversity stewardship) (SANBI 2016). A single integrated dataset of protected areas (Section 5.4, Figure 5.10) were collated for NBA 2018 (Skowno *et al*. 2019). This data layer, buffered with a 500 m buffer to improve spatial inaccuracy, was combined with the river ecosystem types in a natural or near-natural condition (i.e. A or B ecological category) to calculate the length of each river ecosystem type under protection. It differed from the dataset employed in the NBA 2011 which only included formal protected areas. No differentiation was made between rivers that are protected on both river banks and ones that form the boundary of the protected area (i.e. therefore only protected on one side) (Nel & Driver 2012).

For each river ecosystem type, the length in a natural or near-natural ecological condition and under protection was expressed as a percentage of the length required by the biodiversity target. The latter was calculated as 20% of the total length for each river ecosystem type. This biodiversity target was used for representing inland aquatic ecosystems (Roux *et al*. 2006; Nel & Driver 2012). The biodiversity target is the minimum proportion of each ecosystem type that needs to be kept in a natural or near-natural state in the long term in order to maintain viable representative samples of all ecosystem types and the majority of species associated with those ecosystems (Reyers *et al*. 2007). In South Africa for example, a river ecosystem with a total length of 200 km would have a biodiversity target of 10 km against which its length in a natural or near-natural condition within protected areas was assessed.

An EPL category was then assigned, where Well Protected river ecosystem types were determined as those with ≥ 100% of their biodiversity target in protected areas and in a natural or near-natural condition. Likewise, Moderately Protected and Poorly Protected river ecosystem types have at least 50% and 5% of their target in protected areas and in a natural or near-natural condition; while not protected have < 5% (Table 6.2).

To assess the EPLs of inland wetland ecosystem types, the spatial data of protected areas (See Section 5.4 for more information) and the ecosystem types in a natural or near-natural (PES = 'A/B') were combined. Although the datasets used different from those of the NBA 2011, the methods and thresholds used were similar: For each ecosystem type, the spatial extent (area) were expressed as a percentage of the area required by the biodiversity target, therefore, 20% of the total spatial extent of each ecosystem type (Nel & Driver 2012). Ecosystem types were considered Well Protected if ≥ 100% of the extent of the ecosystem was within the biodiversity target and in a natural to near-natural ecological condition (Table 6.2). The inland wetland ecosystem types were classified as Moderately Protected if at least 50% of the extent was within the biodiversity target, otherwise it was classified as Poorly Protected if < 50% and Not Protected if < 5% (Table 6.2).

Table 6.2. Ecosystem Protection Levels (EPLs) with biodiversity targets and ecological condition for river and inland wetland ecosystem types*. *PES = Present Ecological State.*

EPL	Thresholds applied to river ecosystems	Thresholds applied to inland wetland ecosystems
Well Protected	Length of river ecosystem type in natural or near-natural ecological condition (PES = A or B) with ≥ 100% of the biodiversity target located within a formal or *de* facto protected area.	Extent (ha) of inland wetland ecosystem type in natural or near-natural ecological condition (PES = A or B) with ≥ 100% of the biodiversity target located within a formal or *de* facto protected area.
Moderately Protected	Length of river ecosystem type in natural or near-natural ecological condition (PES = A or B) with between 50 and 99% of the biodiversity target located within a formal or *de* facto protected area.	Extent (ha) of inland wetland ecosystem type in natural or near-natural ecological condition (PES = A or B) with between 50 and 99% of the biodiversity target located within a formal or *de* facto protected area.
Poorly Protected	Length of river ecosystem type in natural or near-natural ecological condition (PES = A or B) with between 5 and 49% of the biodiversity target located within a formal or *de* facto protected area.	Extent (ha) of inland wetland ecosystem type in natural or near-natural ecological condition (PES = A or B) with between 5 and 49% of the biodiversity target located within a formal or *de* facto protected area.
Not Protected	Length of river ecosystem type in natural or near-natural ecological condition (PES = A or B) with ≤ 5% of the biodiversity target located within a formal or *de* facto protected area.	Extent (ha) of inland wetland ecosystem type in natural or near-natural ecological condition (PES = A or B) with ≤ 5% of the biodiversity target located within a formal or *de* facto protected area.

** No known severe impact of a pressure, such as excessive water abstraction or invasive species, should be known for the protected area. These cases were downgraded to a lower EPL.*

6.2.2 Ecosystem Protection Level results

EPL of river ecosystem types

The protection level analyses revealed that only 14% of the country's river length occurs in protected areas with 43% of these in a natural or near-natural condition (A or B ecological category), 36% moderately modified (C ecological category), and 21% heavily to intensively modified (D, E or F ecological category). It is evident that occurrence in a protected area does not necessarily guarantee conservation of riverine biodiversity, but appropriate land management activities could yield positive results. Gaps in protection levels of river ecosystem types are particularly evident in the in northern interior of the country (Figure 6.9), reflecting the geography of the current protected area network (Figure 5.10). In addition, only 13% of the river ecosystem types in South Africa are Well Protected in the current protected area system while 36% are not protected at all (Figure 6.10). EPL for each river ecosystem type is provided in Annexure D.

It is apparent that while state owned and managed national parks and provincial nature reserves make up the majority of the protected area estate, protected area expansion opportunities through formal provincial and national biodiversity stewardship programmes can increase the country's protection area network. These programmes provide mechanisms to proclaim Protected Areas Act compliant protected environments and nature reserves on private land, typically with a landowner as the management authority. It must also be noted that private nature reserves, proclaimed in terms of older provincial ordinance mostly before the mid 1990's, also contribute to the protected area estate. Although these reserves are recognised in terms of the Protected Areas Act, they rarely have management plans or any restrictions on their title deeds, thus providing insufficient protection from for example habitat loss. However, it would be a worthwhile strategy to rehabilitate or upgrade key areas to an improved protected

area status. Currently, land purchases by the state are mostly lacking in protected area expansion in the country (Skowno *et al*. 2019).

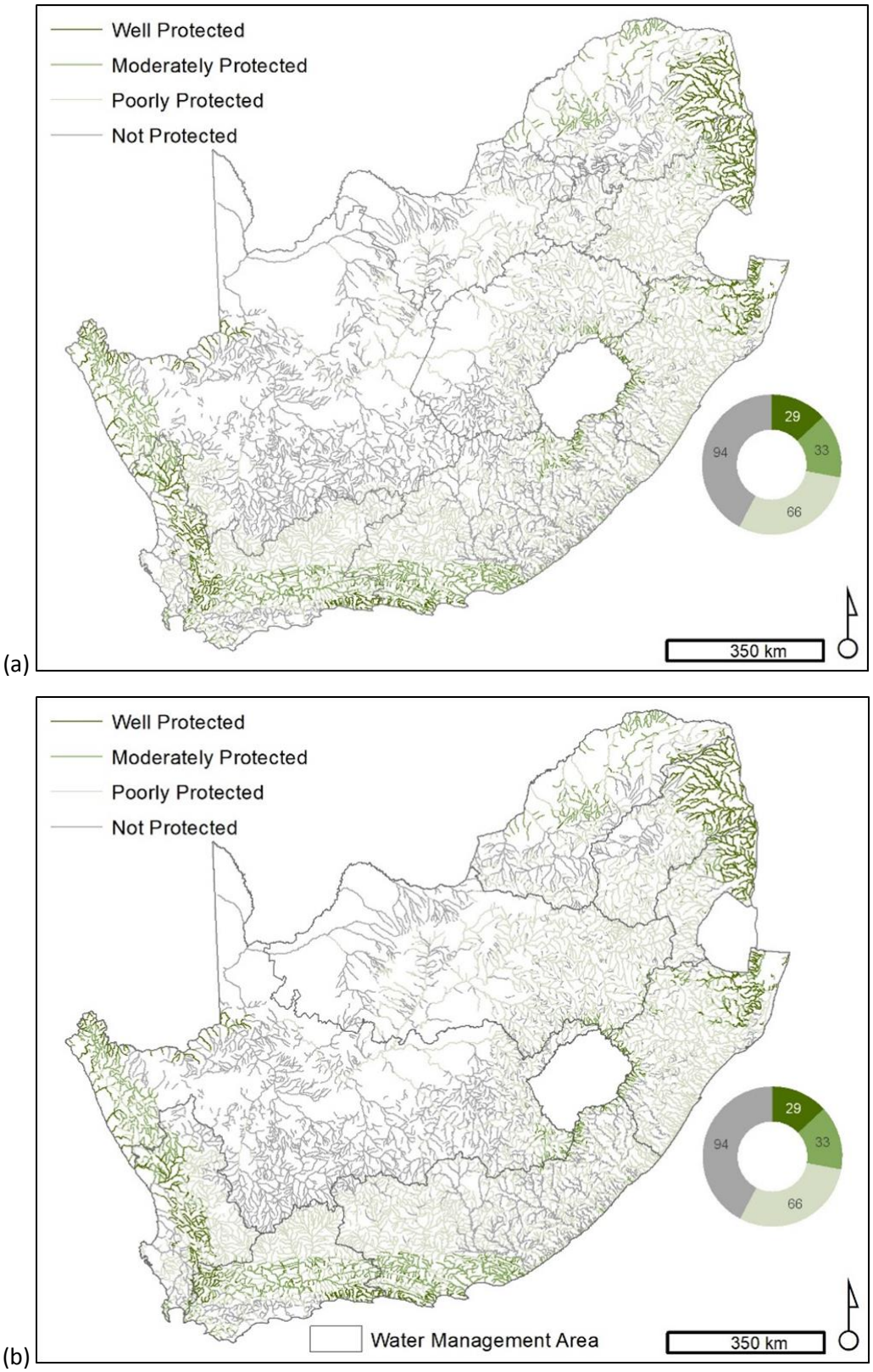


Figure 6.9. Ecosystem Protection Levels for river ecosystem types (a) per province and (b) per Water Management Area (WMA). *Well Protected, Moderately Protected, Poorly Protected river ecosystem types have at least 100%, 50%, 5% of their biodiversity target in protected areas and in natural or near-natural ecological condition; Not Protected river ecosystem types have < 5%. The inset doughnut shows the number of ecosystem types per protection level.*

In terms of river ecosystem types by river slope category, lower foothill and mountain stream geomorphic zones have the highest proportion of Well Protected river ecosystem types (16%), whereas lowland rivers have the highest proportion of river ecosystem types Not Protected, 61% (Figure 6.10a). Similar observations were made in the NSBA 2004 and NBA 2011 although the protected area and river layer datasets differed (Nel & Driver 2012). This result is consistent to a global trend for lowland productive areas (Pressey 1994; Brierley & Fryirs 2005), which indicate that the lowlands are the most threatened of the slope categories and also the least protected (Figure 6.10).

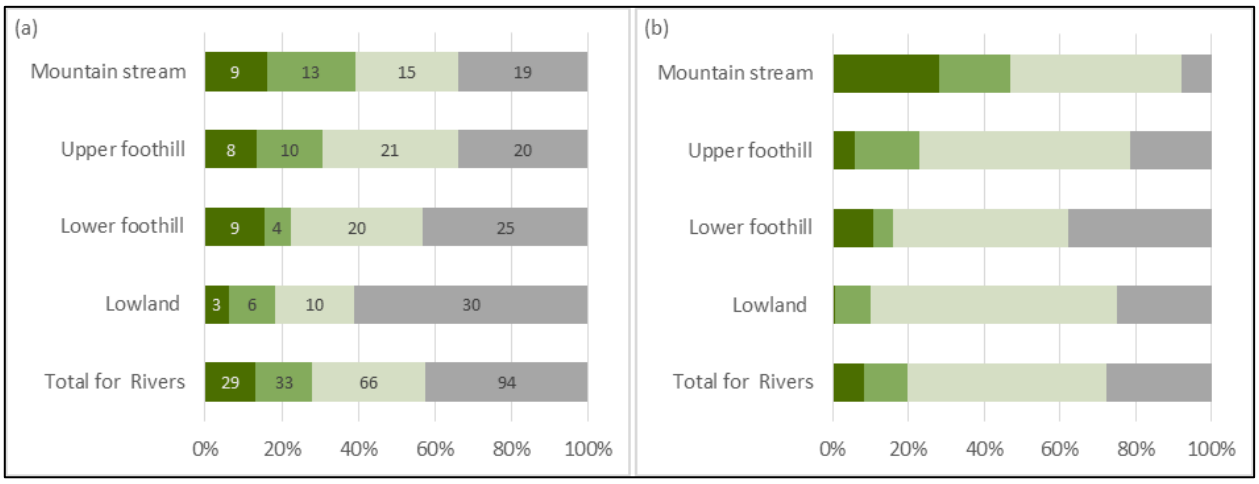
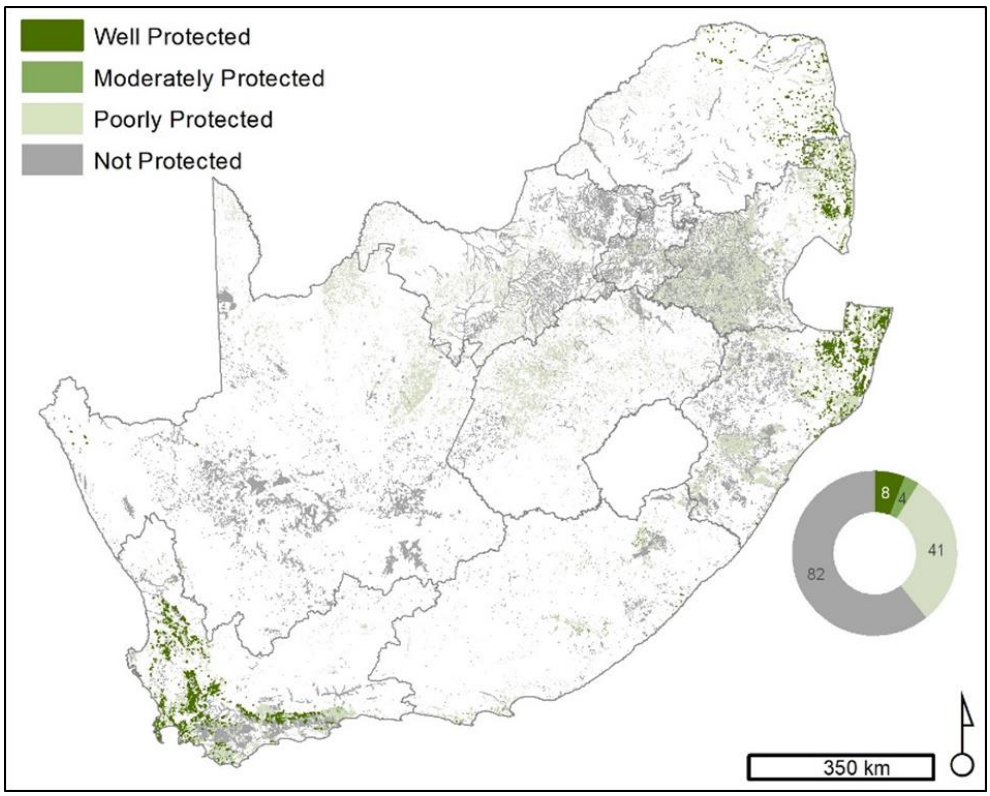


Figure 6.10. Summary of Ecosystem Protection Levels (EPLs) for river ecosystem types and per geomorphological zone (i.e. slope category). *(a) The percentage of river ecosystem types per EPL category (labelled with actual value) with the total for all river ecosystem types at the bottom (labelled with actual value), where percentage is calculated as the as the number of ecosystems in the ecosystem protection level category expressed as a percentage of the total number of ecosystem types (n = 222). Well Protected, Moderately Protected, and Poorly Protected river ecosystem types have at least 100%, 50%, and 5% of their biodiversity target in protected areas and in good condition; Not Protected river ecosystem types have < 5%. The total percentage values for the river ecosystem types are WP = 13%, MP = 15%; PP = 30% and NP = 42%. (b) The percentage of river length (km) within each category with the total length for all rivers at the bottom – providing an indication of the relative extent of each category.*

EPL of inland wetland ecosystem types

Well Protected wetland ecosystem types show scarse distribution in the eastern part of the Mpumalanga Province (within the Kruger National Park), the Maputaland Coastal Plain in the KwaZulu-Natal Province (situated in the iSimangaliso Wetland Park World Heritage Site) and parts of the Western Cape (Figure 6.11). Extensive areas of inland wetland ecosystem types are Not Protected, corresponding to regions where the inland wetlands show to be Critically Endangered too (Figure 6.12).

(a)



(b)

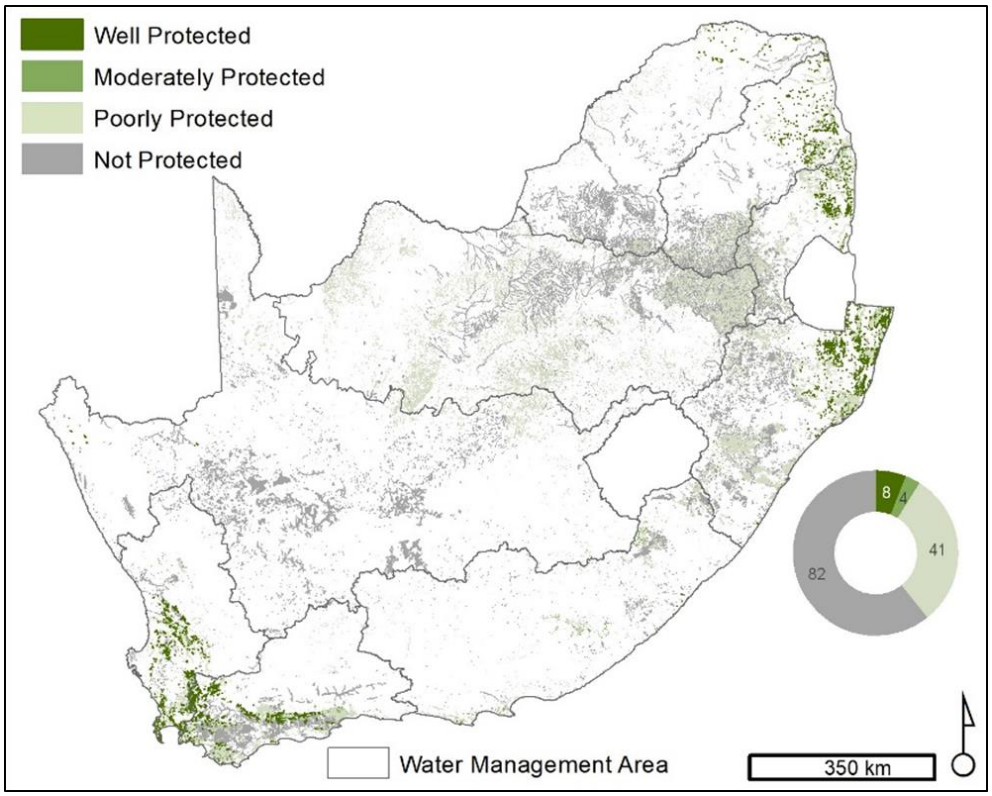


Figure 6.11. Ecosystem Protection Levels for inland wetland ecosystem types. *Well Protected, Moderately Protected, Poorly Protected inland wetland ecosystem types have at least 100%, 50% and 5% respectively, of their biodiversity target in protected areas and in a natural to near-natural condition; Not Protected inland wetland ecosystem types have < 5%. (The boundaries of the wetlands have been enhanced (0.5) to enable better visualisation). The inset doughnut shows the number of ecosystem types per protection level category.*

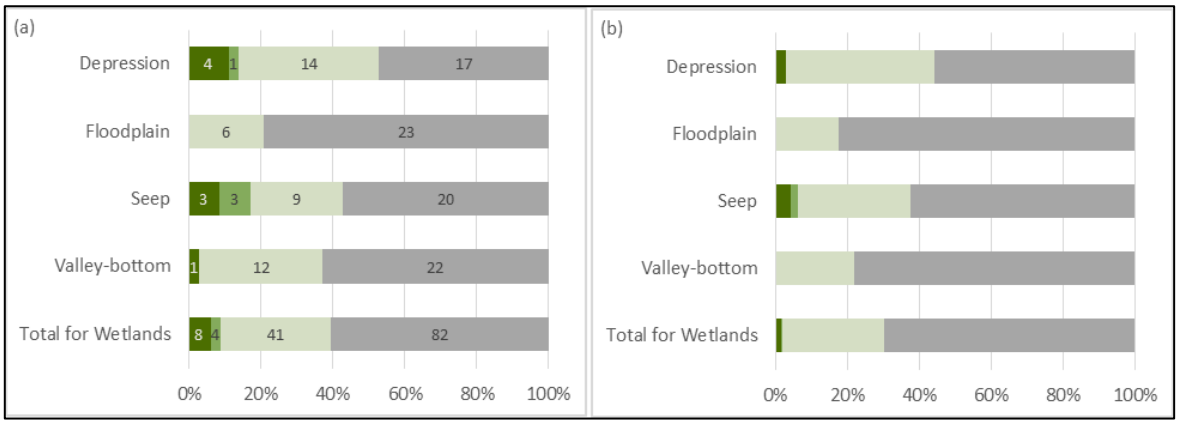


Figure 6.12. Summary Ecosystem Protection Levels (EPLs) for inland wetland ecosystem types and per hydrogeomorphic (HGM) unit. *Wetlands are severely under-protected with only 6% of inland wetland ecosystem types Well Protected. (a) The percentage of ecosystem types per category (labelled with actual value), where percentage is calculated as the number of ecosystem types in each EPL category expressed as a percentage of the total number of ecosystem types (n = 135). Well Protected, Moderately Protected, Poorly Protected inland wetland ecosystem types have at least 100%, 50% and 5% respectively, of their biodiversity target in protected areas and in a natural to near-natural condition; Not Protected inland wetland ecosystem types have < 5%; (b) the percentage of the extent of inland wetlands within each category with the total for all wetlands at the bottom – providing an indication of the relative extent of each category. In b, the total values for inland wetlands are WP = 5.9%, MP = 3%; PP = 30.4% and NP = 60.7%.*

In general, Ramsar sites that do not overlap with the formal protected area network adds another 936.6 ha (Table 6.3) of inland wetland extent, totalling 7.4% of the extent of all inland wetlands(irrespective of the ecological condition). The majority (> 78%) of the inland wetlands within the protected area network are in a poor ecological condition within the protected area network and Ramsar site, with <1.6% estimated to be in a natural or near-natural ecological condition (Table 6.3).

Table 6.3. Extent (ha) of inland wetlands within protected areas network and Ramsar site of South Africa. *Figures in brackets indicate the percentage of the protected area type out of the total extent of protected area types (formal protected areas and Ramsar sites).*

Protected Area Network (PAN) type:	Total extent of inland wetlands within the protected area network (ha); percentage of all inland wetlands within protected area network in brackets	A/B ecological condition	C & D/E/F ecological condition
PAN and Ramsar	194 332.7 (99.5%)	42 066.1 (21.6% *)	152 266.6 (78.4%)
Ramsar additional to PAs	936.6 (0.5%)	180.4 (19.3% *)	756.2 (80.7%)
Total	195 269.3 (7.4% **)	42 246.4 (1.6% **)	153 022.8 (5.8% **)

** Calculated as percentage of all inland wetlands within PAN and Ramsar;*

*** Calculated as percentage of all inland wetlands mapped in the National Wetland Map version 5*

A total amount of 180 ha of inland wetlands, in a natural or near-natural ecological condition, is conserved by Ramsar sites which are not within protected areas (Table 6.4). Most of these Ramsar areas protect a total extent of < 10 ha of individual wetland ecosystem types, except the Verloren Valei Nature Reserve, where the (remaining) Ramsar sites protect 160 ha of the Mesic Highveld Grassland Bioregion Seep type in a natural or near-natural ecological condition. The nomination and declaration of additional Ramsar sites

should be strategically planned for in order for this mechanism to effectively contribute to protection of inland wetlands in South Africa.

Considering that only 7% of inland wetlands are within the PAN and Ramsar sites, it is clear that South Africa has not met the Aichi target 11 which requires 17% for inland wetlands to be within protected areas.

Table 6.4. Extent of inland wetland ecosystem types (ha) in a natural or near-natural ecological condition (Present Ecological State or PES = A/B) within the section of Ramsar sites which are not formally protected.

Ramsar site (across) / Inland wetland ecosystem type (down):	Blesbokspruit	False Bay Nature Reserve	Kosi Bay	Lake Sibaya	Natal Drakensberg Park	St. Lucia System	Verloren Valei Nature Reserve	Total (ha)
Central Bushveld Bioregion (Seep)	0.8							0.8
Drakensberg Grassland Bioregion (Depression)					0.9			0.9
Drakensberg Grassland Bioregion (Seep)					1.2			1.2
Indian Ocean Coastal Belt Bioregion (Depression)			9.4			0.4		9.9
Indian Ocean Coastal Belt Bioregion (Floodplain)						0.0		0.0
Indian Ocean Coastal Belt Bioregion (Seep)			0.1	0.0		0.8		0.9
Indian Ocean Coastal Belt Bioregion (Valley-bottom)				0.5		2.1		2.6
Lowveld Bioregion (Depression)						1.0		1.0
Lowveld Bioregion (Floodplain)						0.6		0.6
Mesic Highveld Grassland Bioregion (Seep)							159.9	159.9
Sub-Escarpment Grassland Bioregion (Seep)					2.2			2.2
West Strandveld Bioregion (Depression)		0.4						0.4
Total (ha)	0.8	0.4	9.5	0.5	4.3	4.9	159.9	180.4

6.2.3 Ecosystem Protection Level trends

Owing to insufficient information on the historical ecological condition of rivers and inland wetlands, for the interval period during which protected areas have been observed to increase (see Skowno *et al.* 2019, Sections 6.4.1), a trend analysis for inland aquatics could not be back-casted for rivers and inland wetlands.

To date, 23 684.7 km of river extent and nearly 200 000 ha of the extent of inland wetlands are included in the protected area network and Ramsar Sites in South Africa (a 500 m buffer was applied to the rivers for this assessment). The Aichi target 11 for 2020, aimed for the inclusion of 17% of the extent of rivers and inland wetlands in the protected area network. This would mean that an additional 4 198 km (3%) of rivers and 450 600 ha (~10%) of inland wetlands should be within protected areas by 2020 for South Africa. Figure 6.13 show that the rate of including inland wetlands in protected areas have been on averrage 500 ha/year, whereas to meet the Aichi target 11 of 2020 by 2013, it should increase to an average of 45 000 ha/year.

These are merely for the extent of the ecosystems, and do not consider the landscape required to maintain their ecological condition. Consequently, a combination of funding both formal protected areas and stewardship programmes are necessary to effect improved river and inland wetland protection (as per Nel *et al.* 2009).

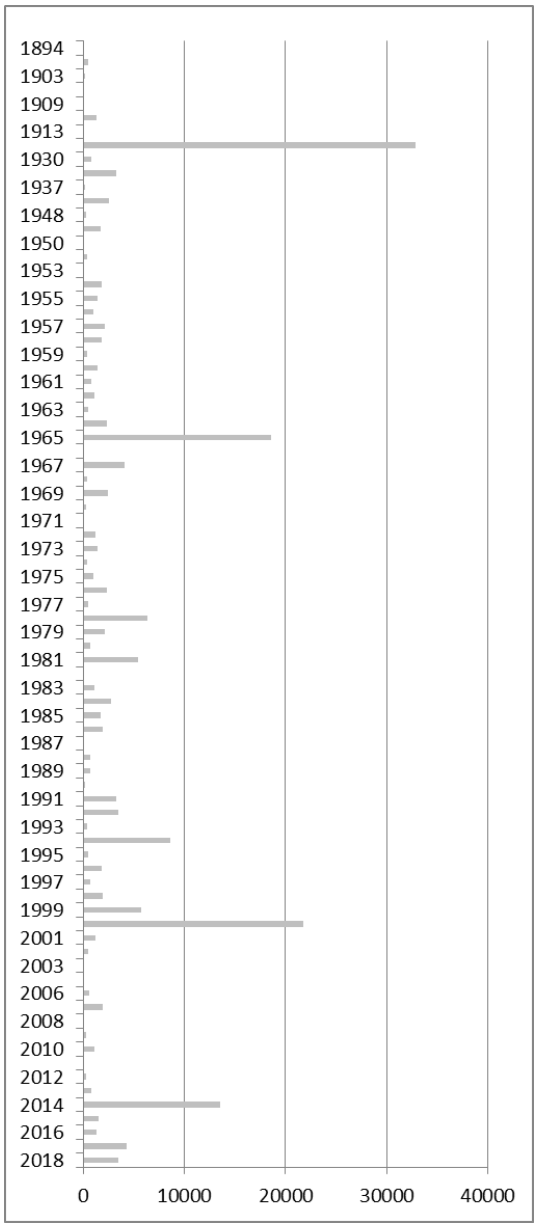


Figure 6.13. Increase in the extent of inland wetlands (ha) within the protected area network and Ramsar sites.

6.2.4 Ecosystem Protection Level limitations in this realm

Aquatic ecosystems can only be considered protected if the pressures which impact them are limited and regulated. Aquatic ecosystems are very connected and inter-dependent, linked to the catchment as a whole. Therefore, inland aquatic ecosystems, particularly the inland wetlands, can only be considered protected, if the impacts from changes of the hydrological regime, impacts on water quality, degradation, invasive species and climate change are minimised. Once the pressures are better represented and their

impacts better understood, better indices for the representation of protection levels against these pressures should be developed.

6.3 Freshwater lakes (Limnetic wetlands): Ecosystem Threat Status and Ecosystem Protection Levels

ETS of freshwater lakes

All freshwater lakes (limnetic wetlands) were considered Critically Endangered since < 20% of the spatial extent of these systems is in a natural or near-natural ecological condition (Table 6.5). In addition, extent of the polygon is also geographically restricted (Sub-criterion B1 Area Of Occupancy or AOO < 2 000 km², Bland *et al.* 2017:52).

Limitations of assessing ETS for freshwater lakes

We have a moderate to high confidence that the extent of the polygon is the only true extent of the depression, however low confidence that it is representative of the maximum inundation extent of the system. We have a low to medium confidence in the depth of the systems across varying inter and intra annual hydroperiods. The list of limnetic wetlands had been compiled in Van Deventer *et al*. (2018a) based on former department reports and grey literature, however quantitative statistics on the extent of the depth of the systems have not been surveyed. Hydroperiod analysis of the depressions in the Mpumalanga Lake District (MLD), as part of the WRC K5/2545 project (Van Deventer *et al*. 2017) and derived from Sentinel optical data (Thompson *et al*. 2018; see the MzansiAmanzi website at https://www.water-southafrica.co.za/), showed that Lake Banagher is likely to be a littoral system and not limnetic, and that other depressions in the MLD could be limnetic and not littoral. Additional hydroperiod surveys are essential before any responses are implemented following from the ETS and EPL results of the freshwater lakes (limnetic wetlands). The DWS's Directorate: Surface and Ground Water Monitoring intends to verify the depth of these systems (Mr E. Mogakabe, November 2018, *pers. comm.*).

Ecological condition of freshwater lakes

Surface and groundwater abtraction impact on the hydroperiod and water availability of the freshwater lakes to various degrees (Table 6.6). Land conversion to agriculture, urban development and particularly forest plantations (the change from Pine to Eucalyptus, see Appendix C and D), has reduced the groundwater levels and increase in sedimentation, salinity and nutrient levels in the lakes (Humfries & Benitez-Nelson 2013; DWS 2015). For Lake Sibaya, the use of Dichloro Diphenyl Trichloroethane (DDT) for malaria control resulted in contamination of sediments and water (Humfries 2013). The introduction of alien freshwater fish species, as well as the translocation of indigenous freshwater fish species from other regions impacted on the natural fauna diversity of De Hoop, Groenvlei and Lake Sibaya since around the 1930s (Whitfield *et al*. 2019).

Table 6.5. Ecosystem Threat Status and Ecosystem Protection Levels for eight freshwater lakes (limnetic wetlands) of South Africa. *The extent of inland wetlands in a natural or near-natural ecological condition, which is situated within the part of the Ramsar sites that do not coincide with the formal protected area boundaries, is indicated in brackets. CR = Critically Endangered; MLD = Mpumalanga Lakes District; NR = Nature Reserve.*

Name of depression	Bioregion	Extent in a natural or near-natural ecological condition (A/B)	Extent in a modified ecological condition (C)	Extent in a heavily to severely /critically modified ecological condition (D/E/F)	Total ha	IUCN Criterion C (%AB)	IUCN Criterion B (Restricted distribution km²)	IUCN ETS	Protection	Informal protection	Pressures	EPL
Groenvlei	Albany Thicket			357.3	357.3	-	3.57	CR	100% (Provincial NR)			Poorly Protected
Lake Fundudzi	Central Bushveld Bioregion			196.3	196.3	-	1.96	CR	0%			Not Protected
Barberspan	Dry Highveld Grassland Bioregion			1 727.7 (7)	1 727.7 (1 735)	-	17.28	CR	0%		Water abstraction; effluent	Not Protected
De Hoop	East Coast Renosterveld Bioregion		949.3 (11.8)		949.3 (961)	-	9.49	CR	Partially protected (Provincial NR)	Partially protected as Ramsar sites		Poorly Protected
Lake Sibaya	Indian Ocean Coastal Belt Bioregion			8 233.3 (59.3)	8 233.3 (8 293)	-	82.33	CR	Partially protected (Provincial NR)	Partially protected as Ramsar sites	Water abstraction; climate change	Poorly Protected
Tevredenpan, Lake Banagher and Chrissiesmeer in the MLD	Mesic Highveld Grassland Bioregion	329.2		1 467.1	1 796.3	18.3	17.96	CR	0%	Chrissiesmeer Protected Environment	Mining; (grazing)	Not Protected

Table 6. 6. Known pressures on freshwater lakes (limnetic wetlands) based on reports and expert opinions*.

Name of depression	Bioregion	Pressures
Groenvlei	Albany Thicket	- Alien fish population explosion (specifically carp); - Direct abstraction (private houses, reserve, hotel); - Close proximity borehole abstraction (commercial and household); - Pollution from stormwater runoff (N2 etc.) and possible seepage from other sources like agricultural chemicals (herbacides and pesticides) & industry; - Alien invasive plants in catchment (pines and other smaller infestations around the lake such as Australian Blackwood, Ink Berry, Port Jackson and others); - Fish diseases & parasites (private koi collection at cement molding company on otherside of N2 has signs of Epizootic Ulcerative Syndrome (EUS); - Change in water chemistry (due to possible fires & ash); and - Contamination from sewerage storage tanks.
Lake Fundudzi	Central Bushveld Bioregion	- Catchment: o Loss of natural habitat: Commercial forestry and cultivation (small scale farming), bush clearing, overgrazing and village development; o Sheet rill and gully erosion due to practices above as well as storm water runoff from villages and related road infrastructure, as well as tracks and paths against steep slopes; and o Alien invasive infestation. - Wetlands bordering (buffering) the lake: o Clearing, cultivation, draining, erosion, fragmentation; o Alien invasive infestation. - The Lake: o Large scale sediment influx (as a result of the above land use changes and impacts).
Barberspan	Dry Highveld Grassland Bioregion	Historic changes to the hydrological regime: a connection between the Harts River and this freshwater lake (limentic depression) was made in 1913, connecting these two different wetland types (see http://www.saramsar.com/2015/06/barberspan.html; Hutchinson *et al.* 1932). Today, sewerage pollution from Lichtenburg's Waste Water Treatment Work (WWTW) reaches Barberspan via the Harts River.
De Hoop	East Coast Renosterveld Bioregion	Water abstraction in catchment, fragmentation, water pollution from upstream agriculture, invasive species, transformation of riparian zones, erosion, sedimentation, increasing impacts from recreational and tourism activities.
Lake Sibaya	Indian Ocean Coastal Belt Bioregion	Increasing water abstraction, water pollution, urbanisation and development within immediate catchment, alien invasive and translocated species (snails and plants); land uses (particularly plantations), loss of natural habitat and climate change.
Tevredenpan, Lake Banagher and Chrissiesmeer in the MLD	Mesic Highveld Grassland Bioregion	Applications for mining rights received in close proximity to the pans; Mineral (coal) resources present within Acid Mine Drainage (AMD) generating geology of prime concern; Intensive agriculture (primarily maize production) within close proximity of pans; Poor management of municipal sewage and waste from Chrissiesmeer abattoir threatens Lake Chrissie; Exotic and invasive plant species within wetlands; and Road infrastructure intercepting wetlands; cattle overgrazing.

**Information compiled from references listed in text related to Table 6.6, as well as personal communitication with several people, including (alphabetical order of surnames): Dr Jeanne Gouws (CapeNature), Dr Piet-Louis Grundling (DEA), Sue Janse van Rensburg (SAEON), Mr Anton Linström (WetEarth Pty Ltd), Dr Mervyn Lötter (MTPA), Mr Wayne Meyer (CapeNature), Dr Susan Taljaard (CSIR and Dr Steven Weerts (CSIR). Also see CapeNature, 2016.*

EPL of freshwater lakes

Five of the freshwater lakes (limnetic wetlands), including the three depressions in the MLD, Lake Fundudzi (Limpopo) and Barberspan (North West Province), are Not Protected. Lake Sibaya and De Hoop are currently Poorly Protected as the boundary of the provincial nature reserve does not extend to the maximum inundation extent of the polygon, and does not protect the system from run-off and pollution of the sub-quaternary catchment. In addition, particularly for Lake Sibaya, water abstraction is a current and increasing pressure, whereas climate change predictions are indicative of lower precipitation and higher temperatures (Muthige *et al*. 2018; see also Appendix D). The extent of the Groenvlei limnetic depression falls completely within the Goukamma Provincial Nature Reserve. Urban densification, agriculture and plantations within its sub-quaternary catchments results in hydrological disturbances, degraded water quality and land degradation in the catchment, leaving the system in a largely to critically modified ecological condition (PES of D/E/F).

We recommend the consideration of these eight freshwater lakes (limnetic wetlands) for the Red List of Ecosystems (RLE). Further in-depth analysis of these systems should be done as part of the RLE to verify extent, depth across inter and intra annual hydroperiod, as well as the characteristics of the pressures on these systems.

6.4 Changes in free-flowing and flagship rivers

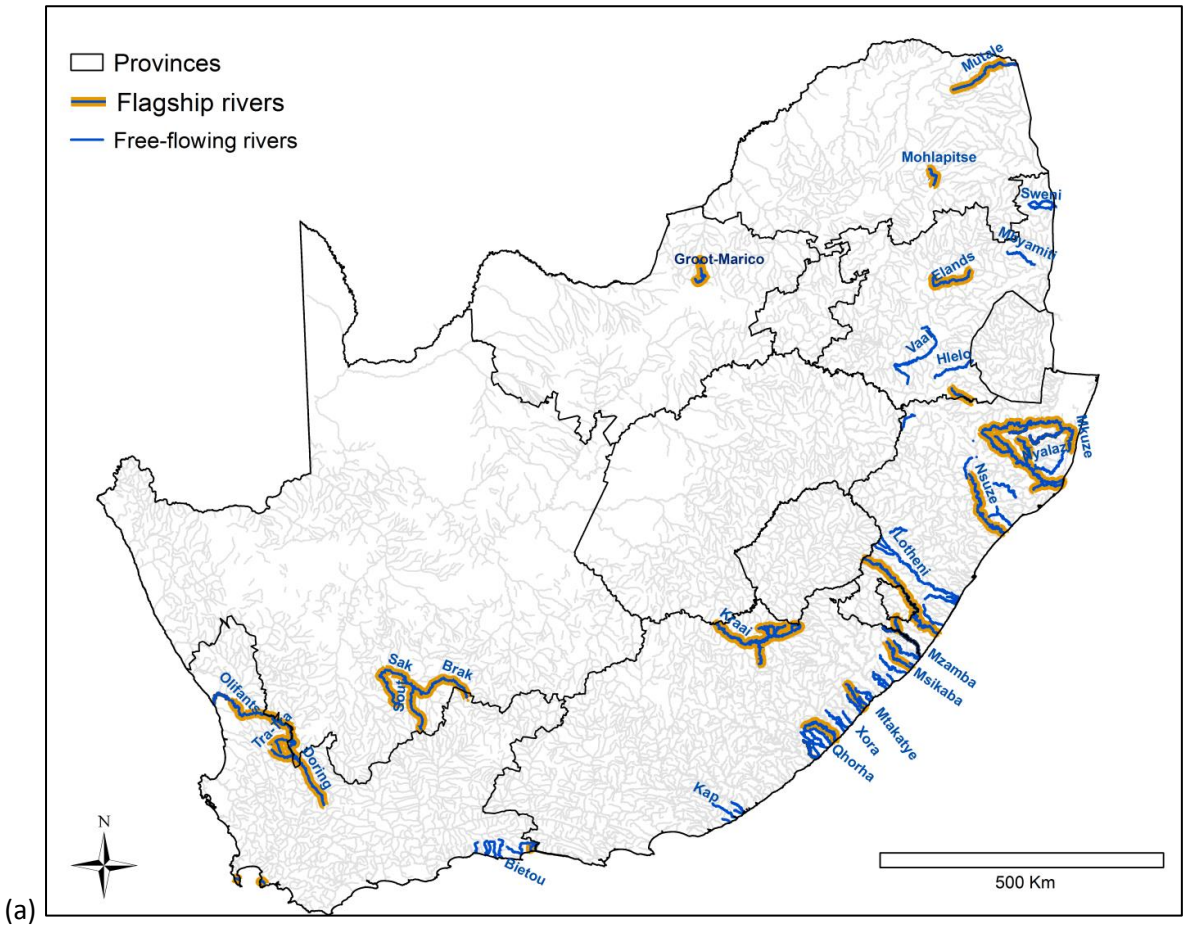
The NFEPA project identified 62 free-flowing rivers, of which 19 are free-flowing rivers where ideally no large dams should be developed. The flagship rivers serve as examples of river ecosystem types which are intact from source to mouth (estuary) along the variation of its geomorphological zones, and demonstrate significance for ecosystem processes and biodiversity value. Changes in ecological condition of free-flowing rivers have occurred since the assessment in the NFEPA project and PES in 2011 when compared to the PES update in 2017 (Figure 6.14). Figure 6.15 a and b shows the summary of the extent of river length and percentages of the free-flowing rivers of the river condition during the 2011 process and during the updates in 2017/18.

Ecological condition change occurred due to the presence of a dam or water quality deterioration. Google Earth historic imagery of between 2007 and the most recent imagery, showed the dams had already been built on the rivers shown in Table 6.7 by 2007, but were not yet represented in the dams layer used for the NFEPA project which dated to 2006 (DLA:CDSM 2006). Three rivers, however, remained on the list of free-flowing rivers, based on recommendations of experts during the workshops, regardless of them not meeting the ecological condition criterion (Table 6.7). These rivers are the Kobonqaba, Groot Marico and the Mutale Rivers.

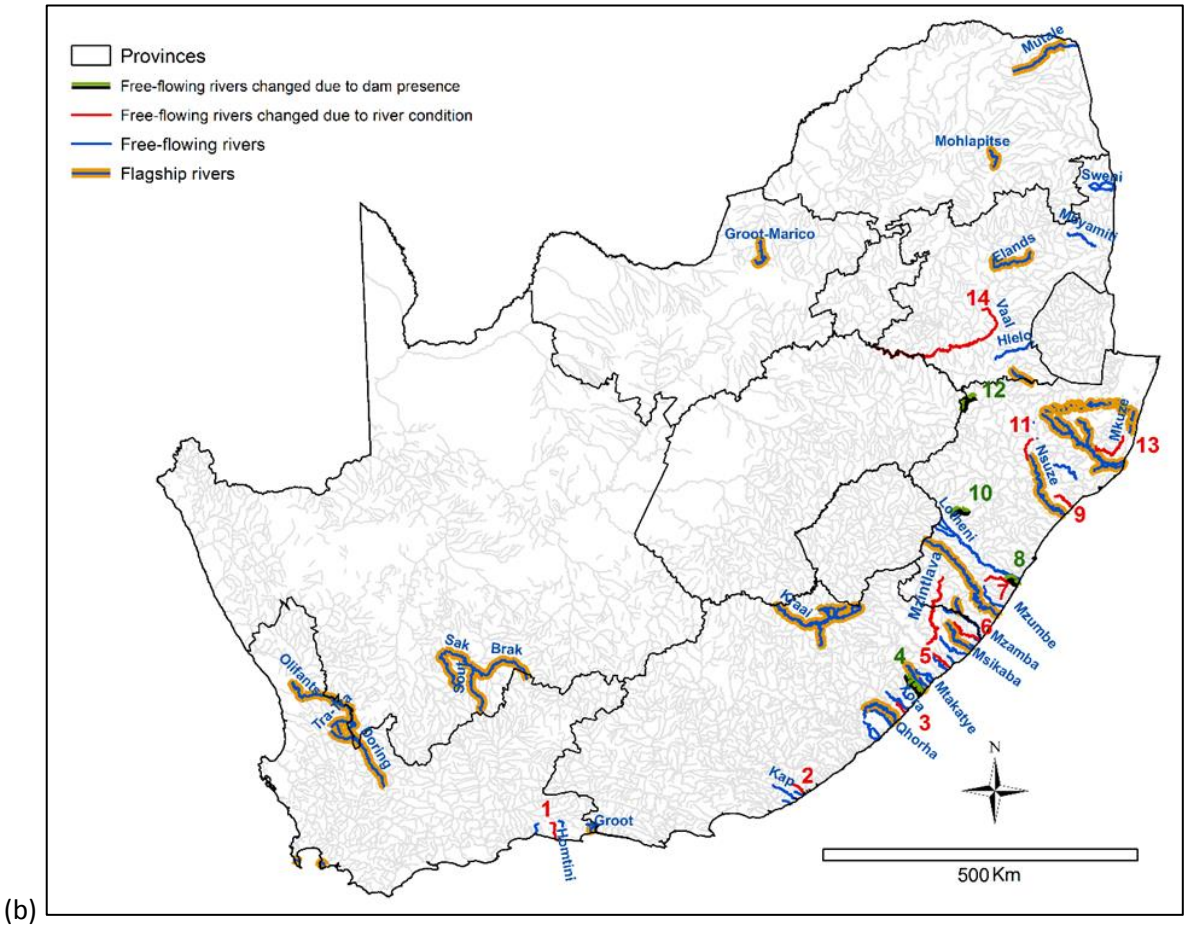
The four rivers which were impacted by dams and no longer classified as free-flowing rivers, are the Mdumbi (Eastern Cape), aMahlongwa, Nsonge and Ngogo Rivers in the KwaZulu-Natal Province (Table 6.7; Figure 6.14b). The dams, however, are located in the upper reaches of the rivers with the exception of the Nsonge River, where a smaller capacity irrigation dam is located in the upper reaches but a larger irrigation dam is located in the lower foothills.

Table 6.7. List of rivers no longer fulfilling the criteria for free-flowing rivers. *Numbers are shown in Figure 6.14(b).*

Rivers	Province	Reason for loss of status
1. Homtini	Western Cape	PES status change
2. Mgwalana	Eastern Cape	PES status change
3. Ntlonyane	Eastern Cape	PES status change
4. Mdumbi	Eastern Cape	Dam and PES status change
5. Mzintlava	Eastern Cape	PES status change
6. Mzamba	Eastern Cape	PES status change
7. Mpambanyoni	KwaZulu-Natal	PES status change
8. aMahlongwa	KwaZulu-Natal	Dam and PES status change
9. Matigulu	KwaZulu-Natal	PES status change
10. Nsonge	KwaZulu-Natal	Dam and PES status change
11. Nondweni	KwaZulu-Natal	PES status change
12. Ngogo	KwaZulu-Natal	Dam and PES status change
13. Nyalazi	KwaZulu-Natal	PES status change
14. Upper Vaal	Mpumalanga	PES status change



(a)



(b)

Figure 6.14. Free-flowing and flagship rivers identified in (a) 2011 and (b) 2017.

Another ten rivers have changed from an A/B ecological category (natural and near-natural ecological condition) to degraded ecological conditions (D to F ecological categories), and therefore are no longer qualify for the criteria of free-flowing rivers (Table 6.8; Figure 6.15). Figure 6.16 shows a decreasing ecological condition with time for these river systems.

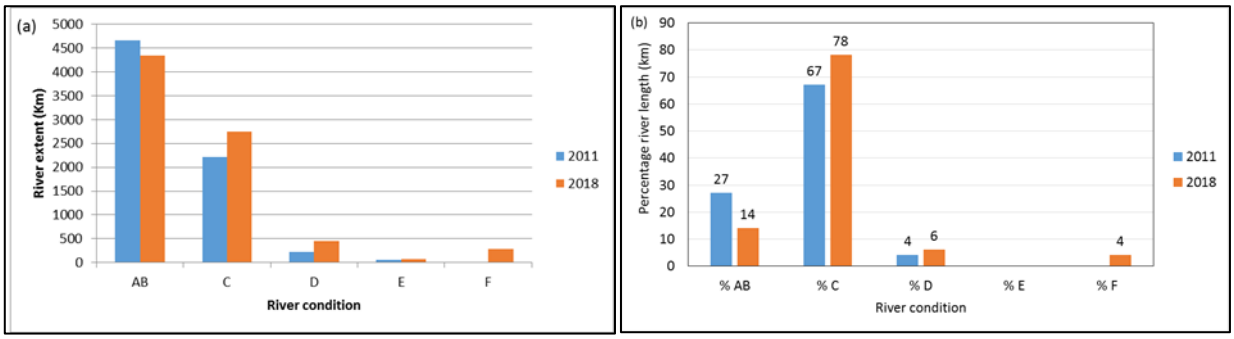


Figure 6.15. Summary of free-flowing rivers for river condition (main rivers and tributaries); (a) river extent in km and (b) change in river extent condition percentages from PES in 2011 to PES in 2018.

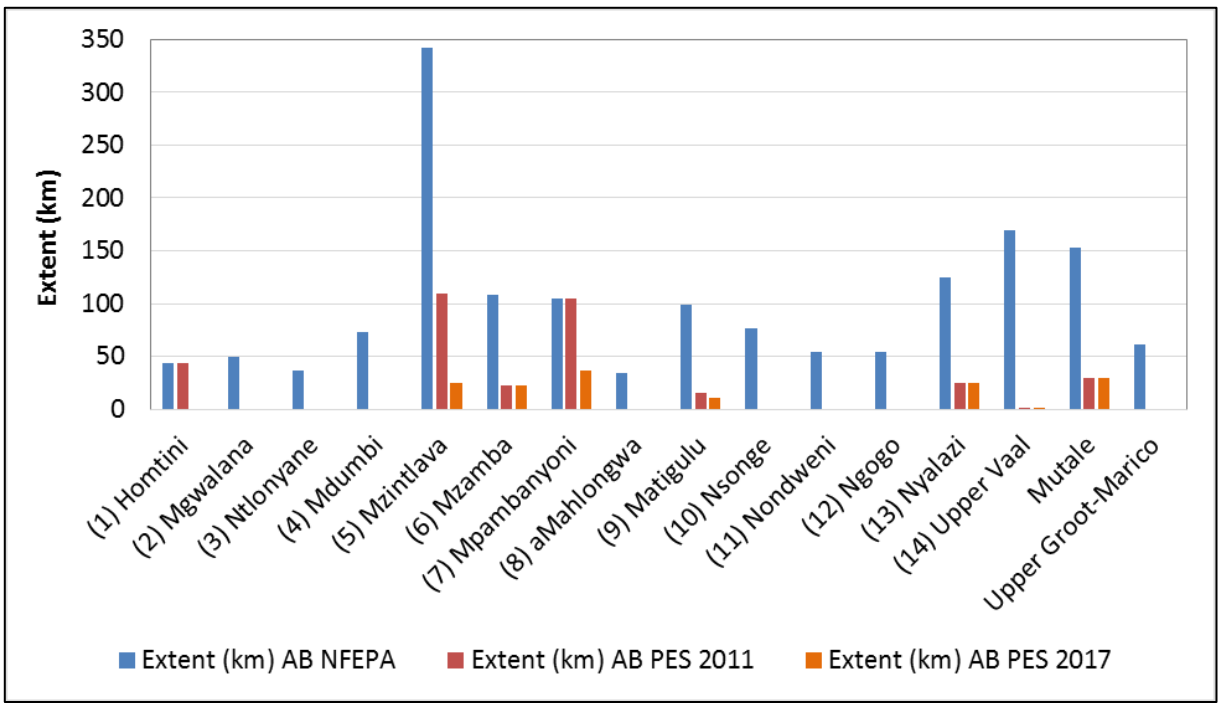


Figure 6.16. Extent of free-flowing rivers where river condition deteriorated below the A/B ecological criterion (unnumbered rivers are those kept as free flowing regardless of ecological category).

Therefore, a total of 14 rivers of the original 62 free-flowing rivers have lost their status, totalling 22% of the total number of free-flowing rivers. The remaining free-flowing rivers are shown in Table 6.9. The 19 flagship rivers showed no changes in status or ecological category.

Table 6.8. Matrix showing the change in the (a) extent (km) and (b) percentage of river ecological condition between 2011 and 2017.

(a)

		2017						
	Ecological category	A	B	C	D	F	Data deficient	Grand Total
2011	AB	0.0	0.0	0.0	-	-	0.0	0.4
	B	0.0	0.8	0.2	0.1	-	-	1.1
	Z	-	0.2	-	-	-	-	0.2
	(blank)	165.8	711.0	258.1	37.8	6.4	9.2	1 188.3
	Grand Total	**165.9**	**712.3**	**258.3**	**37.8**	**6.4**	**9.2**	1 190.0

(b)

	Ecological category	A	B	C	D	F	Data deficient
2011	AB	0.00	0.00	0.00	-	-	0.00
	B	0.00	0.07	0.02	0.01	-	-
	Z	-	0.01	-	-	-	-
	(blank)	13.94	59.74	21.69	3.17	0.54	0.78

6.5 Highly threatened and unprotected ecosystems

The results of the ETS and EPL for rivers and inland wetlands have been combined to identify those systems which are highly threatened and unprotected.

A total of 140 (64%) river ecosystem types are categorised as threatened and under-protected (Table 6.10). Further work is required at provincial scale to verify the extent of these systems and improve the modelling of their ecological condition and to verify whether these modelled results are suitable for prioritisation in spatial planning.

Table 6.9. Free-flowing rivers, or rivers without dams, in South Africa. *Those in bold italics are flagship free-flowing rivers that are top priority for retaining their free-flowing character.*

NORTHERN CAPE	EASTERN CAPE	KWAZULU-NATAL
Upper Sak, Klein- Sak & tributaries*	Riet	***Mzimkhulu****
	Kap	Mzumbe
WESTERN CAPE	Mpekweni	Mkomazi & tributaries*
Doring & tributaries*	***Kobonqaba***	***Mkuze & tributaries****
Klaas Jaagers	iNxaxo	***Nsuze* tributary of Thukela***
Rooiels	Qhorha & tributaries*	***Black Mfolozi & tributaries****
Touws	Shixini	Mfule*
Karatara, Hoogekraal	***Nqabarha****	
Knysna	Xora*	**MPUMALANGA**
Bietou, Palmiet	Mncwasa	***Ntombe tributary of Phongolo***
Groot (West) (Garden Route), Bloukrans	***Mtakatye****	Hlelo*
	Mnenu	***Elands****
LIMPOPO	Sinangwana	Mbyamiti
Mutale-Luvuvhu*	Mngazana	Nwanedzi*
Mohlapitse	Mntafufu	Sweni*
	Mzintlava	
NORTHWEST	Mkozi	
Upper Groot-Marico	Msikaba*	
	Mtentu*	
	Sikombe	
	Mpahlane	
	Mzamba*	
	Mtamvuna & tributaries*	
	Kraai & tributaries*	

** Free-flowing rivers longer than 100 km*

Table 6.10. Cross tabulation of ecosystem threat categories and protection levels for riversfor river ecosystem types (total *n* = 135) within the risk category (indicated in brackets). *CR = Critically Endangered; EN = Endangered; LC = Least Concern and VU = Vulnerable.*

Ecosystem Threat Status (ETS) across / Ecosystem Protection Level (EPL) down	CR	EN	VU	LC	Total
Not Protected (NP)	65	10	1	18	94
Poorly Protected (PP)	26	20	3	17	66
Moderately Protected (MP)	4	11		18	33
Well Protected (WP)		1	1	27	29
Total	**95**	**42**	**5**	**80**	**222**

Sixty-one of the 135 (45%) inland wetland ecosystem types are both CR and NP (Table 6.11). A total of 99 (73%) of inland wetland types (total *n* = 135) are threatened with EPL between Not Protected (NP) or Poorly Protected (PP), making them highly threatened and unprotected.

Table 6.11. Risk categories for inland wetland ecosystem types and number of inland wetland ecosystem types (total *n* = 135) within the risk category (indicated in brackets). *CR = Critically Endangered; EN = Endangered; LC = Least Concern and VU = Vulnerable.*

Ecosystem Threat Status (ETS) across / Ecosystem Protection Level (EPL) down	CR	EN	VU	LC	Total
Not Protected (NP)	C16 (61)	C14 (0)	C12 (4)	C10 (15)	82
Poorly Protected (PP)	C15 (23)	C13 (9)	C11 (2)	C9 (9)	41
Moderately Protected (MP)	C8 (1)	C7 (0)	C6 (1)	C2 (2)	4
Well Protected (WP)	C5 (0)	C4 (1)	C3 (5)	C1 (2)	8
Total	**83**	**12**	**12**	**28**	**135**

Most of the ecosystems considered as highly threatened and unprotected are located in the Gauteng Province, the western half of the Mpumalanga Province, eastern parts of the North West and KwaZulu-Natal provinces, the central region of the Northern Cape Province and the southern and western parts of the Western Cape Province (Figure 6.17).

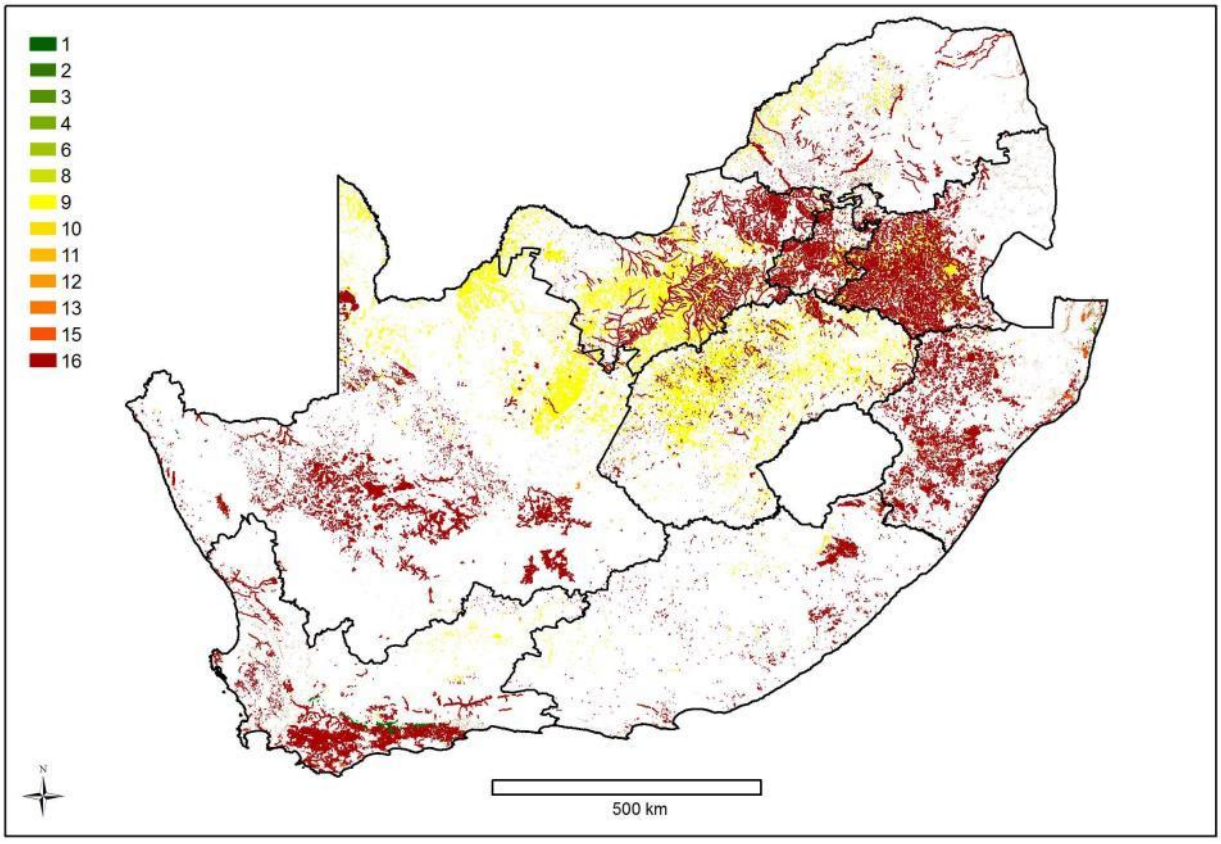


Figure 6.17. Distribution of 'unlucky' inland wetland ecosystem types in South Africa. *Numbers indicate a low risk (not threatened and Well Protected) whereas numbers 11–16 are threatened ecosystem types which are Not Protected or Poorly Protected.*

6.6 Comparison of NBA 2018 to NSBA 2004 and NBA 2011

The results of the three national assessments of NSBA 2004, NBA 2011 and NBA 2018 are difficult to compare owing to differences in the input data used, methods for determining the ecological condition as well as differences in the number of inland wetland ecosystem types (Table 6.12). In the NBA 2011, Nel *et al*. (2011:52–53) stated that 'By implication, it is therefore more important for future improvements of ETS to invest in developing high confidence data layers for river condition, than to develop and test approaches for classifying river ecosystem types'. However, in the NBA 2018, more attention was paid to improving the extent and typing of the inland wetlands, compared to the rivers.

The first national assessment of inland aquatic ecosystems, done in a systematic manner and spatially explicit way, was the NSBA 2004 (Nel *et al*. 2004). In the NSBA 2004, the two new headline indicators for assessing the state of South Africa's biodiversity were introduced: ETS and EPL. These two headline indicators were still used in the NBA 2011 and NBA 2018. In the NBA 2011 the ecosystem types of the rivers were improved, while inland wetlands have been incorporated for the first time in a national assessment. Updates imply that improved datasets be used, and logically improvements lead to changes in the understanding and modelling of ecosystem tupes, extent and ecological condition. Although the data layers and methods of these assessments differed, they consistently showed that rivers and inland wetlands are threatened and their ecological condition is deteriorating. This trend is also found in international assessments, irrespective of the data and methods used in assessments (see for example Finlayson *et al*. 2005, the wetland specialist report for the MEA 2005).

Table 6.12. Comparison between the three National Biodiversity Assessments (NBAs) for rivers and inland wetlands.

	NSBA 2004*	NBA 2011**	NBA 2018
Guidelines	International Union Conservation of Nature (IUCN), 1989.	Rodrigues *et al.* 2011.	Bland *et al*. 2017.
River ecosystem types	Assessed mainstem rivers only.	Assessed mainstem rivers and tributaries.	Assessed mainstem rivers and tributaries.
	Used the present ecological status category (PESC) desktop estimates between 1998 and 1999.	Present Ecological State (PES) were derived from DWS PES categories, site collection data, modelled data and expert review.	PES categories were updated from the NBA 2011 with the PES categories provided by DWS update between 2011 and 2017.
	Tributaries were not assessed.	PES for some tributaries were modelled using the land cover data from 2009.	Tributaries without PES categories were identified as 'data deficient' as per Bland *et al*. 2017.
	PESC were lumped as AB, C and DEF.	PES categories were lumped as AB, C, D, EF and Z.	PES categories were not lumped but left as A, B, C, D, E or F.
	River sections / reaches within large dams were not excluded.	River sections / reaches within large dams were not excluded.	River sections within large dams and estuaries were given an 'F' ecological category.
	River sections / reaches within estuaries were not excluded.	River sections / reaches within estuaries were not excluded.	River sections / reaches within estuaries were excluded.
	Erosion datasets were not used.	Erosion information was used in modelling PES categories.	Erosion datasets do not distinguish between natural and induced erosion and were therefore not used.
	Used 120 river ecosystem types.	Used 223 river ecosystem types.	Used 222 river ecosystem types. One of the NBA 2011 river ecosystem types were found to be outside South Africa's boundaries.
Inland wetland ecosystem types	Extent of inland wetlands were not included	Extent of inland wetlands was included. Level 4A: Depressional hydrogeomorphic (HGM) units were used from the topographical maps whereas the remaining 6 HGM units were modelled (Van Deventer *et al*. 2016).	Extent of inland wetlands was included. 113% more wetland extent was used compared to NBA 2011 with less errors. Level 4A: HGM units were identified at desktop level; only 4 HGM units were used, namely depressions, valley-bottom, floodplain and seeps.
		331 wetland vegetation groups were used at Level 2.	135 vegetation bioregions were used at Level 2.
		791 inland wetland ecosystem types were used in the assessment.	135 inland wetland ecosystem types were used in the assessment.
	N.A.	Ecological condition was modelled for wetlands using land cover data.	Ecological condition was modelled for wetlands using land cover and ancillary point datasets.

** National Spatial Biodiversity Assessment (Nel et al. 2004)*
*** Nel & Driver 2012*

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7. INDIGENOUS FRESHWATER SPECIES ASSESSMENTS

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This chapter provides a meta-analysis of IUCN Red List Assessments for all known vertebrate and one invertebrate group occurring in aquatic systems of South Africa. Here the threat status of these species are presented and what the main drivers of this threat is (Section 7.1). For the first time in the NBA, trends in species status is being presented (Section 7.1.3) and an assessment of how well species are protected by the protected area network of South Africa (Section 7.2).

> Please take note: A taxon (plural taxa) is any unit used in the science of biological classification, or taxonomy. Some species have been split into sub-species and assessed at these levels. Consequently, if a taxonomic group includes sub-species or varieties, the summary statistics use the term 'taxa'. If a group contains only species then the term 'species' is used in the summary statistics.

7.1 Species threat status (Red List of Species)

7.1.1 Species threat status calculation method

Threat status of South Africa's indigenous (Red List Assessments – RLA) inland aquatic species was calculated using the latest version of the International Union for the Conservation of Nature (IUCN) Red List Categories and Criteria, version 3.1 (IUCN 2012a). The categories are summarised in Figure 7.1, and the criteria thresholds are summarised in Appendix F. No modifications were made to the IUCN Categories and Criteria. South Africa uses the IUCN Red List system as it is a quantitative, objective system that can be consistently applied across a range of taxonomic groups. The quantitative criteria are based on scientific studies of populations of a range of different species and the biological conditions under which they are highly likely to go extinct (Mace *et al*. 2008). The quantitative nature of the system demands that assessments are justified by supporting data. Key data that were collected for each species in order to apply the IUCN Red List Criteria included: distribution (Extent of Occurrence – EOO); area of occupied habitat (Area of Occupancy – AOO), population size and structure, changes in population size over a specified time period, pressures to each species and the impact that these pressures are having on the population size and the quality of available habitat (Figure 7.2). Section 5.6 and Table 5.13 outlines major input data for assessments and what the key sources of information were for each taxon group. While certain Red List parameter data could be calculated using spatially available data on species occurrences and land use, parameters such as population decline were gathered by running workshops with expert groups (see Appendix G for list of experts that contributed to the Red List Process and Appendix H for list of workshops undertaken). All assessments were independently reviewed by experts that were not involved in the actual assessment, SANBI's Threatened Species Unit ensured overall consistent level of assessment quality and correct application of the IUCN Red List categories and criteria.

The fact that the IUCN system is objective and scientifically based, as well as its wide use internationally, means assessments produced for this National Biodiversity Assessment (NBA) can be consistently compared with assessments produced by the IUCN globally for the same taxonomic groups and are available for use in national and international reporting frameworks. For the majority of taxa assessed, global level assessments were conducted meaning that the IUCN assessment criteria were applied to the entire global population of each taxon. This is due to South Africa having high levels of species endemism where the majority of taxa found in South Africa, and where the entire population occurs within our borders or over 50% of the species range is found within our borders. For charismatic or economically important species with peripheral distributions occurring within South Africa and for range restricted species where their distributions occur in centres of endemism that cross national boundaries, national level assessments were conducted using the IUCN's regional assessment criteria (IUCN 2012b). For all endemic species global level assessments were conducted meaning that the IUCN assessment criteria (Appendix F) were applied as the entire global population occurs within our borders.

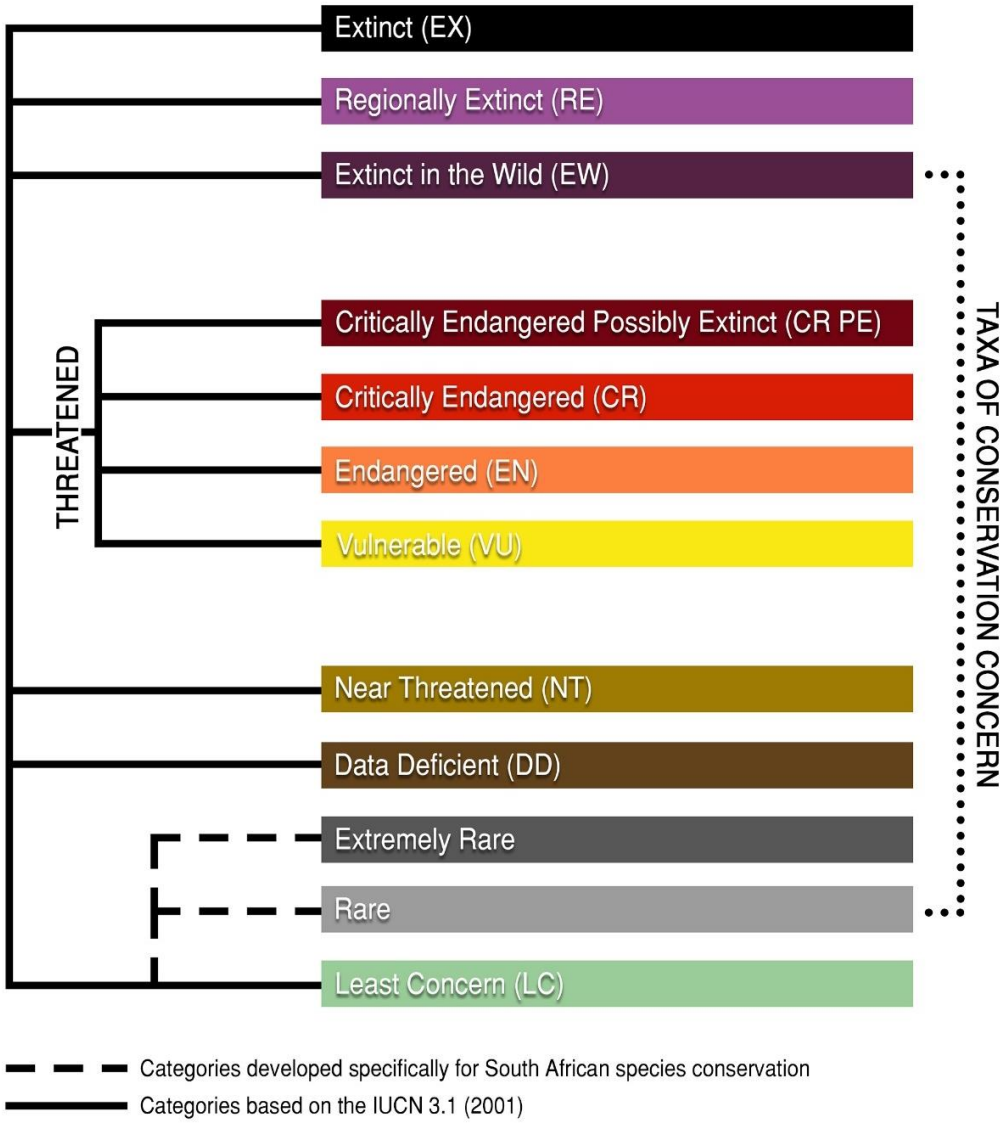


Figure 7.1. Categories for species Red List Assessment work, note South Africa uses the IUCN Red List Categories and Criteria, version 3.1 (IUCN 2012a) but for national monitoring includes subcategories of rarity within the global category of Least Concern. The Rare category is applied to restricted endemics (EOO < 500 km^2) that are not known to be declining. Extremely Rare is applied to taxa confined to a single site and declining.

Table 7.1. The number and scope of inland aquatic species Red List assessments, including the total number of species present in South Africa in brackets, for each taxonomic group.

Taxon group	Number of indigenous species	Number of Endemics	Assessment scope Global*	Assessment Scope National**	Date of most recent assessment	Most recent Red List Assessment
Aquatic plants-sample	100† (26000)	14†† (13890)	14 (13754)	86 (6616)	2018	Red List of South African plants version 2017.1 http://redlist.sanbi.org/
Birds	175 (846)	0 (38) ***	115 (599)	26 (133)	2015	Taylor et al. 2015 http://speciesstatus.sanbi.org/
Reptiles	15 (407)	6 (209)	6 (222)	9 (174)	2017	Red List of South African reptiles published online http://speciesstatus.sanbi.org/
Mammals	20 (343)	6 (57)	6 (57)	14 (279)	2016	Red List of South African mammals published online https://www.ewt.org.za/reddata
Amphibians	102 (125†††)	48 (61)	101 (125)	0 (0)	2016	Red List of South African reptiles published online http://speciesstatus.sanbi.org/
Freshwater fish	118	58	94	24	2018	Red List of South African reptiles published online http://speciesstatus.sanbi.org/
Dragonflies	162	28	140	22	2018	Red List of South African reptiles published online http://speciesstatus.sanbi.org/

* Assessments conducted using IUCN 3.1 Categories and Criteria, assessments from South Africa will be the same as those reflected on the global IUCN Red List.

** Assessments conducted only on the South African portion of the species range utilising the IUCN Regional Criteria, these are National Red List assessments and are not submitted to the IUCN Red List; *** Endemic counts include Lesotho.

† Sample of inland aquatic plants of South Africa (Cook 2004), †† Endemics of sample of inland aquatic plants (Cook 2004), ††† New species recently described not included here.

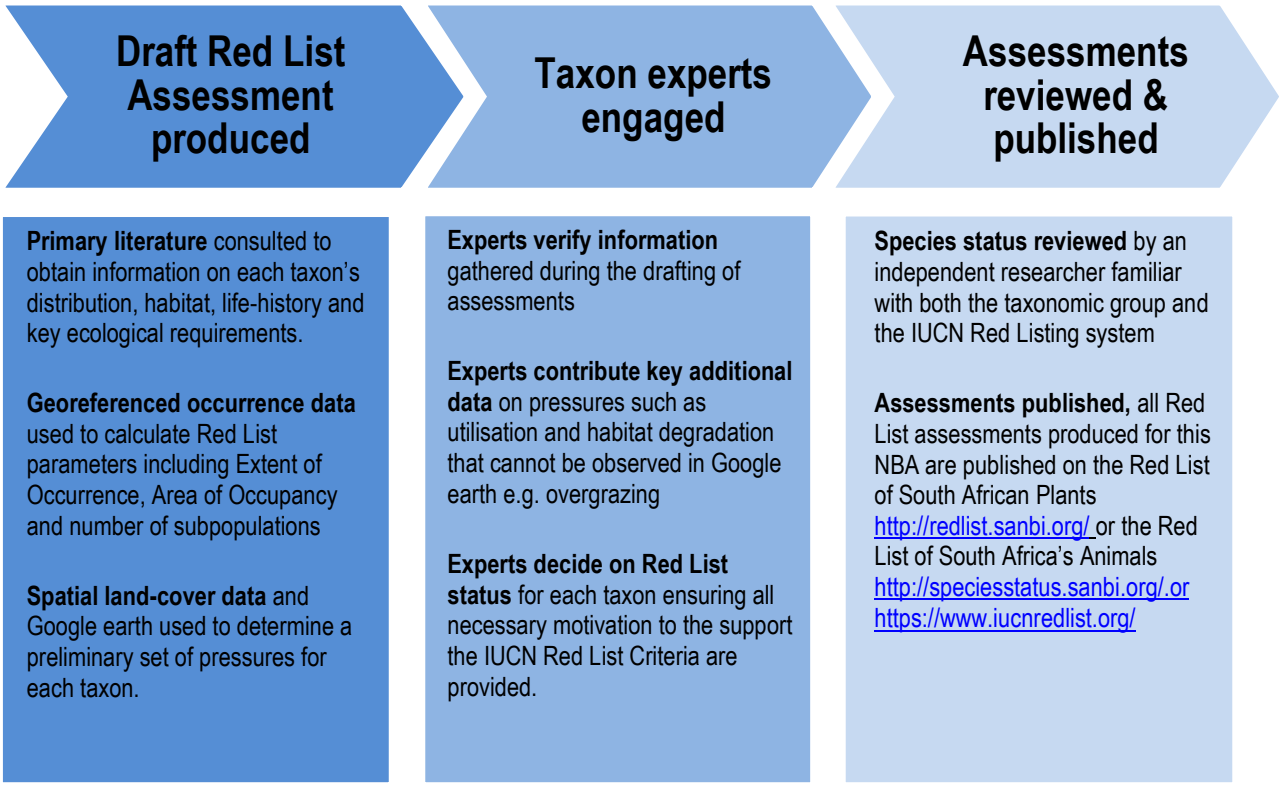
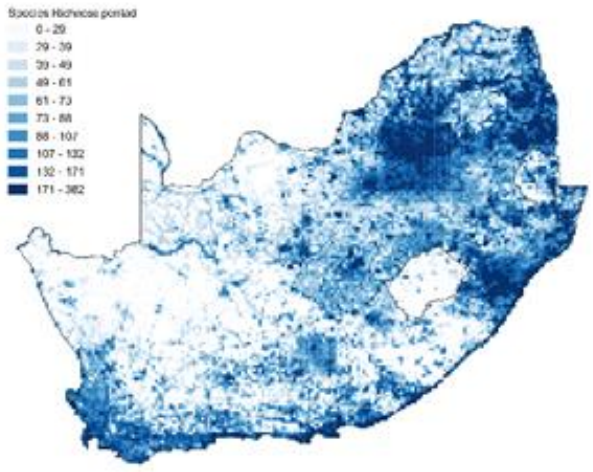
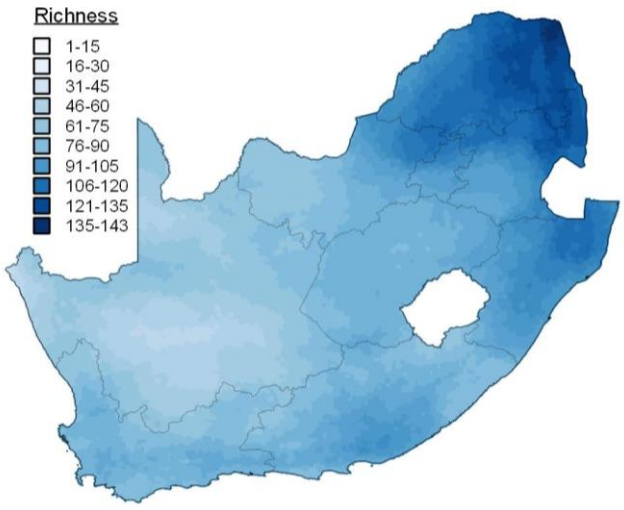


Figure 7.2. Red List Assessment process conducted for each taxon assessed.

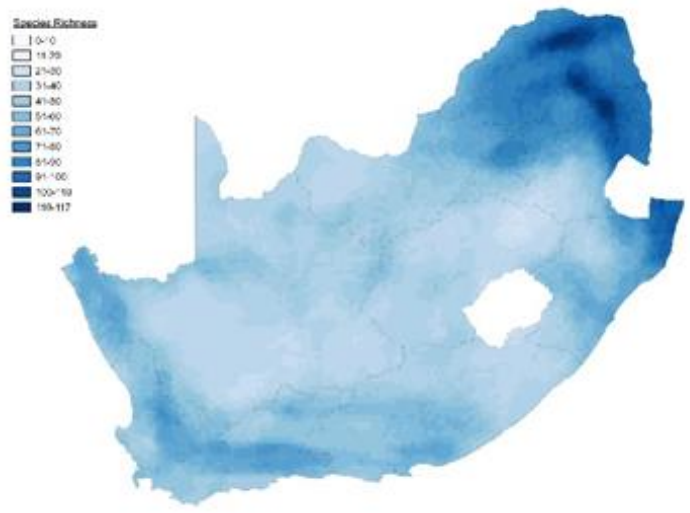
Birds



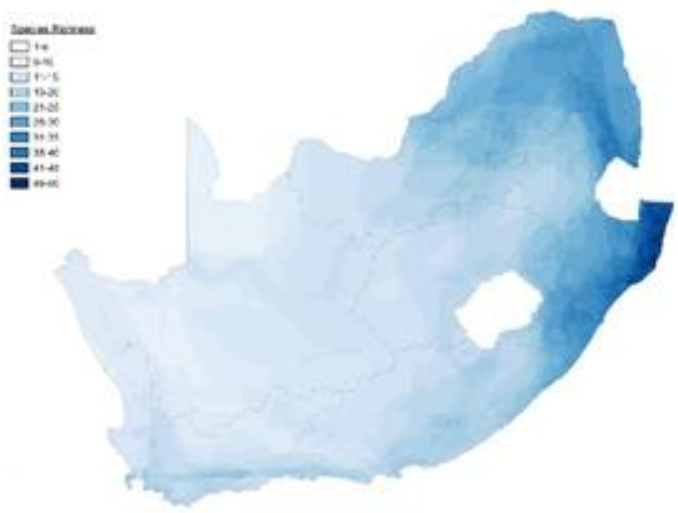
Mammals



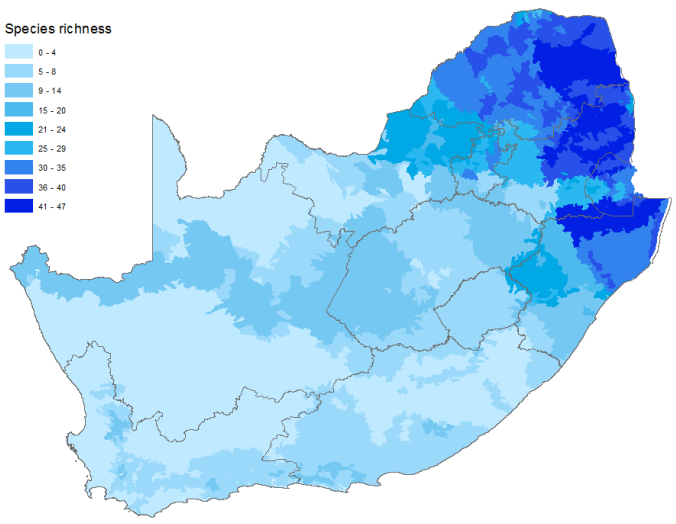
Reptiles



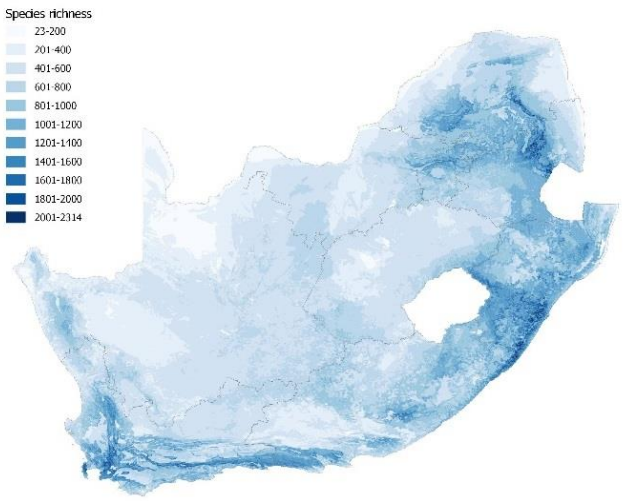
Amphibians



Freshwater Fish



Plants



Dragonflies

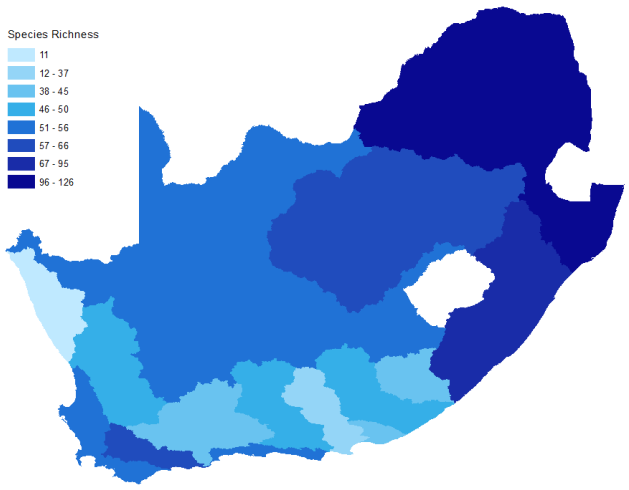


Figure 7.3. Species richness estimate maps (entire taxonomic groups, not only inland aquatic taxa) for all taxonomic groups included in the inland aquatic assessment, (birds, mammals, reptiles, amphibians, freshwater fish, plants and dragonflies). *Richness estimates for plants, amphibians, reptiles and freshwater fish are based on expert interpreted distributions. While for mammals, dragonflies and birds, estimated richness is based on data collected from field surveys only and as such may include sample bias.*

7.1.2 Species threat status and trends

Species threat status is as per IUCN definition and threatened species include Critically Endangered (CR), Endangered (EN) and Vulnerable (VU) species, while additional Taxa of Conservation Concern (ToCC) include Near Threatened (NT), Data Deficient (DD) and in the South African context, Extremely Rare (Ex Rare) and Rare species, and collectively these are considered ToCC (Figure 7.1). The trend in species status over time is measured using the globally recognised indicator the Red List Index (RLI) developed by Butchart *et al*. (2007). The RLI is calculated for specific groups of species based on genuine changes in Red List categories over time and indicates trends in the status for each group of species. The RLI value ranges from 0 to 1. The lower the value the faster the group of species is heading toward extinction. If the value is 1, all species are Least Concern and if the value is 0, all species are Extinct.

Taxa of Conservation Concern (ToCC) are species and subspecies that are important for South Africa's conservation decision-making processes. They include all taxa that are assessed according the IUCN Red List Criteria as Critically Endangered (CR) Endangered (EN), Vulnerable (VU), Data Deficient (DD) or Near Threatened (NT). Detailed information on the pressures impacting these taxa has been captured during the Red List assessment processes. Throughout the NBA reference to the impact of a particular pressure on a taxonomic group is determined from the proportion of ToCC impacted by that

The RLI value for each specific assessment time period is calculated by multiplying the number of species in each Red List category by a category weight (0 for LC, 1 for NT, 2 for VU, 3 for EN, 4 for CR and 5 for EX). These products are summed, divided by the maximum possible product (number of species multiplied by the maximum weight 5), and subtracted from one (Butchart *et al.* 2007). To accurately determine trends over the different time periods requires that assessments are back cast and that all information available at the later time period is considered for previous assessments. This ensures that changes such as taxonomic changes and new information do not incorrectly bias the results of the index. Since there is a lag time between assessments and we don't have information on Data Deficient species, there is a level of uncertainty in the calculation of the RLI. A method has been developed by Butchart *et al*. (2010) and Rodriquez *et al.* (2014) to incorporate this uncertainty. This method was followed and the RLI was modelled to take into account uncertainty and to generate a 95% confidence interval. This was based on the two levels of uncertainty 1) the number of Data Deficient species, each of these species are assigned a RL category (Least Concern to Extinct) with a probability proportional to the number of species in the non-Data Deficient category and 2) Extrapolation uncertainty, even thou RLI are extrapolated linearly based on the slope of the closest two assessment points, there is uncertainty in how accurate the slope is, this uncertainty is accommodated by using a normal distribution with a probability equal to the slope of the closest two assessed points and a standard deviation equal to 60% of this slope.

Repeat assessments have been conducted for seven inland aquatic species groups in South Africa including birds (141 taxa), mammals (20 taxa), reptiles (15 taxa), amphibians (102 taxa), freshwater fish (118 taxa), dragonflies (refers to all Odonata, 162 taxa) and plants (100 taxa – sample). Each taxon group included in the RLI have conducted a minimum of two Red List assessments (Table 7.1). All datasets used in this analysis can be found on the SANBI NBA 2019 website.

7.1.3 Species threat status and trends results

Freshwater fish

Of all South African species groups that have been comprehensively assessed, freshwater fish have the highest proportion of species that are threatened with extinction (36%), and more than half of South African freshwater fish are ToCC (53% or 62 species) (Figure 7.4 and Table 7.2). A large portion of these species occur in the Cape Fold Ecoregion (CFE) (Ellender *et al*. 2017) (Figure 7.5). A total of 90% of freshwater fish endemic to South Africa are ToCC (Figure 7.4 and Table 7.2). Freshwater fish have the lowest Red List Index (RLI) value of any inland aquatic taxonomic group (Figure 7.6). Furthermore, there has been a decline in the RLI value since the last assessment in 2007. Overall, the status of South African freshwater fish is still declining with eight species having moved to a higher category of threat (Table 7.3). Many other freshwater fish are similarly being impacted by a range of pressures, but declines have not resulted in change in category of extinction risk. The high levels of extinction risk to fish corresponds to the poor condition (67% of rivers are degraded) and status (64% are highly threatened) of rivers reflected in the inland aquatic ecosystem assessment (Section 5.2.1 and 6.1.1).

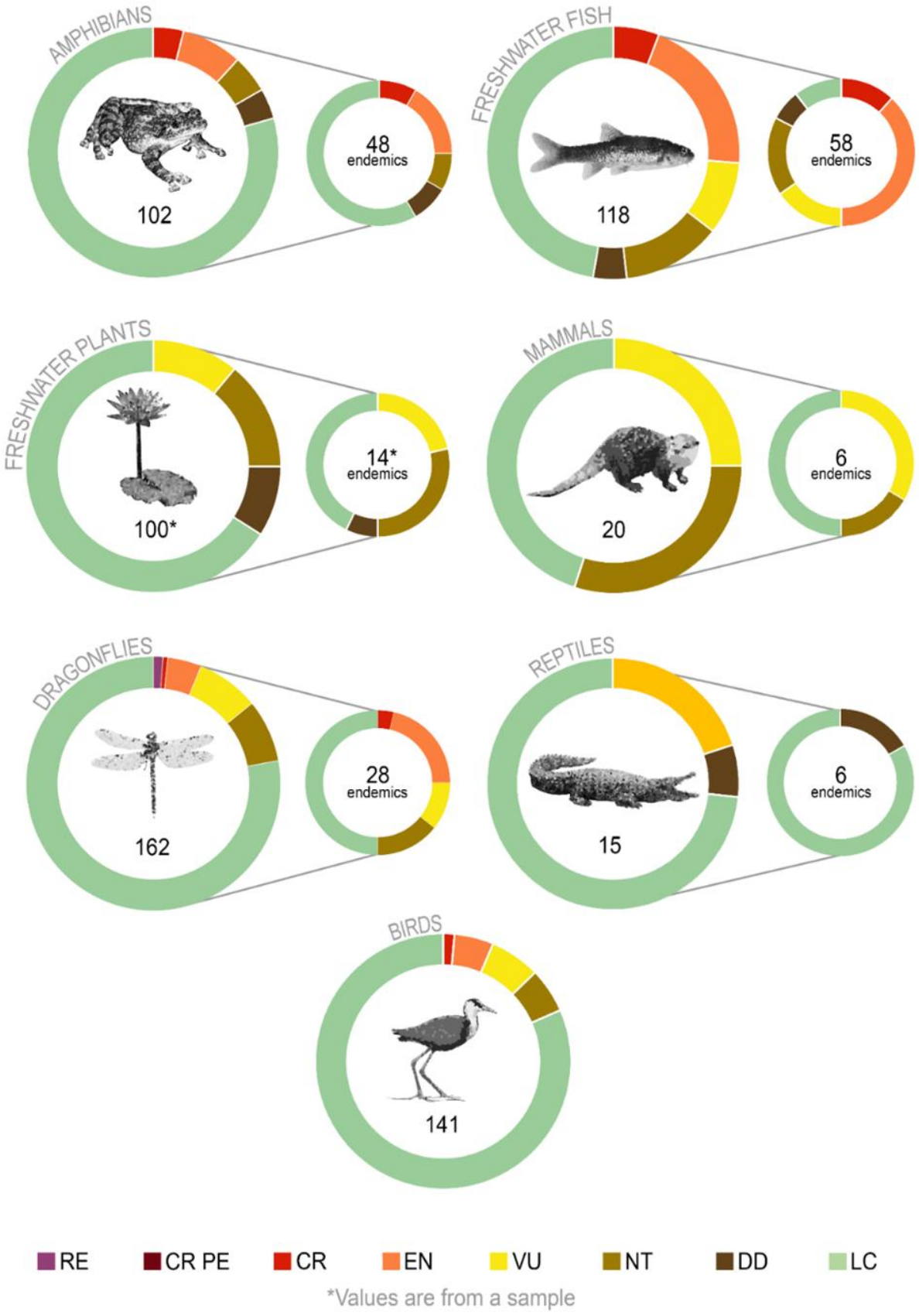
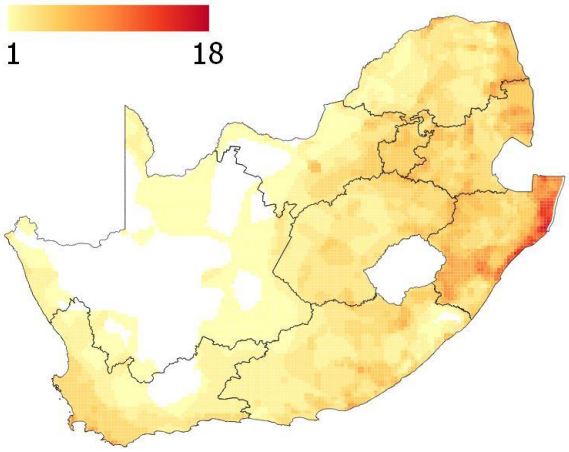
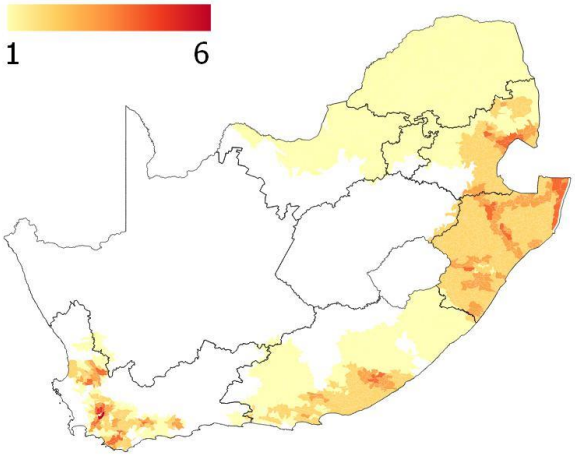


Figure 7.4. The number of taxa in each Red List category for each taxonomic group shown for all inland aquatic species and for endemics (smaller circles) for each taxon group. EX – Extinct, CR – Critically Endangered, EN – Endangered, VU – Vulnerable, NT – Near Threatened, DD – Data Deficient, RE – Regionally Extinct, and LC – Least Concern.

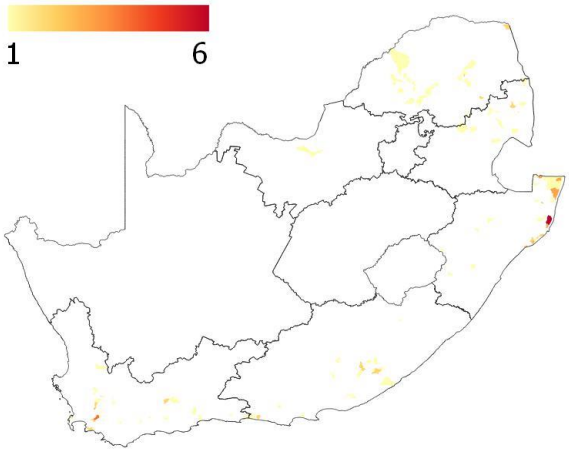
Combination of animals (Amphibians, Birds, Reptiles and Mammals)



Freshwater fish



Odonata (Dragonflies and Damselflies)



Aquaitc plants

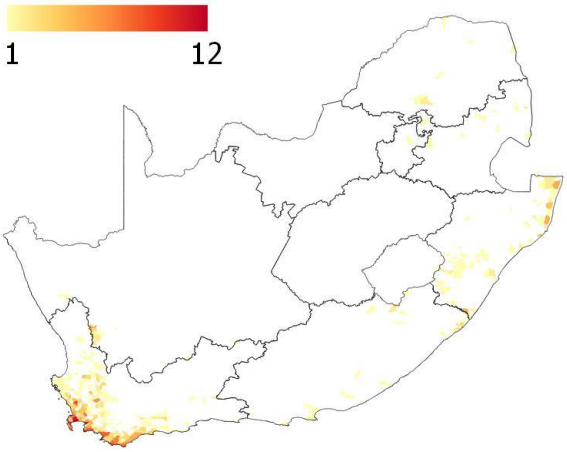


Figure 7.5. Richness of threatened freshwater species, showing maps for all the taxonomic groups included in the inland aquatic assessment, which are a combination map of birds, mammals, reptiles and amphibians, as well as individual maps of freshwater fish, Odonata and aquatic plants. *For amphibians, reptiles and freshwater fish, richness estimates are based on expert validated species distributions informed by habitat suitability and occurrence records. Plants richness estimates are based on modelled distributions while for mammals, dragonflies and birds the estimated richness is based on occurrence data collected from field surveys only and as such may include sample bias.*

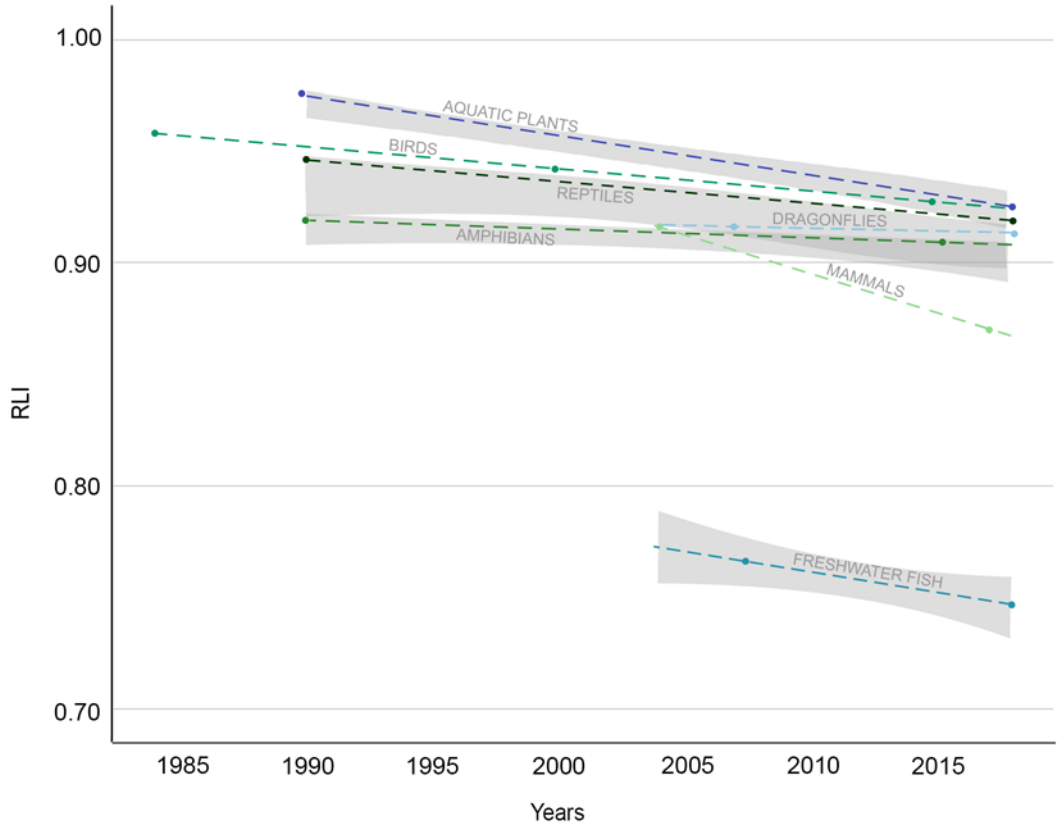


Figure 7.6. The Red List Index calculated for species assessed at different time periods over the past 27 years for the inland aquatic realm. *Each taxonomic group has at least two assessments where change in status of species over time has been calculated.*

Table 7.2. Summary of species driving Red List Index (RLI) change in the inland aquatic realm.

Taxon group	No. of disaggregated taxa assessed	Back cast assessment date	Most recent assessments date	Genuine improvement in threat status (no. taxa & %)	Genuine increase in threat status (No. taxa & %)	Main pressures driving change in status
Amphibians	102	1990	2018	0	5 (4.9)	Habitat loss and invasive alien species.
Reptiles	15	1990	2016	0	3 (20)	Habitat degradation.
Freshwater Fish	118	2007	2018	0	8 (6.7)	Invasive alien species, Habitat loss and Pollution.
Birds	141	2000	2015	0	5 (3.5)	Habitat loss and degradation - Habitat drying.
Mammals	20	2004	2016	0	4 (20)	Habitat loss and degradation – Habitat draining.
Dragonflies	162	2006	2018	2(1.2)	4 (2.4)	Improvement – invasive alien plant clearing, deterioration by habitat loss and degradation.
Aquatic Plants	100	1990	2018	0	14 (14)	Invasive alien plants.

A meta-analysis of the pressures from the RLA indicates that the major drivers of pressure on freshwater fish are impacts of invasive alien fish species, pollution, dam and water management use (Section 4.2.4, Figure 7.7). At least 81% (51 taxa) of freshwater fish ToCC are impacted by invasive alien species, while 70% (44 taxa) are threatened by agriculture and forestry effluents (pollution). A further 63% (40 taxa) of ToCC are impacted by dams and water management/use which includes over-abstraction of above-ground water, change in hydrology, dam construction causing fragmentation as well as sedimentation.

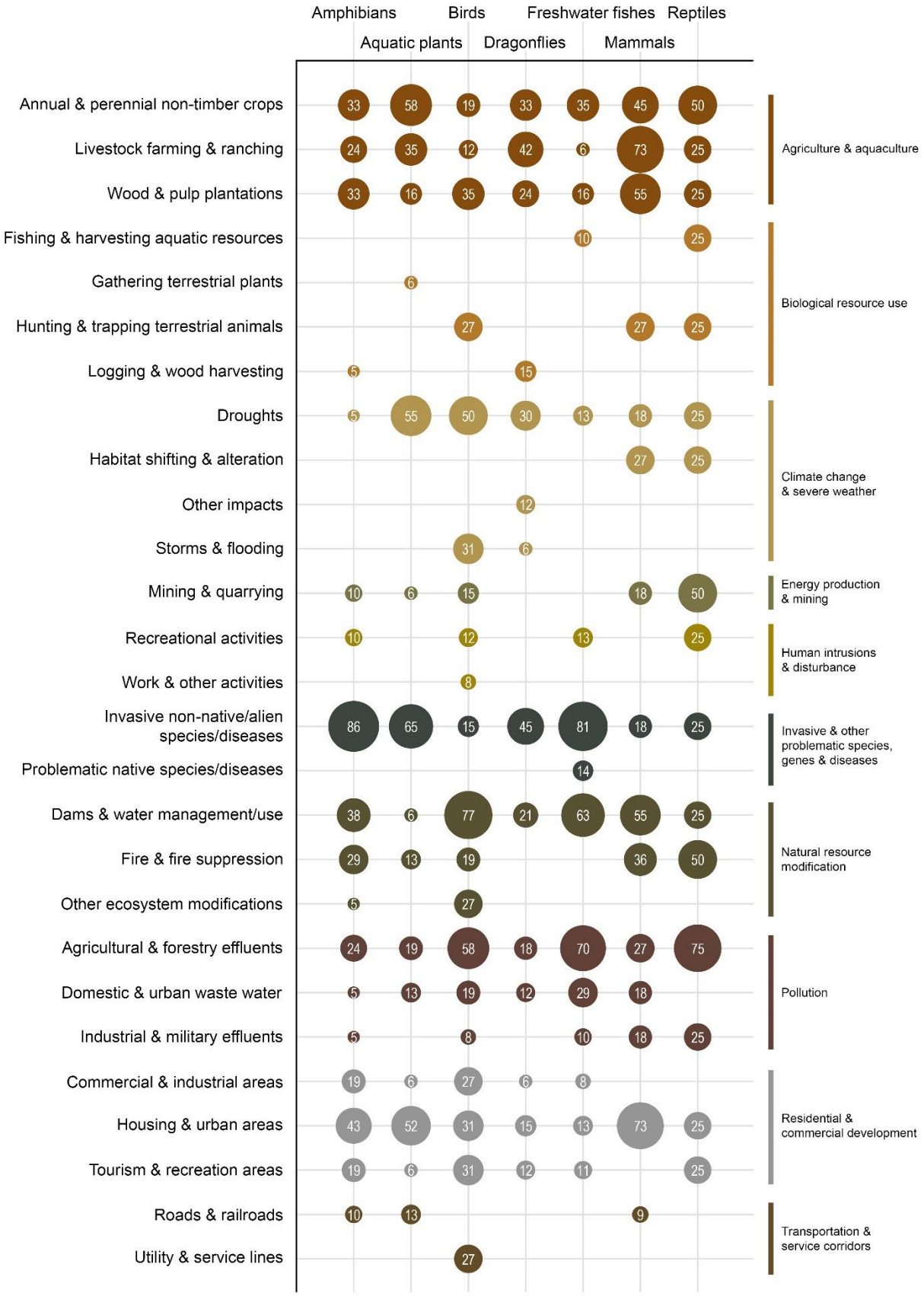


Figure 7.7. Pressure matrix for Taxa of Conservation Concerns (ToCCs) based on a meta-analysis of the South African Species Red List Database for inland aquatic species. The size of the bubble corresponds to the percentage of ToCC in the taxonomic group that is subject to each pressure.

Invasive alien species (IAS), impact freshwater fish through predation (e.g. *Micropterus* species). These IAS directly impact native species, by feeding on juvenile individuals and reducing the population sizes. In many areas, indigenous freshwater fish have been extirpated due to predation by IAS. Invasive Alien Fish also outcompete native species for resources and in some cases such as with the Mozambique tilapia (*Tilapia mossambicus*), there is hybridization with the invasive Nile tilapia (*Oreochromis niloticus*). The pathway for most invasions has been angling, with provincial fish hatcheries such as the now defunct Jonkershoek hatchery outside Stellenbosch playing a major role in the production, supply and distribution of a substantial number of fish species including Common Carp (*Cyprinus carpio*), three Trout species, three Bass species, Tench (*Tinca tinca*), Bluegill (*Lepomis macrochirus*), Mozambique tilapia and Mosquitofish (*Gambusia affinis*) (Impson 2016). Other significant pathways for invasion have been aquaculture and the ornamental fish trade, however the negative impact caused to date on indigenous taxa means extensive research and planning is required as part of the inland fisheries sector development to prevent further introductions and spread of IAS (Box 7.1). CapeNature has tested river rehabilitation projects involving localised eradication of invasive alien fish, one of which has been the successful removal of Smallmouth Bass (*Micropterus dolomieu*) from 4 km of the Rondegat River in the Western Cape Province (see Chapter 9, Box 9.4).

Further, the African Sharptooth Catfish (*Clarias gariepinus* – LC) was identified in the previous RLA (2007) as an upcoming potential future threat, and it has spread as predicted (Darwall *et al*. 2009). Cambray (2003) identified the need for urgent research on this species. In a recent review it has been confirmed that this species has been introduced beyond its geographical barriers and has successfully established in a range of habitats. These introductions have been facilitated by escapees from aquaculture facilities as well as illegal introductions. However there is still a paucity of research on their specific impacts, as most impacts are inferred from field and laboratory observations (Weyl *et al*. 2016). The new emerging threat of invasive alien crayfish species requires close monitoring and rapid interventions, similar to the African Sharptooth Catfish (*Clarias gariepinus* – LC) these crayfish species have already started to spread without much control (Box 7.2).

Pollution in a range of forms from agricultural and forestry effluent, domestic and urban waste water and industrial effluent are impacting freshwater fish ToCC. A large number of rivers are impacted by pollution as 67% of rivers are degraded (see Section 5.2.1.). For example, the Elands River (Inkomti system) flowing past Machadodorp to its confluence with the Crocodile River, is polluted due to a Sappi's Ngodwana paper mill as well as the Machado Waste Water Treatment Works (WWTW) and informal settlements occuring close to the river. These sources of pollution are all impacting on the Incomati Suckermouth (*Chiloglanis bifurcus* – CR) (Roux & Hoffman 2017). The Elands River and its tributaries have been identified as a priority freshwater environment (Important Fish Area) for fish conservation through the National Freshwater Ecosystem Priority Areas (NFEPA) (Driver *et al*. 2012; Nel *et al*. 2011a; 2011b). The Barrydale Redfin (*Pseudobarbus burchelli* – CR) is impacted by eutrophication from the sewage effluenct discharge into the lower Tradouw River below Barrydale (Jordaan & Chakona 2017). A newly described species endemic to the Krom River system, the Krom River Minnow (*Pseudobarbus senticeps* – CR), has been extirpated from its historic range mainly as a result of IAS, while in the Assegaaibosch River, the population is impacted by excessive pollution from settlements in the sub-catchment (Chakona 2017). While some species have a high tolerance for polluted systems such as *Engraulicypris gariepinus* (Bills 2018), the African Sharptooth Catfish (*Clarias gariepinus* – LC) and several tilapia species, most other species are intolerant of polluted water and this is reflected by the increasing incidences of fish kills due to mining effluent and poorly maintained and managed WWTW. In the southern parts of the Western Cape with its hot dry summers at the Olifants-Doring River system, the impact of pollution has been exacerbated by the recent drought and over-

abstraction of water for agricultural activities (see Chapter 9, Box 9.3) and similar conditions have been experienced in KwaZulu-Natal (O'Brien 2017).

Box 7.1. Inland Fisheries in South Africa

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In South Africa, freshwater fishes are utilised primarily for subsistence and recreation by anglers and small-scale fisheries in some regions. **There are about 1.5 million recreational anglers in the country, many of whom fish in freshwaters** (Weyl & Cowley 2015). Some are organised into clubs that are affiliated to formal angling organisations such as the South African Confederation of Recreational Anglers, whilst others represent South Africa at international angling tournaments. These **recreational fisheries contribute significantly to the local and national economy** through expenditure in the retail and tourism sectors (Weyl & Cowley 2015). The contribution of subsistence angling to food security is less well defined, but examples such as the use of Lake Gariep on the Orange River by more than 450 subsistence anglers, indicate that it is an important contributor in some communities (Ellender *et al.* 2010). Formal small-scale fisheries are rare, but on Bloemhoff Dam on the Vaal River, seine net fisheries harvest more than 200 tons of fish a year and contribute to employment in nearby settlements (Barkhuizen *et al*. 2016). As a result, inland fisheries are a potential avenue to address South African National Development Plan objectives concerned with food security and job creation (former Department of Agriculture Fisheries and Forestry, Draft Inland Fisheries Policy, 2018).

Native species that are of interest to anglers include larger species such as the Largemouth Yellowfish (*Labeobarbus kimberleyensis* – NT), Rednose Labeo (Labeo *rosae* – LC), Mozambique Tilapia (*Oreochromis mossambicus* – VU) and African Sharptooth Catfish (*Clarias gariepinus* – LC) (Weyl & Cowley 2015). As good fisheries are generally dependent on healthy ecosystems, anglers often engage with government on conservation issues. For example, the Largemouth Yellowfish (pictured below), is South Africa's largest cyprinid and is used as a river conservation flagship species in the Vaal and Orange River systems (Granek *et al.* 2008). Alien fishes, such as Rainbow Trout (*Oncorhynchus mykiss*), Common Carp (*Cyprinus carpio*) and Largemouth Bass (*Micropterus salmoides*) that were introduced into South African freshwaters since the 1890s, are however currently the most important components of inland fisheries in South Africa (Ellender *et al*. 2014).

Due to the relatively low development of South Africa's inland fisheries, current utilisation levels are low and there are currently no freshwater fishes that are threatened by over-exploitation. This may be subject to change as most large native species are characterised by long-lived, slow-growing and late-maturing traits that infer vulnerability to overfishing and long recovery after stock depletion (Weyl & Cowley 2015). **It is therefore important that the potential impacts of fisheries on native species are considered when planning for the development of the sector.** In addition, fisheries stock enhancements through the introduction of alien species are a major driver of the spread of alien fishes (Ellender *et al.* 2014). As alien fishes are one of the major threats to small-bodied native fishes in the country, the use of legislative instruments such as the NEMBA, which restrict the stocking and use of alien fishes in fisheries to areas of high conservation concern, will become increasingly important (Woodford *et al.* 2017).

Photo: Largemouth Yellowfish (*Labeobarbus kimberleyensis*). Photo credit: Leon Barkhuizen.

Box 7.2. Invasive freshwater crayfish in South Africa, a two–way affair, manage and/or eradicate

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The Redclaw Crayfish (*Cherax quadricarinatus*) and the Redswamp/Louisiana crayfish (*Procambarus clarkii*) have been introduced into South Africa and are now naturalised in the wild. The two species however have different distribution ranges. The former is widespread while the latter is localised. This infers different management approaches to the invasions as outlined below.

Redclaw Crayfish is indigenous to Australia and has established widespread in several river catchments in South Africa and neighbouring countries (Nunes *et al*. 2017a). The Redclaw Crayfish was first detected in South Africa in 2012 and it is assumed they were introduced through natural dispersal of aquaculture escapees from Swaziland. It is now established in the Komati River and adjacent river systems such as Mbuluzi, Usutu, Lomati, Mlawula and Crocodile rivers (Nunes *et al*. 2017a; Petersen *et al*. 2017). This species is also known to be used in the aquarium trade, yet sparse information is available to quantify the introduction of the species through this pathway. The species is currently listed on the A&IS Regulations (2016) as a category 1b species - *species that must be controlled and where possible removed and destroyed, and any form of trade or breeding is strictly prohibited*. To date there is no management programme that has been implemented to manage the Redclaw Crayfish invasion. There is need for such a species management plan in order to reduce the species spread and impacts. This species has also been introduced and is now naturalised in five countries in the sub-region including Mozambique, South Africa, Swaziland, Lesotho, Zambia and Zimbabwe (Nunes *et al*. 2017). These riparian linked countries have an agreed Southern African Development Community (SADC) Protocol on fisheries that seeks consensus on the introduction of alien species into shared aquatic ecosystems. Cooperation and commitment to this protocol is essential for the effective management of alien species within the region and to prevent further cross-border introductions.

Red swamp/Louisiana Crayfish (*Procambarus clarkii*) is indigenous to Mexico and the south-east United States of America. It has been introduced into many countries in the world as part of aquaculture and the aquarium trade. In other countries where it has invaded, it escaped aquaculture facilities and entered the natural system. In East Africa, specifically Kenya, this species was introduced in the 1970's and has since has caused a reduction in plant species abundances as well as competitive exclusion of native crustacean species. Further, it is a burrowing species that digs tunnels as deep as 90 cm, a behaviour that causes physical damage to irrigation infrastructure, river banks and dams. This is especially an important threat in a water scarce country like South Africa, where irrigation plays an important role in the agricultural sector.

In South Africa, the Louisiana Crayfish (*Procambarus clarkii*) is currently known from only two localities. Its introduction has been strongly linked to the aquarium trade, where it was illegally imported into South Africa and sold. It was first recorded in 1988 from the Driehoek Farm, near Dullstroom, Mpumalanga, South Africa (Nunes *et al*. 2017a). It occurred in a small section of the Crocodile River that flows through the farm. Eradication was considered by the then Transvaal Nature and Environmental Conservation Directorate, but these eradication efforts failed as a recent survey found the species to be still present at this locality, albeit in very low numbers (Nunes *et al*. 2017b). Unfortunately, a recent public announcement by the Department of Environmental Affairs (DEA) reported that the Louisiana Crayfish has established in the Mimosa municipal dam in the Free State Province's Goldfields (Barkhuizen & Potgieter 2018). Local scientists have confirmed the species identity and that the species is established. The Department of Environment, Forestry and Fisheries (DEFF) is working closely with Free State provincial conservation authorities and other concerned stakeholders to develop a species management strategy for the Louisiana Crayfish . Such a plan will likely consider eradication as an option due to the species' localised distribution, as well as the implementation of a a public awareness programme to try and curb further spread of the species. This Louisiana Crayfish species is currently listed as prohibited in South Africa and the A&IS regulations needs to be updated to reflect that the species is already established in the country.

Redclaw and Louisiana crayfish have both been documented to cause negative environmental impacts elsewhere in the world in areas they have been introduced (Hamman & Jordaan 1988). However, in South Africa, there is limited

information available on the impacts of these species in areas where they have established. Most crayfish species are keystone consumers in their native habitats, feeding on benthic invertebrates, detritus, macrophytes and algae in lotic and lentic waters. They are also important prey for otters, birds and fish. Crayfish are well-accustomed to integrate into the food web, at many levels in the invaded range which can cause adverse changes to community structure and functioning. Crayfish are also bio-turbators (species that reworks soils and sediment), potentially having direct and indirect impacts on the ecosystem.

In other countries the species have been managed by using mechanical (trapping and electrofishing), physical (draining water bodies or creating barriers), chemical (use of biocides) or biological (microbial insecticides and introduction of fish predators) methods of control, and/ or a combination of these control methods, such as reducing the population numbers using mechanical or physical methods, followed by predation by natural occurring predators such as crocodiles and otters (Freeman *et al* 2010). These methods should be tested and applied in South Africa in order to contain and manage these species, as they are predicted to have a much larger distribution potential based on habitat suitability models.

Redclaw and Louisiana crayfish have both been documented to cause negative environmental impacts elsewhere in the world in areas they have been introduced (Hamman & Jordaan 1988). South Africa is currently undergoing a Strategic Environmental Assessment (SEA) for aquaculture where the risks and benefits of utilizing certain species will be evaluated together with potential negative impacts to the environment. The two species can potentially become conflict-generating species, as they are conceived to provide some benefits to society (aquaculture and aquarium trade) but the species has also been implicated in causing negative environmental impacts (see Zengeya *et al*. 2017). In South Africa, the scale of these benefits and costs, especially the negative impacts is still to be evaluated.

Photo: The Louisiana Crayfish (*Procambarus clarkia*). Photo credit: Leon Barkhuizen.

Alterations to the hydrological regime, loss of natural habitat and subsequent fragmentation impacts 40 freshwater fish ToCC. For example, the Twee River Redfin (*Pseudobarbus erubescens* – CR) endemic to the Twee River Catchment in the Olifant-Doring River System, has suffered from over-abstraction of surface water especially during the summer months. This practise has reduced available stream flow. Water is abstracted mainly for intensive farming of deciduous and citrus fruit, these orchards are planted very close to the river which also exposes the species to agrochemicals spray drift and water contamination from irrigation return flows. The impacts of pesticides have not been assessed specifically in the Twee System where this species occurs (Jordaan *et al.* 2017). The Incomati Suckermouth (*Chiloglanis bifurcus* – CR) is endemic to the Upper Crocodile River and Elands River of the Inkomati River System, South Africa (Jubb & Le Roux 1969; Gaighe 1969; Kleynhans 1982; 1984; 1986; Skelton 1987; Kleynhans *et al*. 1992) and in the

Upper Mlumati River in Swaziland (Monadjem *et al*. 2003; Bills *et al*. 2004). In the Crocodile River (Inkomti system), below the Kwena dam, the population has gone extinct most likely due to continuous flow regulation from the Kwena Dam (Roux & Hoffman 2017a).

As part of the NFEPA process (Nel *et al*. 2011a; 2011b), fish sanctuaries were identified to designate the most important catchments for the conservation of threatened and range restricted fish species. Many 'fish sanctuaries' are not situated in formally protected areas and remain susceptible to a range of anthropogenic pressures. Some landowners have been actively involved in conserving threatened fish species, whilst CapeNature as the provincial conservation agency for the Western Cape, has been promoting the conservation of these 'fish sanctuaries' (Impson *et al*. 2017). An example of these activities includes the major collaborative project, the Berg River Improvement Programme, led by the Pollution and Chemical Management Directorate within the Department of Environmental Affairs and Development Planning (DEAD&DP) along with many partners including CapeNature to improve the water quality within the Berg River catchment (quaternary catchments G10A–B, G10C–D, G10E–G10M) (BRIP, 2014). The rehabilitation of the riparian zone and management of the buffer zone was prioritised, which involved the plan for the reintroduction of White Fish (*Cheilobarbus capensis* – EN) (Gouws & Gordon 2017). While, Mpumalanga Parks and Tourism Agency (MPTA) worked closely with Mondi Timbers to support the habitat of the Treur River Barb (*Enteromius treurensis*) by establishing National Heritiage sites. However the area where this species occurs has now changed land ownership and there is no formal agreement in place with the new landowners, York Timbers (Roux & Hoffman 2017b).

In recent years, for specific groups of freshwater fish, there has been an increased effort in research particularly in the Western Cape and some areas of the KwaZulu-Natal Province. This includes research on Cyprinids (e.g. *Pseudobarbus*) and Cape *Galaxias*, leading to new species descriptions such as the Giant redfin (*Pseudobarbus skeltoni* - EN) (Chakona & Swartz 2013). Recent intensive field work in the Western Cape has increased the number of known populations of some of the threatened species and in some cases resulted in the down listing of species (e.g. *Sedercypris calidus* (VU to NT) (Van der Walt *et al.* 2017), *Pseudobarbus asper* (EN to VU) (Jordaan & Chakona 2017)).

There are four eel species present in South Africa. Due to eels completing different parts of their lifecycle in distinct marine and freshwater environment, and due to their wide global range, South Africa's four eel species have been assessed at the global level. *Anguilla bengalensis* is Near Threatened (NT) with most threatening impacts occurring in other countries where this species occurs. Fishing pressure and poisoning have, however, been identified as specific pressures occurring in South Africa. In addition, major impoundments and weirs, that are barriers to eel movement, may reduce this species area of occupancy in future (Jacoby *et al*. 2014). *Anguilla bicolor*, has been assessed for the first time as NT globally in 2014, the major driver for up listing the species has been the growing exploitation of the species as a result of other eel species having been over-exploited. Commercial eel exploitation is limited in South Africa, however, the most vulnerable stage of this species' life cycle, when it returns to the marine environment to spawn is under pressure with large impoundments and weirs hindering migration as well as harvesting by subsistence anglers (Jacoby *et al.* 2014). While *Anguilla marmorata* and *Anguilla mossambica* experience similar pressures on their migratory movements, these species are still abundant (most east flowing rivers from Breede River eastwards) and are both currently assessed as Least Concern.

Table 7.3. The number of taxa in each IUCN RedList category for all indigenous and endemic species occurring in inland aquatic ecosystems of South Africa for each of the seven taxonomic groups that have had Red List assessments completed.

Red List Category	Birds		Mammals		Reptiles		Amphibians		Plants - sample		Freshwater Fish		Dragonflies	
	All indigenous	Endemics	All indigenous	Endemics	All indigenous	Endemics	All indigenous	Endemics	All indigenous	Endemics	All indigenous	Endemics	All indigenous	Endemics
Extinct	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Regionally Extinct	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Extinct in the Wild	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Critically Endangered (Possibly Extinct)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Critically Endangered	**2**	0	0	0	0	0	**4**	**4**	0	0	**7**	**7**	**1**	**1**
Endangered	**7**	0	0	0	0	0	**8**	**8**	0	0	**24**	**22**	**5**	**5**
Vulnerable	**9**	0	**5**	**2**	**3**	0	0	0	12	3	11	9	14	4
Near Threatened	**8**	0	**6**	**1**	0	0	**5**	**4**	**10**	**4**	**15**	**10**	**13**	**4**
Data Deficient	**0**	0	0	0	1	1	**4**	**4**	**9**	**1**	**6**	**4**	0	0
Rare and Extremely Rare	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0
Least Concern	**115**	0	**9**	**3**	**11**	**5**	**81**	**28**	**69**	**6**	**55**	**6**	**127**	**14**
Total	**141**	0	**20**	**6**	**15**	**6**	**102**	**48**	**100**	**14**	**118**	**58**	**162**	**28**

Dragonflies and Damselflies (Odonata)

Odonata (dragonflies and damselflies) species are excellent indicators of freshwater habitat condition and serve as umbrella species for other aquatic macro-invertebrates (Samways & Simaika 2016). There are 162 species known to occur in South Africa, with a fifth of these species endemic to the country (Figure 7.4). This group has been assessed multiple times globally and nationally. This is the first time that this group has been included in an NBA report. Recently, an update was completed for all endemic species at the global level (2015–2017). A select number of species were subsequently prioritized for national assessments (2017). All these taxa qualify as Least Concern globally, but in South Africa are at the edge of their geographical range and threatened in these areas.

Most of the dragonfly species have been assessed as Least Concern (79%), as they have wide distribution ranges. They have also shown little change in their Red List status over the past 10 years, as measured using the RLI (Figure 7.6). Some taxa are range restricted and 33 taxa (20%) are ToCC (Figure 7.4 and Table 7.2). The main pressure faced by dragonflies is the shading out of their habitat by invasive alien trees (15 taxa), they are also threatened by habitat transformation due to livestock farming (14 taxa) and non-timber crop cultivation (11 taxa) (Figure 7.7). Some reprieve for the 15 taxa facing impact from invasive alien trees has come from highly effective invasive tree eradication programmes, with some remarkable success stories of re-colonization of habitats following the removal of these trees (Box 7.3). Two species (*Chlorocypha consueta* and *Crenigomphus cornutus*) that were previously assessed as Critically Endangered Potentially Extinct (CRPE) have been re-assessed as Regionally Extinct (RE). These species were searched for extensively over many years but have not been re-recorded since their initial discovery in South Africa in the 1950s and 1960s respectively.

Box 7.3. Dragonfly recovery following removal of invasive alien trees, a victory

By Prof. Michael J. Samways, Distinguished Professor, Department of Conservation Ecology and Entomology, Stellenbosch University

South Africa has 162 dragonfly species, with a fifth endemic to the country (Simaika & Samways 2009; Clausnitzer *et al*. 2012). Some of these endemic species are ancient, with the oldest, the Yellow Presba (*Syncordulia gracilis*) holding the record at an estimated 59.57 million years old (Ware *et al.* 2009).

Dragonflies are variously sensitive to habitat condition, and, as a group, are good indicators of water quality (Simaika & Samways 2012). South African dragonflies in general prefer sunlit conditions, from fully open biotopes with low vegetation, to sun flecks among closed forest canopies (Smith *et al.* 2007; Samways & Niba 2010). Adults are also sensitive to in-water conditions, selecting microhabitats best suited not only for them but also their larvae (Kietzka *et al*. 2017).

South African species range from those that are widespread, and often locally common, to those that are highly localized and often confined to a particular geographical area. The Greater Cape Floristic Region is especially important for highly localized and rare endemic species (Grant & Samways 2007; 2011). While they are well adapted to harsh natural conditions of flood and drought, they can be highly sensitive to novel impacts such as invasion from invasive alien trees (IATs), especially *Acacia* spp., which shade out their habitat (Samways & Taylor 2004; Samways & Sharrat 2010). The shading effect comes from replacing indigenous vegetation by dense stands of IATs that block-out essential light. It is these IATs that overall are the greatest threat to the endemic species, resulting in several species being globally Red Listed (Samways 2006).

The Working for Water Programme has been highly successful, enabling recovery of indigenous aquatic biodiversity. Removal of IATs has provided extinction reprieve for several species, with three of them (*Spesbona angusta* (EN), *Pseudagrion newtoni* (VU), and *Proischnura polychromatica* (CR)) only having been rediscovered, after decades of no sightings, at localities where IATs had been removed (Samways *et al.* 2005).

These three species, as well as others, no longer occur at their type localities, which are too infested with IATs. However, at other localities, where IATs have been cleared, and natural, open vegetation has re-established, these species were re-recorded for the first time in many years. These three species illustrate how rapidly species can recover when an identified major threat such as IATs is mitigated.

Spesbona angusta and *Proischnura polychromatica* were rediscovered in the Du Toits River, Western Cape. In turn, *Pseudagrion newtoni* was found in Mpumalanga, and no longer occurs at its KwaZulu-Natal type locality, which is not only overgrown with IATs, but also overgrazed by livestock.

A freshwater index, the Dragonfly Biotic Index, was developed to measure changes in the dragonfly fauna, whether negatively from the impact of IATs, or positively through indicating recovery following removal of IATs (Samways & Simaika 2016). Recovery of endemic dragonflies following removal of IATs has been particularly good in the Western Cape, but improvements have also been excellent nation-wide.

(a)

(b)

(c)

Photos of (a) *Spesbona angusta,* (b) *Pseudagrion newtoni &* (c) *Proischnura polychrimatica* (Photos credit: Michael Samways).

Plants

Plant species occurring and dependent on aquatic habitats have been assessed based on a sample of 100 species, from a set of 337 species that have been identified as inland aquatic species (Cook 2004). Nine (9%) taxa have been assessed as threatened, all qualifying under the category Vulnerable, a further 24 (24%) taxa qualify as either Near Threatened or Data Deficient (Figure 7.4 and Table 7.2). Sixty-six taxa were assessed as Least Concern. Of the 100 sampled taxa, 14 are endemic to South Africa, and three of these are threatened and five taxa are additional ToCC. What is important to note is the large number of Data Deficient species (nine taxa), (species without sufficient information available to make an informed assessment), this represents 9% of the sample, and the majority of these have no recent records for the species concerned and are only known from a few historical records. This proportion of Data Deficient species is much higher than for all plants in South Africa, where only 6% of plants are assessed as Data Deficient (Raimondo *et al*. 2019). More research is required on species that are restricted and dependent on these aquatic habitats and their threat status needs updating.

Invasion of wetlands by alien invasive plants is the major pressure on inland aquatic plants (Figure 7.7), with 20 taxa directly impacted due to competition for space and resources from invasive species. *Isoetes capensis* (VU) is one of the species that is heavily impacted by alien invasion. It only occurs in lowland wetlands in the South Western Cape, and the majority of the localities where it remains are threatened by alien invasive acacias (e.g. *Acacia saligna* and *A. mearnsii*). Invasive plant species are also the main pressure driving the change in RLI for aquatic plants. Fourteen taxa increased in threat status since 1990 due to increases in habitat loss and degradation as a result of invasive alien plant invasions (Table 7.3). Not only is this group of taxa affected by alien invasion, but it is also severely impacted by habitat loss and fragmentation mainly due to crop cultivation, as 18% of the plant species assessed are declining as a result of crop cultivation. One example is *Oxalis dines* (VU), restricted to Cape Vernal Pools and other similar temporarily inundated habitats, which is experiencing ongoing habitat degradation due to crop cultivation and trampling by livestock. It is also susceptible to severe drought conditions and these events exacerbate the impacts of other pressures. Although a number of aquatic plants are subjected to severe pressures, the majority are resilient to habitat changes as evident in the fact that 66 % of the plants assessed qualify as Least Concern (Sieben, *pers. comm*., 2018).

Inland aquatic plants included in this chapter refers to aquatic species as per definition by Cook (2004), which includes plants whose photosynthetically active parts are permanently or at least, for several weeks or months each year partly or wholly submerged in water or which float on the surface. This includes plants making use of wetland as well as riparian zone habitats and other water bodies.

Mammals

At least 343 mammal species occur in South Africa, of which, 331 species, subspecies or subpopulations were assessed in 2015 (Child *et al.* 2016). At least 20 of the 331 taxa assessed, make extensive use and are dependent on inland aquatic habitats. Of these 20 species, 20% (5 taxa) are threatened and 30% (6 taxa) Near Threatened (Figure 7.4 and Table 7.2). Only six species are endemic and two of these are Vulnerable and one Near Threatened, these include the Laminate Vlei Rat (*Otomys laminatus* – NT) that is only known from two isolated populations in the Western Cape and in the Drakensberg Mountains of KwaZulu-Natal and Mpumalanga, and could in future represent two separate species, following taxonomic investigation. This species occurs in wetlands, and since 1990, there has been a reduction in its habitat due to anthropogenic activities and drier climatic conditions. Agricultural activities, human settlement sprawl and

mining, has also contributed to this species habitat reduction (Taylor *et al.* 2016b). The African Marsh Rat (*Dasymys capensis* – VU) requires intact river and wetland systems, and has been impacted by a loss of natural wetland habitat in the last ten years. These losses are attributed to agricultural and human settlement, which in turn increases the pressures of water abstraction, overgrazing, pollution and invasive alien plants (Pillay *et al*. 2016). In a different environment, Sclater's Forest Shrew (*Myosorex sclateri* – VU), is endemic to subtropical swamps, wetlands and coastal forests in northern KwaZulu-Natal and like the African Marsh Rat, requires intact habitats to persist. Its habitat is fragmented and it is continuously being lost due to coastal development and other development pressures (Taylor *et al*. 2016a). A meta-analysis of pressures affecting species based on data collated during the red listing assessment process for all inland aquatic ToCC shows that the main pressures to inland aquatic dependent mammals are housing and urban expansion, livestock farming and dams and water management activities. All these land uses result in transformation of wetlands and typically in the drying up of these habitats. At least eight taxa (73% of ToCC) are impacted by housing and urban development and a further eight taxa (73% of ToCC) are impacted by agricultural activities, causing habitat loss and degradation. These include taxa that make use of both inland aquatic as well as terrestrial habitats. The Spotted Otter (*Hydrictis maculicollis* – VU) has been assessed as Vulnerable based on an inferred reduction in its population numbers, mainly as a result of alterations or degradation of freshwater habitats and riparian vegetation. This decline in available habitat is driven by increased agricultural activities and human settlements, which in turn increases direct and indirect persecution of the species (Reed-Smith *et al.* 2015). At least six taxa (55% of ToCC) are impacted by dam and water management or use, this includes over-abstraction of surface water. Sclater's Forest Shrew (*Myosorex sclateri* – VU) is an example of a species that is both impacted by habitat loss and degradation of moist habitats and rank grasslands due to over-abstraction of surface water as well as urban, industrial and agricultural expansion (Taylor *et al*. 2016a).

When considering the RLI, there is a sharp decline in RLI value since 2004 that is contradictory to the findings for terrestrial mammals where decline in RLI since 2004 is minimal (Raimondo *et al*. 2019) (Figure 7.6). Of the 20 taxa dependent on inland aquatic systems, four species have increased in their threat status, and this has largely been due to reduction in wetland habitat causing species population reduction in the last ten years (Table 7.3). There has been no improvement in species status, as has been observed for other mammals in terrestrial habitats (Raimondo *et al*. 2019). This illustrates that there needs to be more conservation effort focused on restoring and maintaining key habitats for river and wetland dependent mammals.

Birds

Waterbirds and birds dependent on freshwater and estuarine ecosystems for food resources are excellent indicators of the health of ecosystems. A total of 18% (26 birds) of the 141 taxa classified as waterbirds that have been assessed within this group are threatened or Near Threatened, and none are endemic to South Africa (Figure 7.4 and Table 7.2). These taxa are mainly threatened by natural system modification, due to dam and water management activities (35 taxa impacted). Pollution from agricultural activities (25 taxa impacted) follows in severity, with climatic related events including drought, storms and flooding also having a serious impact (24 taxa impacted) (Figure 7.7). One threatened wetland dependent bird is the White-winged Flufftail (*Sarothrura ayresi* – CR), it is one of the world's most threatened and rare birds. This species is only known from Ethiopia and South Africa, and only recently it was found to breed in South Africa. This species inhabits wet high-altitude grasslands, and loss of these very sensitive wetland habitat due to changes in hydrology caused by over-abstraction of water has been so severe that the species is no

longer found at certain localities. For example it was lost at Seekoeivlei (Free State Province) after the raising of the dam wall and subsequent flooding of its habitat (Taylor *et al*. 2015). There is currently a conservation plan being implemented for this species through collaborative efforts of BirdLife South Africa, Middelpunt Wetland Trust and the Ethiopian Wildlife and Natural History Society (Colyn *et al.* 2017). The Wattled Crane (*Bugeranus carunculatus* – CR) is a further example of the devastation habitat loss and degradation has on wetland dependent species. The continuous decline over the past three decades in permanent, palustrine wetlands through intensified agriculture, afforestation, dam construction, alien species infestation and drainage of wetlands is the main drivers of this species risk of extinction (Taylor *et al*. 2015).

Other threatened birdsthat are restricted to a few breeding locations include the Yellow-billed Stork (*Mycteria ibis* – EN) and the Pink-backed pelican (*Pelecanus rufescens* – VU). Both species are declining as a result of wetland drainage, damming for development or agriculture as well as pollution. In the case of the African Black Harrier (*Circus maurus* – EN) it is not the changes in extent of permanently inundated wetlands and reed beds, but the changes in extent of moist wetland edges and surrounding grassland that has the more significant impact as this results in loss of prey habitat (Taylor 2015).

When assessing the RLI for this group, there were few changes in species status, with only five species experiencing deterioration as measured by the index (Figure 7.6). The main driver of change for these species was habitat loss and degradation due to drying of their habitats (Table 7.3).

Of the 11 riverine specialist birds, six are threatened or Near Threatened, major pressures to these species as a group are habitat modification due to dam and water management as well as pollution from agricultural and forestry effluent (Taylor *et al*. 2015). Two specific examples include the Saddle-billed Stork (*Ephippiorhynchus senegalensis* – EN) and Pel's Fishing Owl (*Scotopelia peli* – EN) both impacted by a loss of suitable habitat due to a decline in water quality (pollution) and quantity (e.g. water extract and/or damming) in rivers and other water bodies (Botha 2015a; 2015b).

Frogs (Amphibians)

A total of 125 amphibian species occur in South Africa with a few newly described species not included here, of these 102 species are depended on inland aquatic ecosystems for survival and successful reproduction as per classification in the IUCN Red List. Of these, 102 taxa, 12% (12 taxa) are threatened and an additional 9% (nine taxa) are additional ToCC. Almost 50% (48 taxa) of inland aquatic amphibians are endemic of which 18% (12 taxa) are threatened and 12% (8 taxa) are additional ToCC (Figure 7.4 and Table 7.2). At least 18 (86%) ToCC are threatened by invasive alien species, the presence of these invasive species, specifically invasive alien trees, impacts water storage reservoires and interrupts stream-flow consistancy. For example, the Cape Flats Frog or Micro Frog (*Microbatrachella capensis* – CR) has had all known subpopulations impacted by invasive alien trees, that alter the water qaulity and result in drying out of their breeding sites, this species has also lost most of it habitat to urban development and still faces continued threats from development in its remaining, highly fragmened populations. Amphibians are also heavily impacted by habitat loss to urban development (43% of ToCC) and their habitat is further impacted by dam and water management activities (38% of ToCC). Habitat loss due to annual and perennial non-timber and wood and pulp plantation combined account for 66% of pressures impacting amphibian ToCC.

Amphibians have shown a genuine change (RLI value) in five species threat status over the assessment period (1990–2017), these species have all become more threatened (Figure 7.6) due to a range of pressures. Habitat loss due to livestock farming, coastal development and afforestation, specifically in the

Eastern Cape and KwaZulu-Natal provinces, areas of high amphibian richness, (Figure 7.3) has resulted in three taxa becoming more threatened (Figure 7.5). A meta-analysis of pressures affecting all inland aquatic amphibian ToCC collated during the red listing assessment process shows that major pressures to amphibians are impacts of invasive alien species and problematic native species (e.g. hybridization with *Xenopus laevis*, invasive alien trees – drying out breeding habitat, predatory invasive fish, disease – chytrid infections) as well as habitat loss due to agriculture and residential development which contributes to habitat fragmentation (Figure 7.7).

Reptiles

Of the 407 reptile taxa indigenous to South Africa, 391 species have been assessed, of these 15 make use and are dependent on inland aquatic habitats. Three of the 15 species (20%) dependent on aquatic habitats are threatened and one is assessed as Data Deficient (Figure 7.4 and Table 7.2). The major pressure on these ToCC are agricultural and forestry effluent that are entering the aquatic systems impacting 75% of these species. Furthermore, annual and perrenial non-timber crops, fire and fire suppression and mining and quarrying are each impacting two ToCCs (impacting 50% of ToCC). Veld fires during the wrong season may affect these species during their hibernation period. Mining in dunes is a new pressure, especially on the coastal dunes north of Mtunzini, KwaZulu-Natal for the Variable Hinged Terrepin. Based on the RLI for inland aquatic reptiles, there has been little change in aquatic reptile species status over the assessment period (Figure 7.6 and Table 7.3). Three species experienced a change in status: the Nile Crocodile (*Crocodylus niloticus* – NT to VU), the Yellowbelly Mud Turtle (*Pelusios castanoides* – from LC to VU) and the Variable Hinged Terrapin (*Pelusios rhodesianus* – from LC to VU). The Nile Crocodile species requires a large natural habitat to support a sufficient prey base. However, it has experienced overall extensive degradation of its habitats including fragmentation through dam construction and general pollution and water abstraction of rivers and estuaries. The combination of these pressures has resulted in the species declining to the point that is has been listed as Vulnerable. Based on a recent population estimate, there are only about 5 389 individuals remaining in the wild (Ferreira 2017; Warner 2016), which is 1 000 less than a 2013 population estimate of the species (Woodbourne *et al*. 2012).

Despite only these few reptiles increasing in threat status since 1990, a number of reptiles remain threatened. The Variable Hinged Terrapin (*Pelusios rhodesianus*), is not endemic to South Africa, however, there is evidence that populations in KwaZulu-Natal, have been lost, these losses are ascribed to habitat loss and a decline in habitat quality due to in-filling of its wetland habitat, it is also affected by pollution (Hofmeyr & Boycott, 2017). The Yellowbelly Mud Turtle (*Pelusios castanoides*) has faced similar pressures, and in addition to habitat loss due to in-filling and/or drainage of its wetland habitats, the long term effects of insecticide spraying are suspected to be causing population decline. Further research is required to establish the degree of impact. Both species are found in KwaZulu-Natal and between 1994 and 2011, 46% of their natural habitat has been transformed (Jewitt *et al.* 2015). In the case of the Yellowbelly Mud Turtle, land cover maps shows that apart from conservation areas, the majority of this species range have been modified by anthropogenic changes including forestry and cultivation (Schoeman *et al*. 2013; Jewitt *et al*. 2015).

The Cream-Spotted Mountain Snake (*Montaspis gilvomaculata*) is Data Deficient, little is known about this species, however, it is assumed to make use of mountain streams and vleis at high altitude. This species is endemic to South Africa, specifically in the KwaZulu-Natal Drakensberg Mountain where the only four collections have been made.

7.1.4 Summary of species status and pressures

The results of this assessment of seven inland aquatic taxonomic groups indicate that freshwater fish have a higher proportion threatened taxa than all inland aquatic groups. Interestingly at the global level, amphibians are considered the most threatened taxonomic group that make use of inland aquatic ecosystems based on the current global summary of threat status of the IUCN Red List. However, only a limited number of freshwater fish have been assessed globally while amphibians are much better represented. A possible reason for freshwater fish, being more threatened than amphibians in South Africa is that they only occupy river systems. In contrast, most restricted endemic amphibians occur in wetlands and the species that occupy rivers are generally widespread generalists. Furthermore, amphibians have the ability to move within the different habitats, while fish have very limited dispersal abilities. Similarly, dragonflies, the only other completely aquatic dependent group, are less threatened than freshwater fish, with only a few species assessed as threatened or Near Threatened. While dragonflies are highly sensitive to poor water quality and overall changes in ecosystem condition, unlike fish, they are highly mobile and can move away to seek favourable conditions. Thus their dispersal ability allows dragonflies to escape pressures.

7.1.5 Limitations to the assessment of species threat status

There is an urgent need to increase survey efforts in under-sampled areas for all taxonomic groups, especially in hotspot areas where there are high concentrations of threatened species. Atlas projects over the past decade have increased the number of occurrence records for species, however inland aquatic ecosystems in some areas such as the Karoo and the Drakensberg Mountain Range remain under-sampled. Targeted surveys of a range of taxonomic groups across a representative sample of South Africa's inland aquatic ecosystems are required. Co-ordinated cross taxa surveys have recently been funded by the National Research Foundation's Foundational Biodiversity Information Programme (FBIP) in terrestrial systems (e.g. the Karoo region via the BioGaps project and the Eastern Cape Forest Survey's project). Opportunity exists to request FBIP integrated grant funding for cross taxa surveys of inland aquatic ecosystems. These types of surveys would allow the collection of data on pressures as well as species population statuses. Such data would further support the RLA process as well as other conservation efforts at the provincial level and would allow for further national prioritization using threatened species data.

Currently all assessments for animal taxa in South Africa are done in the IUCN's Species Information System. A centralized assessment system specifically for South Africa that gives access to multiple assessors, would greatly enhance the workflow of the current RLA process.

For freshwater fish, many taxa have only recently been discovered and published in the scientific literature as lineages (e.g. *Galaxias zebratus* complex) and do not yet have formal species level taxonomic descriptions. Red List assessments for these undescribed taxa have been included on South Africa's National Red List http://speciesstatus.sanbi.org/ and some that have been assessed for the first time, are also available on the global IUCN RedList. However, other lineages that were assessed in 2007 but still have not been described were not permitted by the IUCN to be published on the Global IUCN RedList. This is due to IUCN rule that undescribed species may only remain on the IUCN Red List for five years after which they can only be included if they have been formally described. SANBI has a commitment from SAIAB researchers that all newly proposed lineages will be described in the next five years. This work requires funding and training of taxonomist with a passion for the profession. Similar limitations are present for

other taxonomic groups, where conservation actions for newly discovered restricted and threatened endemic species are limited by the availability of experts to formally describe them.

A further limitation for freshwater fish is that for certain taxa few recent records are available this lack of knowledge of the current status of subpopulations makes assessments extremely difficult. Such taxa are a priority to include in future monitoring projects.

Threatened and restricted freshwater fish species distributions are concentrated in the Cape Fold Ecoregion (Ellender *et al.* 2017) (Figure 7.5); these patterns are similar to those reported for the inland aquatic taxonomic groups included in the **Status and Distribution of Freshwater Biodiversity of Southern Africa** (Darwall *et al*. 2009). Our current species richness maps for overall richness as well as threatened species distributions are limited by the lack of modelled species distributions. There is currently active work by the Endangered Wildlife Trust (EWT) to improve species distribution mapping for a select number of vertebrate species in South Africa.

Invertebrates were highlighted in the previous NBA (2011) as under-represented (Driver *et al.* 2012). In this NBA dragonflies were added as the first inland aquatic invertebrate group to be comprehensively assessed. However, there are many more invertebrates that require assessment and that will likely show different patterns to those shown by taxonomic groups assessed thus far. In Box 7.4., we highlight just one of these fascinating groups of invertebrates that require future work. Also noting that not all invertebrate groups lend themselves to RLA, and other methods of monitoring needs to be developed.

7.2 Protection level for species

7.2.1 Species protection level calculation method

Protection level of species is presented for the first time in this NBA. With no global protection level assessment system in existence we have developed a methodology specifically for this NBA. Our approach is a new practical method for tracking progress towards a population conservation target set for each species which provides an indicator at the national level for the effectiveness of a country's protected area network for the conservation of different taxonomic groups. As a starting point we propose the definition of a fully protected species as a species that is adequately represented by viable subpopulations within protected areas where the management is effective to maintain the ecological functioning of the species and prevent population decline.

The Protection level indicator we propose has two components. The first measures how well represented a species is within the protected area network. This component allows the identification of which species require further protection, where distribution data for species not represented or poorly represented within the protected area network are prioritised for inclusion in spatial planning for protected area expansion. Component two includes a measure of management effectiveness within each protected area and when combined with protected area representation provides an overall effective protection level measure for each species. Measuring the effectiveness of the protected area network requires the setting of a conservation target for species that represents either an estimate of the area of suitable habitat required to preserve a minimum viable population (MVP) to ensure long term persistence for each species, or a target of between five and 10 viable subpopulations protected. The way targets were set is detailed in the table below (Table 7.4 and 7.5). Representation in protected areas (PL_R) values is then interpreted as shown in Table 7.5.

Box 7.4. Arid depressions teeming with special shrimps

The importance of invertebrates for biodiversity monitoring and ecological condition assessments in arid, intermittently inundated pans

By Dr Betsie Milne, South African Environmental Observation Network (SAEON) work funded by the former Department of Science & Technology (DST) and National Research Foundation (NRF) through the Professional Development Programme (PDP) and additional Foundational Biodiversity Information Programme (FBIP) grant.

Arid depressions are dominated by a group of Crustaceans that are specifically adapted to survive prolonged desiccation. *Branchiopoda* (Tadpole shrimps, fairy shrimps clam shrimps and water fleas), *Ostracoda* (seed shrimps) and *Copepoda* have all developed life history strategies to ensure continued existence in unpredictable aquatic environments. The most astonishing adaptation is their dormant eggs that can survive extremely harsh conditions for decades. The eggs accumulate to form an egg bank in the same crust that gives the arid depressions their dry and lifeless appearance. The crust is essentially the biodiversity vault of each pan and only gets unlocked during inundation to allow for a wetland resurrection. Although these species are endemic to ephemeral waters, very little is known about their habitat selection, diversity and distribution in the Northern Cape which is where the majority of arid depressions are found. Information on these groups is limited and their role and inclusion in conservation assessments have not been considered. They have also largely been overlooked as key descriptors of depressions in wetland assessments.

In the Northern Cape, 109 pans across the four main wetland hotspot regions in the province; i.e. Kalahari, Ghaap Plateau, Bushmanland and Upper Karoo (Kotze *et al.* 2019) were investigated. Two species that have never before been recorded from South Africa were discovered, as well as a number of range extensions, and new species that have not yet been described. These recent discoveries will be published in journal papers and all biodiversity distribution records from the pans of the Northern Cape will be submitted to the South African National Biodiversity Institute (SANBI) in 2019. Considering the increased development pressures in the Northern Cape, these findings are welcomed as timely evidence of the urgent need to protect one of the most disregarded wetland systems and possibly preventing the extinction of species before they are even discovered. Furthermore, the surveys conducted provide a valuable dataset for future Red Listing of this important group of species.

Photo: Tadpole shrimp (*Triops granarius*). Photo credit: Betsie Milne.

Box 7.5. Method for setting targets and measuring the protection level for species.

Taxon type	Conservation target ($Target_{Species}$)	Equation to calculate representation in PA network	Equation to be used to calculate overall PL that includes the management effectiveness factor
Vertebrates with sufficient MVP studies to extrapolate reference MVP (large mammals, birds).	Area required to support a minimum viable population using taxon specific reference MVPs listed in Trail *et al*. 2007.	$PL_{R\ Species} = \frac{\sum_{PA} P_{PA}}{Target_{Species}}$	$PL_{\ Species} = \frac{\sum_{PA} P_{PA} \times E_{PA}}{Target_{Species}}$
Vertebrates with insufficient MVP studies to extrapolate reference MVP and plants.	Area required to support 10 000 individuals the threshold in criterion C of the IUCN's quantitative criteria (Mace *et al*. 2008).	$PL_{R\ Species} = \frac{\sum_{PA} P_{PA}}{Target_{Species}}$	$PL_{\ Species} = \frac{\sum_{PA} P_{PA} \times E_{PA}}{Target_{Species}}$
Taxa that experience natural annual fluctuations in population size or where densities are very high (terrestrial invertebrates, FW vertebrates and invertebrates).	10 viable subpopulations*	$PL_{R\ Species} = \frac{\sum_{PA} P_{PA} \times V_{PA}}{Target_{Species}}$	$PL_{\ Species} = \frac{\sum_{PA} P_{PA} \times V_{PA} \times E_{PA}}{Target_{Species}}$
	*Note for naturally range restricted and rare taxa where fewer than 10 subpopulations exist, the target should be set at the total number of original subpopulations.		

Where P_{PA} is the population score for each protected area a species is recorded in. P_{PA} can take the following values, depending on what data is available and following this preference hierarchy:

1. Estimated or surveyed number of individuals in the protected area
2. Average density (D) x area of suitable habitat in protected area (A_{PA})
3. The number of subpopulations present within a protected area (should only be used for species where estimating population size is not possible or where there are natural and regular fluctuations in population size)

V_{PA} is the score of viability of a populations

4. 1 where viability indicated as 'Viable'
5. 0.1 where viability indicated as 'Non-viable'

E_{PA} is the effectiveness score of the protected area for the particular population of the species occurring within the protected area. E_{PA} can take one of the following values:

		E_{PA} Score
Good	Protected area is fully effective in protecting the species against major threats and ensuring the long-term persistence of the population present	**1**
Fair	Protected area provides some mitigation of major threats to species, but is not completely effective	**0.5**
Poor	Protected area provides no mitigation of major threats to species – individuals inside the protected area are no better off than those outside	**0.1**

In order for species to be effectively protected within a protected area, pressures such as poaching, invasive alien species, poor fire regime, poor land use practices on and within protected area boundaries need to be effectively managed and controlled. As such, not all protected areas have equal probabilities of mitigating pressures on species. Thus, protected area effectiveness is included as an adjustment factor in assessing each protected area contribution to the target in addition to a population estimate. As different species respond uniquely to both management interventions and threatening processes, networks of taxon experts provided a management effectiveness score applicable to each species based on their knowledge of that species' response to the management of the protected area in question.

Table 7.4. Method for setting targets and measuring the protection level for species.

% of target met	PL category
0 – 4.9%	Not Protected
5-49%	Poorly Protected
50-99%	Moderately Protected
100+%	Well Protected

7.2.2 *Species protection level results*

How well species are protected within protected areas has been evaluated for each of the taxonomic groups and the results are presented here. These include only taxa that are associated with or depend on inland aquatic systems.

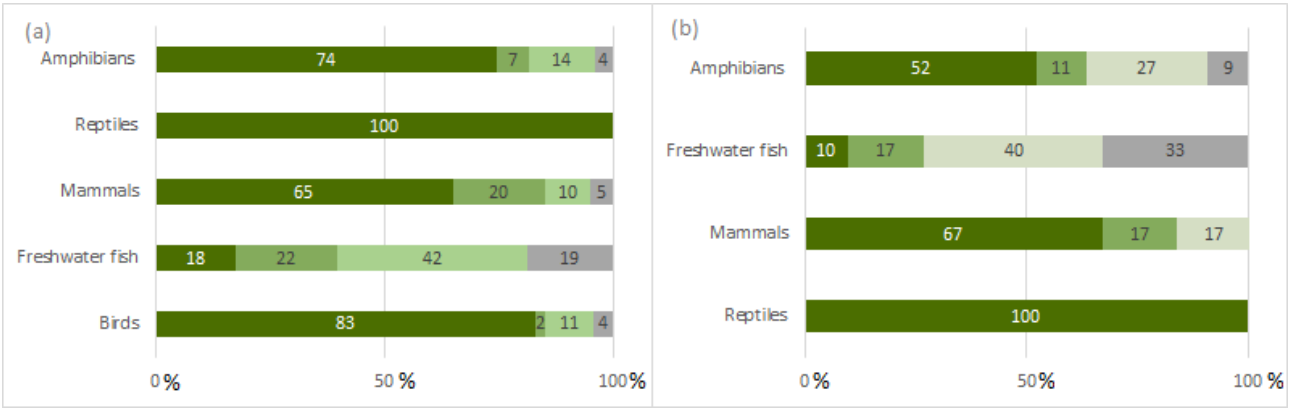

Figure 7.8. Protection level of taxa depended on inland aquatic habitats; a) overall (mammals (20 taxa), waterbirds (95 taxa), amphibians (98 taxa), reptiles (15 taxa), and freshwater fish (96 taxa)) and b) endemic species (mammals (6 taxa), waterbirds (0 taxa), amphibians (46), reptiles (5), and freshwater fish (52)).

Freshwater fish are the most Poorly Protected of South Africa's inland aquatic taxonomic groups assessed. Only 18% of freshwater fish taxa included in the analysis were Well Protected (17 taxa), while the majority (82%) of taxa are under protected (Not Protected (18 taxa), Poorly Protected (40 taxa) or Moderately Protected (21 taxa)) (Figure 7.8). Seven freshwater fish are assessed as Critically Endangered and four of these taxa are assessed as Not Protected. These four are the Treur River Barb (*Enteromius treurensis*), Barrydale Redfin (*Pseudobarbus burchelli*), *Pseudobarbus senticeps* and *Galaxias* sp nov 'slender', which all have very restricted distributions, some limited to a single stretch of a river or a single sub-quaternary catchment. Forty taxa are listed as Poorly Protected, these occur across South Africa with the majority of the taxa assessed as threatened or Near Threatened (27 taxa). The main reason that so many freshwater fish are under protected is because of the spatial distribution of protected areas which mostly does not include the catchment areas and/or a sufficient extent of rivers to mitigate against pressures. In addition, the impact of certain pressures such as pollution and water abstraction that originate upstream and outside of protected areas, cannot be mitigated against within proteted areas, as there are no or limited interventions. For other pressures such as invasive alien species the protected area can minimize these impacts by installing barriers to prevent invasion or prevent detrimental land use activities.

Other taxonomic groups included in this analysis contrast strongly with freshwater fish, as the majority of species are Well Protected (Figure 7.8). However, in each group there are species that are Not Protected, these include mostly threatened and Near Threatened species for birds (4 taxa), amphibians (4 taxa) and mammals (1 taxon) (Figure 7.9). Of the four birds that are Not Protected the Grey Crowned Crane (*Balearica regulorum* – EN) occurs in wetlands and breeds in or along these habitats. In South Africa, this species is monitored annually by the Avifaunal Road Counts at the Animal Demographic Unit (ADU) at the University of Cape Town (UCT), as well as by annual aerial surveys conducted by the Endangered Wildlife Trust (EWT) and the provincial conservation agency Ezemvelo KwaZulu-Natal (KZN) Wildlife (or EKZNW) across its range in that province (BirdLife International 2016). Based on these surveys, there seems to be an increase in the number of individuals of Grey Crowned Crane's (*Balearica regulorum*) in KwaZulu-Natal over a 21 year monitoring period (Smith & Craigie 2014), however the species still faces pressures such a habitat destruction and alteration, where its wetland habitat is lost to mining, forestry, crop farming, overgrazing and drainage or damming, as well as industrial developments. Furthermore the Grey Crowned Crane is poorly represented in protected areas. Other bird species that are Not Protected include the Black Stork (*Ciconia nigra*) – VU, Chestnut-banded Plover (*Charadrius pallidus* – NT) and the Maccoa Duck (*Oxyura maccoa* – NT) (Figure 7.9). The four amphibian species assessed as Not Protected include two Critically Endangered amphibians the Amatole Toad (*Vandijkophrynus amatolicus*) the Table Mountain Ghost frog (*Heleophryne rosei*), the Endangered Hogsback Caco (*Cacosternum thorini*) and the Cape Dainty Frog (*Cacosternum capense* – NT). Even though the Cape Dainty Frog (*Cacosternum capense* – NT) occurs in three protected areas, none of these sites support a minimum viable population based on available suitable habitat within these reserves. In addition management is suspected to be fair and thus is not good enough for the species' ecological needs to be met. It therefore qualifies as Not Protected when applying the criteria shown in Table 7.4. In the case of mammals there is only one species that qualifies a Not Protected, the Spotted-Necked Otter (*Hydrictis maculicollis* – VU). This species is widespread within South Africa, however, it does not occur within any protected area. This reflects the terrestrial bias of the current protected area network which was not designed to protect rivers. Future protected area expansion needs to address this bias and include a greater extent of this species' and other freshwater species' habitat (Figure 7.9).

7.2.3 Limitation to the species protection level assessment

The protection level assessment presented here is a new indicator for South Africa developed specifically for this National Biodiversity Assessment. No other country has ever attempted to conduct a protection level assessment for all taxa in a taxonomic group that measures how well a species persistence population target is protected. Experts involved in conducting the assessment for each group were able to set targets for species and use either actual population count data from reserve, or modelled habitat suitability data combined with population density estimates, or the number of viable subpopulations present to determine how well represented a particular taxon was within the protected area network. Determining effectiveness of all reserves for each taxon proved more challenging, and experts had to score the effectiveness of certain protected areas as unknown. Subsequent testing of what difference this made to the results showed that management effectiveness was mostly unknown for small private reserves and this had an insignificant impact on the overall protection level results. In addition, effectiveness for each reserve for each taxon was typically determined using expert knowledge. There is a need to develop a standardised number of options by which effectiveness is measured for each taxonomic group. Such standardised criteria are currently being developed and tested.

Protection level assessment for freshwater fish was limited by available threat data as well as on the ground data of protected area condition and management. Distribution records for invasive alien species are an important source of understanding this pressure and these data were not readily available. Other taxonomic groups had similar limitations in both determining pressures within a protected area and if these were being mitigated and managed for. This highlights the need for a national database for protected area condition, management reports and active species monitoring projects within protected areas.

(a) Freshwater fish	(b) Wetland-dependent birds	(c) Other wetland and river related species
Treur River Barb (*Enteromius treurensis* – CR) Photo credits: Francios Roux	Grey Crowned Crane (*Balearica regulorum* – EN) Photo credits: Peter Vos	Amatole Toad (*Vandijkophrynus amatolicus* – CR) Photo credit: T Hardaker
Barrydale Redfin (*Pseudobarbus burchelli* – CR) Photo credit: Riaan van der Walt	Black Stork (*Ciconia nigra* – VU) Photo credit: Ernest Retief	Table Mountain Ghost frogs (*Heleophryne rosei* – CR) Photo credit: Alexander Rebelo
The indigenous Krom River Redfin (*Pseudobarbus senticeps*), has been extirpated from its historic range as a result of invasive alien species – CR Photo credit: Albert Chakona & Paul Skelton - SAIAB	Chestnut-banded Plover (*Charadrius pallidus* – NT) Photo credit: Mark Anderson –BirdLife	Cape Dainty Frog (*Cacosternum capense* – NT) Photo credit: Alexander Rebelo
Galaxias sp nov 'slender' – CR Photo credit: Albert Chakona a& Paul Skelton - SAIAB	Maccoa Duck (*Oxyura maccoa* – NT) Photo credit: Ernest Retief	Spotted-Necked Otter (*Hydrictis maculicollis* – VU) Photo credit: Mariaan Golding

Figure 7.9. (a) Freshwater fish species that are highly threatened (CR) and Not Protected; (b) Threatened bird species that are Not Protected; (c) ToCC amphibians and mammals that are Not Protected.

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8. THE GENETIC PERSPECTIVE ON INLAND AQUATIC ECOSYSTEMS

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8.1 Introduction

The importance of genetic variation for maintaining biological diversity and evolutionary processes has been recognized by researchers for decades (e.g. Frankel 1974; Lande & Shannon 1996; Frankham 2005; Hughes *et al*. 2008; Bijlsma & Loeschcke 2012). Intraspecific genetic diversity, in particular, represents a species' evolutionary potential to evolve and adapt within a changing environment. In this way, genetic diversity drives the process of speciation and plays a pivotal role in ecosystem structure and function (Hughes *et al*. 2008; Whitham *et al.* 2008). A prime example of this can be seen within the Cape Galaxias, *Galaxias zebratus* (Wishart *et al.* 2006). What was assumed to be a single species occupying the rivers across the Cape Peninsula is actually numerous species, each occupying its own river. This has been attributed to periods of low sea level creating opportunities and alternative dispersal and migratory routes for populations to evolve.

Many species are equipped with sufficient evolutionary resilience, or genetic diversity, to overcome rapid environmental change (Hughes *et al.* 2008); however, others are not, as is evident by the rapid loss of biodiversity reported globally (Millenium Ecosystem Assessment (MEA) 2005). Most of these instances of decline, however, have been documented in cultivated species or species that are heavily exploited. For wild species, there are few data on the actual changes in the magnitude and distribution of genetic diversity (MEA 2005). This realization prompted the conservation of genetic diversity being listed as an explicit goal of various national and international agreements. In particular, the Convention on Biological Diversity (CBD) and its member nations explicitly agreed to 'promote the conservation of genetic diversity' (Goal 3: UNEP 2003) and sought 'to achieve, by 2010, a significant reduction in the current rate of biodiversity loss at the global, regional and national levels' (UNEP 2003). Despite this commitment, implementation of the conservation and monitoring of genetic diversity has lagged behind implementation for other levels of biodiversity (Laikre 2010; Laikre *et al.* 2016). This has generally been attributed to the lack of genetic diversity indicators and thresholds (Walpole *et al.* 2009; Laikre 2010; Tittensor *et al*. 2014; Laikre *et al*. 2016). Although there are examples of conservation genetic studies that have utilised genetic parameters, such as allelic richness (i.e. allelic diversity) and heterozygosity, to monitor changes in the genetic composition of species over time, there has been no consistent and comparable approach among them with respect to the number of sampling periods, sampling intervals, the type and number of genetic markers used, and the number of individuals sampled. Consequently, it has been difficult to identify simple and direct indicators sensitive enough to detect genetic erosion (i.e. loss of genetic diversity), resulting in genetic biodiversity indicators being largely overlooked until recently.

With the release of the Aichi Biodiversity Targets in 2010, there is a renewed emphasis on the conservation of genetic diversity. Aichi Target 13 makes specific mention of minimizing genetic erosion and safeguarding genetic diversity, which implies that genetic diversity be monitored over time in a given population. This temporal dimension is key as some studies claim to monitor genetic diversity when in fact they are actually

'assessing' genetic diversity at a single point in time (Schwartz *et al*. 2007). For example, using genetic data from a single year or pooled data from multiple years to provide a single-point estimate of a population's diversity and structure (e.g. Baker *et al.* 2000; Hua Yue *et al*. 2004; Cannas *et al*. 2016).

Within South Africa, several single point estimates of genetic diversity (i.e., population genetic assessments) have been undertaken have been undertaken on freshwater taxa (e.g. SAIAB's Topotypes Projects; crabs: Gouws *et al.* 2015; Wood & Daniels, 2016; fish: Chakona *et al.* 2013; isopods: Gouws *et al.* 2004; snails: Mkize *et al.* 2016; frogs: Tolley *et al.* 2010; Da Silva *et al.* 2016); yet, to date, there has only been one published study that explicitly monitored temporal shifts in a species genetic diversity — a narrowly endemic amphibian believed to have undergone an enigmatic decline (Da Silva & Tolley 2018; Box 8.1). This study is fairly short-term (i.e., under 20 years and/or within a few generations) and as such, may be considered uninformative and potentially overlooked given that there is less chance of detecting strong genetic change. However, even studies based on two time points can potentially provide invaluable information on how a population has changed, what underlying conditions precipitated the change, and how this can inform the future management of the population (Leonard 2008; Potvin *et al.* 2017). Even if no change is detected, such studies are a critical first step in establishing the appropriate genetic monitoring framework for a population or species (e.g. by helping to decipher the appropriate monitoring intervals, how many samples and markers to use). Without them, long-term monitoring programs may never be established.

Box 8.1. Rose's Mountain Toadlet (*Capensibufo rosei*) by Da Silva & Tolley (2018)

Capensibufo rosei is a small (c. 2–3 cm in length), range-restricted threatened amphibian endemic to the Cape Peninsula of South Africa. This toadlet is found only in the naturally fire-prone fynbos habitat (heathland vegetation type endemic to the Cape of South Africa: Mucina & Rutherford 2006). Unlike most anurans, it has no calling or auditory apparatus, making it the only known voiceless amphibian in southern Africa (Grandison 1980). These cryptic toadlets breed in small, shallow (10–30 mm depth, ca. 10–50 cm diameter) ephemeral pools formed by winter rainfall, with masses of males aggregating at these breeding pools during their relatively short breeding season (approximately 2 weeks in July or August) (Minter *et al*. 2004; Edwards *et al*. 2017). The pools are scattered within an area not usually more than a few hundred metres across. Individual females enter the pools briefly only to lay eggs (clutch size < 100 eggs: Grandison 1980), which are externally fertilized by males. Females leave as soon as spawning is complete, while males remain at the pool throughout the breeding season (Becker *et al.* 2018; Edwards *et al.* 2017; Tolley, personal observation).

This toadlet is believed to have experienced an enigmatic decline, with the loss of several of its historical breeding populations despite the presence of apparently suitable habitat with natural vegetation and pools of water (Cressey *et al.* 2015). It is speculated that the suppression of natural fires and the loss of grazing wild animals from the Cape Peninsula may be the primary cause of this decline (Becker 2014; Cressey *et al.* 2015). Without these disturbances, the fynbos becomes overgrown and can even revert to thicket or forest (Bond 1997), and although some pools might still form, the pool characteristics (depth, size, shading, water retention) are probably affected. The loss of historical breeding sites has resulted in a considerable reduction in this species' distribution, with its's current Area of Occupancy at less than 10 km², resulting in it being listed as Critically Endangered on the IUCN Red List (SA-FroG 2017).

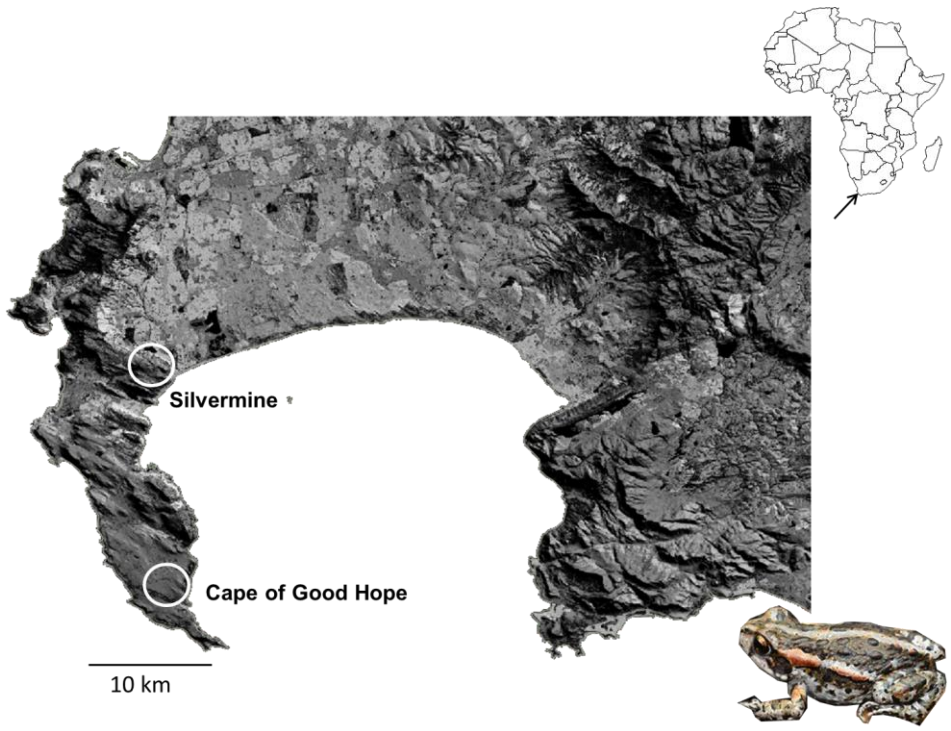

Figure 8.1. Map depicting the approximate locations of the two breeding sites (white circles) of *Capensibufo rosei* (inset) on the Cape Peninsula (taken from Da Silva & Tolley 2018).

Currently, it is known from two populations, both with Table Mountain National Park – one historical site in Silvermine Nature Reserve and a new breeding site discovered in 2010 in the Cape of Good Hope (CGH) Nature Reserve (Figure 8.1). The Silvermine and CGH populations are approximately 20 km apart and population genetic analyses have shown that there is strong population structure with presumably no gene flow between sites, likely owing to the loss of the other historical breeding sites disconnecting dispersal pathways (Cressey *et al.* 2015; Da Silva *et al.* 2016). Moreover, within a seven-year time period (2008–2014), the survival and recruitment rates of *C. rosei* fluctuated considerably in response to rainfall, with high survival and low recruitment during low rainfall years, and the inverse during high rainfall years (Becker *et al.* 2018). Their isolation and the sharp fluctuations in their survival could potentially translate into population size fluctuations (e.g. Altwegg *et al.* 2003; McCaffery & Maxell 2010; Newell *et al.* 2013), which could result in changes in genetic diversity within a relatively short time period. To test this, a genetic monitoring study was conducted comparing the genetic diversity of toadlets from two time periods – 2011 and 2015 (Da Silva & Tolley 2018). These dates were chosen because (1) the five-year time interval fits within the temporal sensitivity requirement of genetic monitoring studies (i.e. at least one generation time of a species: Pereira *et al.* 2013; for *C. rosei*, this time period encompasses between two to five generations), (2) 2011 represents the earliest year in which samples from both populations were available, and (3) 2015 the most recent batch of samples at the time. The study found that both populations were genetically stable over the five-year time interval in terms of retention of total diversity, and that the levels of genetic diversity increased slightly between sampling periods for both populations. Although this increase was not statistically significant, it does appear to correspond to increases in population size estimates detected by Becker and colleagues (2018) following a fire in 2015; likely suggesting that habitat quality (i.e. vegetation not overgrown, appropriate pool characteristics) is an important factor influencing the viability of these toads. Ongoing genetic monitoring at approximately five year intervals will build upon this initial assessment and help SANParks in the adaptive management of this species.

8.2 The way forward: the future of genetic monitoring within South Africa's inland aquatic realm

The overall paucity of genetic monitoring datasets should not quash any and all attempts at establishing genetic monitoring programs. If anything, it should strengthen our pursuit in recognizing and utilizing what tools are currently available, and identify tools that are needed and yet to be developed.

Indeed, the plethora of population genetic assessments already published provide a baseline of genetic diversity, upon which future short- and long-term genetic monitoring studies could be based. In some instances, reorganizing datasets might even allow for initial short-term monitoring studies to be conducted without the addition of extra samples. Additionally, museums and other natural history collections have long been recognized and utilized as sources of historical genetic material (e.g. Roy *et al.* 1994; Bouzat *et al.* 1998; Ross *et al.* 2006; Martínez-Cruz *et al.* 2007; Wandeler *et al.* 2007; Ugelvig *et al.* 2011; Banhos *et al.* 2016). Furthermore, comprehensive tools exist that can aid researchers in the planning and design of genetic monitoring studies. For example, ConGRESS (Conservation Genetic Resources for Effective Species Survival) is an online platform with a variety of free tools that can assist reserachers and decision makers in designing conservation and population genetic projects (http://www.congressgenetics.eu/; Hoban *et al.* 2013). For a more comprehensive look at each of these, refer to Da Silva *et al*. 2019 [Chapter 3, Volume 7].

With the advent of new molecular techniques, such as Next Generation Sequencing, it is becoming easier and more practical to monitor genetic diversity within species, as well as entire biological communities by using 'environmental DNA' and bioinformatic processing of DNA metabarcoding. Moreover, there is a need for a national genetic monitoring framework to help researchers develop and standardize population genetic studies and genetic monitoring programmes, so that long-term datasets can be established, comparable and used to better inform management and conservation.

8.2.1 Environmental DNA

As species interact with their environment, their DNA via faeces, saliva, urine, feathers and skin cells, for example, is continuously being shed into their surroundings (Rees *et al.* 2014; Mächler *et al.* 2014; Deiner *et al.* 2016; Baird & Hajibabaei 2012; Thomsen & Willerslev 2015). This DNA is known as eDNA. Depending on the environmental conditions at the time, this DNA may become preserved in various media, such as ice cores or terrestrial and aquatic sediments, or it may begin to degrade rapidly as is found with surface soil and water. As such, eDNA can provide information on species composition from ancient and contemporary ecosystems, respectively (Baird & Hajibabaei 2012; Deiner *et al.* 2016; Mächler *et al.* 2014; Rees *et al.* 2014; Thomsen & Willerslev 2015). Moreover, because many species utilise the same environment, this method not only allows for the detection and monitoring of specific species in terms of presence or absence, but also entire community assemblages with the help of metabarcoding and bioinformatics (Thomsen & Willerslev 2015; Rees *et al.* 2014; Cristescu 2014; Kelly *et al.* 2014; Evans *et al.* 2016).

Even though there are growing examples from the international conservation community where eDNA has been applied, by and large, this molecular approach has proven most successful in aquatic environments, especially freshwater, and hence has proven extremely useful in the field of freshwater conservation. One of the first seminal studies that retrieved eDNA from freshwater focused on the detection of the invasive American Bullfrog (*Lithobates catesbeianus*) in France (Ficetola *et al.* 2008). This study demonstrated that eDNA provided improved detection of an invasive species over traditional methods. Many subsequent studies continued to focus on eDNA to detect invasives (e.g. Dejean *et al.* 2012; Jerde *et al.* 2013; Goldberg

et al. 2013; Piaggio *et al.* 2014). While eDNA has the potential to become a valuable monitoring tool for biological invasions, such as in the early detection of invasive populations, or surveillance of invasion pathways (e.g. ballast water of ships: Egan *et al.* 2015; Zaiko *et al.* 2015; the live bait trade: Nathan *et al.* 2015), to date, it is not routinely used for biosecurity regulation or enforcement. While the majority of freshwater eDNA studies have focused on fish or amphibians, macroinvertebrates make up a far greater proportion of the local diversity in aquatic systems, and their inclusion in biomonitoring is essential, yet to date very few studies have assessed or monitored them using an eDNA approach (Mächler *et al.* 2014).

Environmental DNA monitoring within South Africa is still in its infancy, with only a few studies currently underway that incorporate eDNA to survey biodiversity (e.g., marine coastal diversity: Von der Hayen, *pers. comm.*, 2018; microbial diversity: Ramond *et al.* 2015; Wilcox & Cowan 2016; Segobola *et al.* 2018). Considering South Africa's exceptional biodiversity and the urgent need to protect it, while also understanding the limited financial resources available to do so, it is almost certain that eDNA will become an important tool in species and ecosystem conservation within the country. However, in depth studies are required that compare eDNA metabarcoding approaches to conventional ecological surveys (Deiner *et al.* 2016), especially within a South African context. One such study is currently being initiated within the Table Mountain National Park. The aim is to test the utility of eDNA in correctly (1) detecting the presence of the Table Mountain Ghost Frog (*Heleophryne rosei*) – a Critically Endangered and elusive frog found in five streams on Table Mountain – and (2) identifying or surveying aquatic macroinvertebrates to quantify stream ecosystem health at an equal or greater resolution than the traditional South African Scoring Systems (SASS) and miniSASS methods. Given that many macroinvertebrates are believed to occupy a highly restricted range (Scott *et al.* 2012; McGeoch *et al.* 2011; Scodanibbio 2002), identification to species level would be valuable to guide conservation and management decisions especially for taxa that are known to be highly sensitive to ecosystem disturbance and health, such as members of the *Ephemeroptera* (Mayfly) Order (Bellingan *et al.* 2015; Scodanibbio 2002).

8.2.2 Genetic Monitoring Framework (GMF)

Currently, a Biodiversity Genetic Monitoring Framework (BGMF) is being developed for South Africa. This framework will speak to high-level reporting requirements for all levels of biodiversity, drawing from the CBD's targets, as well as South Africa's national biodiversity policies (namely NEMBA and the National Biodiversity Strategy and Action Plan [NBSAP]). A critical component of this framework will be identifying key monitoring indicators, which will be in line with international monitoring standards and guidelines, such as the Essential Biodiversity Variables being developed by GEO BON (https://geobon.org/ebvs/what-are-ebvs/). Embedded within this, will be a careful evaluation of existing gaps around these indicators.

A Genetic Monitoring Framework (GMF) or guidance document will be a component of the NBMF. Ideally, the GMF will outline how genetic diversity can be monitored at a national, ecosystem and population level. Although a national or ecosystem measure of genetic diversity can be hard to contemplate, if one understands that at the heart of all biodiversity monitoring are population- and species-level assessments, such high-level metrics or indicators are not impossibilities. We may simply need time and data to realise or conceptualise what the best indicators could be. With that said, there are ways in which genetic diversity can be assessed across a landscape (for example, see Tolley & Smid 2019 [Chapter 4, Volume 7]). With respect to population-level genetic monitoring, the content discussed in Da Silva et al. 2019 [Chapter3, Volume 7] will help guide the GMF, with the aim of directing future genetic monitoring research.

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9. RESPONSES TO PRESSURES IN THE INLAND AQUATIC REALM

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This chapter reviews current biodiversity and water sector responses to the key pressures on inland aquatic ecosystems and aquatic species identified in Chapter 4, namely, changes to the hydrological regime, deterioration in water quality, loss of natural habitat, invasive alien species, subsequent fragmentation as a result of these pressures, over-exploitation of freshwater species and climate change. Seven core areas of response are introduced with an overview, followed by a broad status review for each response area in turn, show-casing a selected set of case studies, and concluding each response area with a set of recommendations.

9.1 Overview of responses to pressures experienced

Drawing from the three-way action plan for biodiversity outlined in the National Biodiversity Framework (RSA 2018a), which highlights protection, avoidance of further loss, and rehabilitation of ecosystems and species; as well as the objective of the National Water Resource Strategy version 2 (DWS 2013) that water is protected, used, developed, conserved, managed and controlled sustainably and equitably, this chapter identifies seven core areas of response (Table 9.1).

Any one core area of response not optimally implemented puts at risk all other response efforts. However, if fully implemented in an integrated manner, the seven core areas of response together could form an effective strategic action framework to comprehensively and efficiently guide integrated inland aquatic ecosystem conservation and management throughout South Africa, aligning national, provincial and local catchment actions. This is emphasised in Table 9.1, where it is evident that each area of response plays only a partial, albeit vital, role in addressing each key pressure identified in Chapter 4. Cooperative governance and coordinated action is critical to achieve such a multi-response framework, as no single institution could implement the full suite of responses alone.

Based on this review, none of the seven core areas of response currently appear to be functioning optimally. Moreover, the need to improve compliance within the framework of existing laws, and the need for improved monitoring and associated adaptive management are key imperatives for the inland aquatic realm. This is the case across all realms, and was emphasised in the NBA 2018 Synthesis Report (Skowno *et al*. 2019). The overall implication is that, although examples of success are evident across all responses, we lack a strategic and integrated framework and action plan specific to inland aquatic species and ecosystem conservation and management in South Africa, to effectively and efficiently reconcile response efforts across the sector.

Table 9.1. The seven core areas of a national conservation and management strategy are all required to comprehensively address the key pressures on inland aquatic ecosystems.

Core area	Section	Description	Response to pressures
Foundational information and base data	9.2	Inventory of ecosystems and species, including extent, characterisation of ecosystem type drivers and function, and condition assessment.	Necessary to better understand and measure both ecosystems and pressures, in order to best respond to any of the identified pressures.
Strategic planning, wise use and best management practice	9.3	Strategic planning tools to avoid further degradation and loss, supported by catchment-, ecosystem- and species-specific management actions, Ecosystem-based Adaptation to climate change, and biodiversity management plans for inland aquatic ecosystems and aquatic species.	Requires best possible base data and associated **foundational information** plus **research** to understand, design strategies and know what to measure (**monitor**). Addresses all pressures: changes to the hydrological regime and subsequent fragmentation; deteriorating water quality; loss of natural habitat, modification from natural state and subsequent fragmentation; invasive species, over-exploitation of species and climate change.
Regulation	9.4	Of land and water use activities to avoid further degradation and loss in and adjacent to rivers and inland wetlands (supported by compliance enforcement).	Addresses all pressures: changes to the hydrological regime; deteriorating water quality; loss of natural habitat, modification from natural state and subsequent fragmentation; Invasive species, over-exploitation of species and climate change.
Protection	9.5	Of priority biodiversity and water resources (protected areas and biodiversity stewardship agreements).	
Rehabilitation	9.6	Improve river, riparian area, and wetland ecosystem function and support species recovery, especially in priority areas (including control of biological invasions through pathway management).	
Monitoring	9.7	Status and trends (to support adaptive management, priorities, effective policies, and strategic funding).	Better understand and measure key monitoring sites in order to best respond to all pressures; requires the best possible **foundational information** and **research.**
Sustainable financing and cooperative governance	9.8	To enable capacity for effective governance, monitoring and management, and support development of national, provincial and catchment action plans so that inland aquatic ecosystem conservation goals for the country are achieved in the most efficient manner, cooperation and partnerships are effective, and roles and responsibilities are clear.	Pressures addressed: changes to the hydrological regime; deteriorating water quality; loss of natural habitat, modification from natural state; invasive species, subsequent fragmentation as a result of these pressures; over-exploitation of species and climate change.

9.2 Foundational information

9.2.1 Overview

Foundational information, base data and the generation of associated datasets or information characterising the inland aquatic ecosystems and freshwater species of South Africa inform effective monitoring, assessment and management programmes. Base data is supported by primary data collection on where the freshwater species, inland wetlands, rivers and riparian areas of the country are located, their core habitat (for species) and ecosystem drivers (for ecosystems), diversity, and what pressures they are under. This information is critical for accurate interpretation of ecosystem services and the thresholds of impaired ecosystem function or collapse. It informs specific, rather than generalised, management goals and objectives, and increases our ability to prioritise, measure and strategically monitor, rehabilitate and protect inland aquatic ecosystems and freshwater species.

9.2.2 Status

The inland aquatic ecosystems component of the NBA 2018 presents an overview of the status of rivers, inland wetlands and freshwater species data, and is evidence of continuous improvement in foundational information for the systematic and spatially explicit analysis of these ecosystem types in South Africa since 2004. South Africa has made significant achievements in the building of foundational information of inland aquatic ecosystems and freshwater species to date, including the first assessment of river (mainstem) ecosystem types in the NSBA 2004 (Driver *et al.* 2005), the subsequent revision of the mainstem river ecosystem types and inclusion of tributaries in the National Freshwater Ecosystems Priority Areas (NFEPA) Atlas of 2011 (Nel *et al.* 2011a;b) and National Biodiversity Assessment of 2011 (NBA 2011) (Nel & Driver 2012), and the development of a National Wetland Vegetation Database (Sieben *et al.* 2014). A more comprehensive review of the available foundational information and base data has been published in Van Deventer *et al.* (2018a; 2018b). Much has been achieved since the last assessment (NBA 2011) with improvements to the foundation layers, updated river assessment data, and continued improvements to national wetland mapping. The typing and assessment of river and inland wetland ecosystems at a country-wide scale for arid to semi-arid countries offered examples for other data-poor countries to follow (Chapter 1; Nel *et al.* 2007; 2016; Van Deventer *et al*. 2016; 2018a;b). South Africa is one of very few countries to successfully incorporate rivers and inland wetlands into national-scale systematic conservation planning assessments.

Overall, however, there remain many gaps in location, extent and characterisations of our river and wetland types, their driving processes and associated species. Wetlands remain largely under-represented and insufficiently described, and therefore, significant effort should be afforded to address this gap. In spite of significant improvements during of the National Wetland Map version 5 (NWM5) during the NBA 2018, nearly 70% of the extent of South Africa is still at a low confidence level (Van Deventer *et al.* 2018a).

The NBA 2018 also provides, for the first time, a more comprehensive overview of both vertebrate and invertebrate taxa of freshwater species (Chapter 7 of this report). The Albany Museum, South African Institute for Aquatic Biodiversity (SAIAB) and multiple other custodians around the country contributed to this assessment, through making available highly accurate curated data via the Global Biodiversity Information Facility (GBIF) and other data sources. Despite the formal incorporation and assessment of freshwater species in the NBA 2018 for the first time, a major gap remains the sampling bias for species across the country, and understanding the minimum area and ecological condition that these species

require for survival. In the NBA 2018, the individual assessment of river ecosystem types and freshwater species showed correspondence between river ecosystem threat status and the status of associated freshwater fish, revealing that both habitat and species are critically endangered, highlighting one of the key understandings that ecosystems and species are interdependent. Further work is however essential to address the gaps for aquatic species and their habitats. Through recent funding from the Jacob Richard Schramm (JRS) Biodiversity Organisation, the Freshwater Research Centre (FRC) and SANBI have started to address these gaps in a more formal manner, through collating and making fish, algae and aquatic invertebrate species records electronically available via the Freshwater Biodiversity Information System (FBIS), currently under development. The SANBI Threatened Species Programme also has a five-year plan, leading up to the next NBA, to increase data collection and assessment for aquatic invertebrate species in order to better understand how they are impacted by pressures and how they have been responding over time. Endemic species will be prioritised as well as those areas with little available data, such as the inland aquatic ecosystems in the arid regions of South Africa, and freshwater species groups with well resolved taxonomy and good spatial data.

9.2.3 Recommendations

The key priorities and recommendations of the Wetland Ecosystem Classification Committee (WECC), Wetland Ecosystem Classification Committee (RECC) and South African Inventory of Inland Aquatic Ecosystems (Van Deventer *et al.* 2018) extracted from the meeting minutes and report are listed in order of priority in Table 9.2 and includes consideration of foundational information and base data.

Overall, there are still many gaps in location, extent and detailed characterisation of our river and inland wetland types, their driving processes and lists of associated species. We must certainly proceed with all other response mechanisms to address the pressures rather than wait for 'perfect and complete' base data, but it is critical to invest in the continued development of robust and specific foundational information on inland aquatic ecosystems and freshwater species as an essential base for successfully and appropriately responding to the full suite of pressures identified in Section 9.4. Further key gaps and recommendations include:

- **Reconcile a stable set of catchment boundaries for the country.** Update quaternary boundaries to match the most hydrologically accurate set of quinary catchment boundaries. Consolidate freshwater biodiversity and climatic information (*Nel et al*. 2011a;b; Schulze 2011) for quinary catchments to facilitate integrated management and efficient data-sharing across the multiple projects and users;
- **Undertake a systematic process of detailed taxonomic studies on priority groups, including field collections and DNA barcoding, to enhance national freshwater species datasets.** This needs to increase data on species distribution and life histories, and monitor population trends on a regular basis. It further needs to build and maintain South African taxonomic groups such as aquatic invertebrates, many of which are thought to be habitat and range restricted and in decline. Gaps in knowledge are a major constraint to freshwater species threat assessments and interpretation of the impact of pressures on inland aquatic ecosystems;
- **Develop further biodiversity indices** for including macroinvertebrates, fish, riparian vegetation, diatoms;

Table 9.2. Key priorities and recommendations for improving inventorying and assessment of inland aquatic ecosystems and freshwater species for the next National Biodiversity Assessment (NBA).

Priorities for river ecosystem types (formulated by the River Ecosystem Classification Committee or RECC during 2016–2019 for the next five-year period)	Priorities for wetland ecosystem types (formulated by the Wetland Ecosystem Classification Committee or WECC during 2015–2019 for the next five-year period)
Build a solid database of macroinvertebrates to be used in assessments and planning. SANBI should be involved and the work is long term, it cannot be achieved by means of a workshop. The Albany Museum, SAIAB and South African Biodiversity Information Facility (SABIF) databases should be integrated as well as that of local experts at other institutions or universities.	Improve representation and hydrogeomorphic units of wetland ecosystem types to at least a Low to Medium confidence level for 75% of the country within the next five years through continuous desktop improvement of NWM5, supplemented with the cleaning and typing of the *wetlands probability map*. The NWM5 confidence map should be used to identify areas where the *wetlands probability map* should be used.
Develop indices that are related directly to biodiversity. These include indices for macroinvertebrates, fish, riparian vegetation, diatoms, and several other aspects of river ecosystem types.	Prioritise areas where the NWM needs higher levels of confidence. Set a minimum target for the minimum confidence, omission and commission errors as well as minimum requirements for the mapping and in-field visits for these priority areas. Consideration should be given to prioritise the Strategic Water Source Areas (SWSA), Ramsar sites, and areas where development pressure is high.
River flow categories should be revised and more categories should be added (i.e. flow types for quinary catchments) considering work done by Rivers-Moore *et al*. (2016) as well as Uys & O' Keeffe (1997).	The modelling of the ecological condition of wetlands should be attended to with urgency, particularly identifying data sets which can best be used to represent existing pressures on inland aquatic ecosystems (Ollis *et al*. 2013).
Riparian vegetation mapping should be refined to fine-scale representation for South Africa.	Continue to develop and compare the modelling capabilities of remote sensing and Geographical Information Systems (GISs) to map the extent of inland aquatic ecosystems. The results should be evaluated against fine-scale data sets. Modelled data should be considered to supplement NWM5.
There is a need for endorsed quaternary and sub-quaternary or quinary catchment boundary datasets employing the latest information and methods by considering studies by Nel *et al*. (2011a;b), Weepener *et al*. (2012) and Maherry *et al*. (2013).	
If new river Present Ecological State (PES) data is generated/ recorded at a provincial to local level, or as part of the River Eco-status Monitoring Programme (REMP), then it should be used and incorporated at a national level.	Continue to develop and compare the modelling capabilities of remote sensing and GISs to map inland aquatic ecosystem types. The results should be evaluated against fine-scale data sets mapped by wetland experts. Modelled data should be used only in representing wetland ecosystem types in data-poor areas.

- Identify and monitor species that can serve as **biological indicators for different pressures**;
- Improve the spatial alignment between 1:50 000 and 1:500 000 rivers and develop a representation of rivers as (polygon) features and types;
- **Ground-truth** inland aquatic ecosystem types in priority areas, with those in the Strategic Water Source Areas (SWSAs) a top priority. The ongoing improvement of their descriptions and extent remains a priority, for example, **to enable Natural Capital Accounting** (NCA) and to expand understanding of aquatic ecosystems within **arid regions** of the country;
- **Wetlands, in particular, remain largely under-represented and insufficiently described, and therefore, significant effort should be afforded to** update wetland ecosystem types with primary data, assess wetland functions and values to better understand their contribution within

catchments, monitor wetland ecosystems and their impact thresholds to serve as biological indicators for different pressures, and continue to develop and compare the capabilities of remote sensing and GIS probability modelling to map wetlands; and

- **Undertake a gap analysis of NFEPA** in preparation for NFEPA II**.**

9.3 Strategic planning, biodiversity management plans, and best management practice

9.3.1 Overview

South Africa has developed and implemented a suite of advanced spatial planning tools to direct development away from critically important freshwater biodiversity areas, such as status assessments through the NBAs (Driver *et al*. 2005; Nel & Driver 2012; Skowno *et al*. 2019) and strategic plans, for example, NFEPA (Nel *et al*. 2011a;b), SWSAs (Le Maitre *et al*. 2018), provincial biodiversity sector plans, critical biodiversity area (CBA) maps (Skowno *et al*. 2019), Key Biodiversity Area (KBA) identification, and Environmental Management Frameworks (EMFs) at municipal scale, among others. Given that water is a primary driver in the establishment and persistence of these ecosystems and the species they support, biodiversity conservation and water resource protection are intimately linked, and, thus, water resource protection and strategic planning instruments are also discussed in this chapter. These include Reserve Determination, the Water Resource Classification System (WRCS) at catchment scale, which allocates the full landscape into relative use and management classes (i.e. Water Resource Classes) and sets Resource Quality Objectives (RQOs) for aquatic ecosystems. As part of the WRCS, scenarios are developed to address the pressures of increased water demand (decreased water availability).

9.3.2 Status

A key response to address the systemic pressures outlined in Section 4 is identification of priority inland aquatic ecosystems, but the effectiveness of conservation can only be attained through effective management. At the National scale, a number of freshwater priority areas have been identified as part of the process of listing wetlands of unique biodiversity value through the Ramsar Convention, prioritising areas of high surface water runoff through the SWSAs, and areas of conservation priority through FEPAs in the NFEPA project. In addition, an updated set of KBAs are currently being developed for South Africa. Provincial planning complements these national prioritisation tools and projects, through the identification of provincial CBA and Strategic Environmental Assessments (SEAs). These tools are discussed in more detail below.

Ramsar wetlands of international importance

South Africa has 23 wetlands of international importance (RSA 2018b), also referred to as Ramsar sites, which represent a diverse set of South African aquatic ecosystems (see Chapter 5, Figure 5.11 and Table 5.15). The total area under the Ramsar Convention in South Africa is approximately 554 028 ha or 0.5% of South Africa (RSA 2018b). Twelve of the sites (50% of Ramsar sites) in South Africa are nominated primarily for their inland wetlands assets, while the remaining 50% comprise primarily of estuarine, coastal or island sites (Table 9.3). Ramsar sites add 14 133 ha to the protected area network of South Africa (Section 6.2.2, Table 6.3). Three new Ramsar sites have been submitted in 2018–2019 to the former Minister of Environmental Affairs (now the Minister of Environment, Forestry and Fisheries) to be

considered for gazetting. These include Dyer Island Nature Reserve (288 ha) managed by CapeNature; Kgaswane Mountain Reserve (4 952 ha) managed by North West Parks Board, and Dassen Island Nature Reserve (737 ha) managed by CapeNature (Mr Edward Netshithothole, DEA, *pers. comm*., 12 March 2019). Of these, the Kgaswane Mountain Reserve supports extensive inland wetland ecosystem types. At Ramsar Conference of the Parties (COP) 13, the inventory, conservation and rehabilitation of peat ecosystems was emphasised, recognising that, 'through their sequestration of atmospheric carbon, wisely managed peatlands are an international asset with a value for global climate mitigation independent of their location' as part of the draft resolution of guidance on identifying peatlands as Wetlands of International Importance (Ramsar sites) for global climate change regulation as an additional argument to existing Ramsar criteria (RSA 2018b). Nine out of the South Africa's 23 Ramsar sites are known to support peat wetlands, however, South Africa's peatlands are, overall, poorly mapped and poorly protected (Appendix C) and their improved protection should include better management of integrated catchment landscapes.

The Ramsar Convention requires that countries protect the ecosystem function of Ramsar sites, but does not require that they be placed off-limits to human activity. Rather, the Convention recognises 'the inter-dependence of people and wetlands and the ecosystem services that wetlands provide'. The Department of Environmental Affairs (DEA) (now part of the Ministry of Environment, Forestry and Fisheries [DEFF]) has indicated future plans to support the development of management effectiveness measures across South African Ramsar sites (RSA 2018b) and it is critical that these sites are monitored and that management plans are actively implemented. While many of South Africa's Ramsar wetlands are well-studied in terms of bird life (a common criterion for Ramsar designation), many were found to have little to no information on the aquatic biotic communities present, and there was limited information on their structure, function, importance, and the services that they provide (Malherbe *et al.* 2017). Most sites are in need of updated baseline information and do not have a monitoring programme in place (Malherbe *et al.* 2017). The lack of information was highlighted by the DEA and the Water Research Commission (WRC) in 2013 as a priority research area. A research project was initiated for an aquatic assessment to sample water quality, sediment, diatoms, macroinvertebrates, and fish (Malherbe *et al*. 2017), thereby significantly contributing to improved available baseline information for nine of the 23 Ramsar sites. Five of these nine sites where baseline information were improved, are predominantly freshwater ecosystems, including Seekoeivlei, Blesbokspruit, Ntsikeni, Makuleke and Barberspan. Malherbe *et al*. (2017) found every site to be under pressure from a range of anthropogenic factors including habitat loss, nutrient enrichment, numerous pollutants, urban and rural encroachment, alien invasive species, poor land use species and organic enrichment, with Blesbokspruit, Verlorenvlei and Orange River mouth on the Montreux record[13] (Table 9.3).

[13] A register of sites where significant changes in ecological character have resulted from pollution or other human interference (Ramsar 1996).

Table 9.3. Overview of South Africa's 23 Ramsar sites (adapted from Malherbe *et al*. 2017). Sites highlighted in grey are inland wetlands.

Ramsar site	Year declared	Extent (ha)	Province*	Protected Area**	Management Plan	Ramsar site#	RIS*** date	Key pressures
Barberspan	1975	3 118	NW	NR	Yes	35	1998	Adjacent agriculture; Pollution from adjacent river (Harts) systems released from Lichtenburg and Sannieshof Waste Water Treatment Works (WWTWs)
Blesbokspruit	1986	1 858	GT	NR	No	343	1995	Adjacent mine contamination, Fragmentation and damming (hydrological modification) by infrastructure and eutrophication by sewage input
De Hoop vlei	1975	750	WC	NR	Yes	34	1998	Upstream agriculture
De Mond	1986	918	WC	NR	Yes	342	1998	Upstream agriculture
False Bay Nature Reserve	2015	1 542	WC	NR	No	2219	2014	Alien invasive plants
Klein / Bot River	2017	1 349	WC	No	Yes	2291	2017	Upstream agriculture
Kosi Bay [p]	1991	10 982	KZN	NR	No	527	1995	Slash-burn cultivation, uncontrolled burning, pollution, aquifer abstraction, Afforestation and peat desiccation and peat fires
Lake Sibaya [p]	1991	7 750	KZN	NR	No	528	1988	Slash-burn cultivation, grazing, uncontrolled burning, pollution, aquifer abstraction, Afforestation and peat desiccation and peat fires
Langebaan	1988	6 000	WC	NP	No	398	1991	Aquifer abstraction, development
Makuleke wetlands	2007	7 757	LP	No	No	1687	2007	Upstream over-abstraction and pollution, Internal road networks, sand mining for lodge/roads and erosion as well as Alien Invasive Plants
Natal Drakensberg [p]	1997	243 813	KZN	NR & WHS	No	886	1996	Soil erosion, Alien invasive plants
Ndumo wetlands	1997	10 117	KZN	NR	No	887	1996	Uncontrolled burning, alien invasive plants, Land invasion, slash and burn, illegal infrastructure, erosion and stream flow diversion
Ntsikeni [p]	2010	9 200	KZN	NR	Yes	1904	2010	Adjacent afforestation plant species encroachment
Nylsvley	1998	3 970	NW	NR	No	952	1997	Alien invasive plants, Dams in the catchment, water abstraction, altered hydrology and sewage spills from Nylstroom WWTW
Orange River mouth	1991	2 000	NC	No	Yes	526	1990	Diamond mining activities, Upstream streamflow reduction activities, nutrient inputs from poor agriculture and grazing practices
Prince Edward Islands [p]	2007	37 500	WC	NR	No	1688	2007	Unregulated fishing, Mice infestation, trampling along paths and related erosion
Seekoeivlei	1997	4 754	FS	NR	No	888	1996	Uncontrolled burning, alien invasive plants, artificial drainage canals, upstream township development, Memel WWTW and solid waste site
St Lucia [p]	1986	155 500	KZN	NR + WHS	No	345	1998	Slash-burn cultivation, uncontrolled burning, afforestation, sedimentation to lake, nearby mining, aquifer abstraction
Tongaland complex	1986	39 500	KZN	No	No	344	1984	Oil spills at sea
Umgeni vlei [p]	2013	958	KZN	NR	Yes	2132	2013	Alien invasive plants
Verloren Vallei [p]	2001	5 891	MP	NR	No	1110	2000	Alien invasive plants, erosion, over-grazing, uncontrolled burning
Verlorenvlei	1991	1 500	WC	No	Yes	525	1990	Cultivation, grazing and over-abstraction, nutrient and sediment input, infrastructure encroachment
Wilderness Lakes	1991	1 300	WC	NR	No	524	1990	Artificial manipulation of estuary mouth, upstream land use, nutrient and sediment input

** Provinces: FS = Free State; GP = Gauteng; KZN = KwaZulu-Natal; LP = Limpopo; MP = Mpumalanga; NC =Northern Cape; NW = North West; WC = Western Cape;*

*** NR=Provincial Nature Reserve, NP=National Park, PE=Protected Environment, WHS=World Heritage Site;*

**** RIS=Ramsar Information Sheet; and*

[p] = supports peat wetland.

National Strategic Water Source Areas

Water Source Areas (WSAs) have historically been defined using the criterion of the production of relatively large volumes of runoff which sustain lowland areas downstream (Viviroli *et al.* 2007; WWF-SA 2013). The NFEPA study applied this broad concept and identified sub-quaternary catchments with relatively high mean annual runoff as high water yield areas, as well as identifying high groundwater recharge areas. These high water yield areas correspond well with the Mountain Catchment Areas declared in terms of the Mountain Catchment Act (Act 63 of 1970; RSA 1970). The Act provides mechanisms and incentives for appropriate land management in these areas. This work was then reported on in the NBA 2011 and taken further in a study by WWF-SA and the Council for Scientific and Industrial Research (CSIR) which identified 21 Strategic WSAs for surface water (SWSA-sw) which covered 8% of South Africa and supplied 50% of the mean annual runoff (WWF-SA 2013). This 2013 dataset has now been replaced by a refined dataset produced by a WRC-funded study (Le Maitre *et al*. 2018). There are now 22 Strategic Water Source Areas (SWSAs) for surface water (SWSA-sw) and 37 Strategic Water Source Areas for groundwater (SWSA-gw) that are considered to be strategically important at the national level for water and economic security for South Africa (Figure 9.1). These multi-purpose landscapes are key ecological infrastructure assets for South Africa, supporting growth and development needs.

SWSAs are defined as areas of land that: (a) supply a disproportionate (i.e. relatively large) quantity of mean annual surface water runoff in relation to their size and so are considered nationally important; or (b) have high groundwater recharge and where the groundwater forms a nationally important resource; or (c) areas that meet both criteria (a) and (b). They include transboundary Water Source Areas that extend into Lesotho and Swaziland (Le Maitre *et al*. 2018). Transboundary SWSA-sw that include Lesotho are critically important for the Gauteng metropolitan region which has the largest population and economy in southern Africa. The total identified area for SWSA-gw is 10 365 900 ha, 24% of this overlaps with the areas delineated for SWSA-sw. SWSA-sw cover about 12 407 500 ha (10% of the region) and provide a mean annual runoff (MAR) of 24 954 million m^3 (50% of the total MAR of South Africa) and most of its groundwater recharge, sustaining most of the perennial rivers. The SWSA-gw cover around 9% of the land surface of South Africa, account for up to 42% of the base flow in their areas and have a key role in sustaining surface water flows during the dry season.

The strategic importance of South Africa's water source areas have been recognised and included in the 2018 National Water and Sanitation Master Plan (NW&SMP), the National Spatial Strategic Development Framework and provincial biodiversity conservation plans. The boundaries for the SWSAs have been identified at a national scale and they need to be taken up at sub-Water Management Area (WMA) and local scale (Le Maitre *et al*. 2018). Some sub-national water source areas have already been identified (Le Maitre *et al*. 2018). Several provinces have a process underway to further refine and align the boundaries with their provincial conservation plans so that they can inform other provincial plans (e.g. Strategic Development Frameworks [SDFs]). Non-governmental Organisations (NGOs) are also making a significant contribution in this area of response through for example water funds such as the Greater Cape Town Water Fund. This Water Fund is bringing together private and public sector stakeholders alongside local communities around the common goal of restoring the surface water and aquifer catchments which supply our water. The WWF-SA, for instance, has mobilised community-public-private partnership projects in eight of the SWSA-sw areas and has placed water stewards in the Outeniqua, Wolsely and Riversonderend areas. Other initiatives, e.g. the Matatiele Water Stewardship Initiative, are also underway. The DEA is also including the SWSAs in their Environmental Impact Assessment (EIA) process to support land-use decision making. The Centre for Environmental Rights (CER) has undertaken a comprehensive legal

review to identify and prioritise the most effective legal mechanisms for securing the long-term protection of these areas.

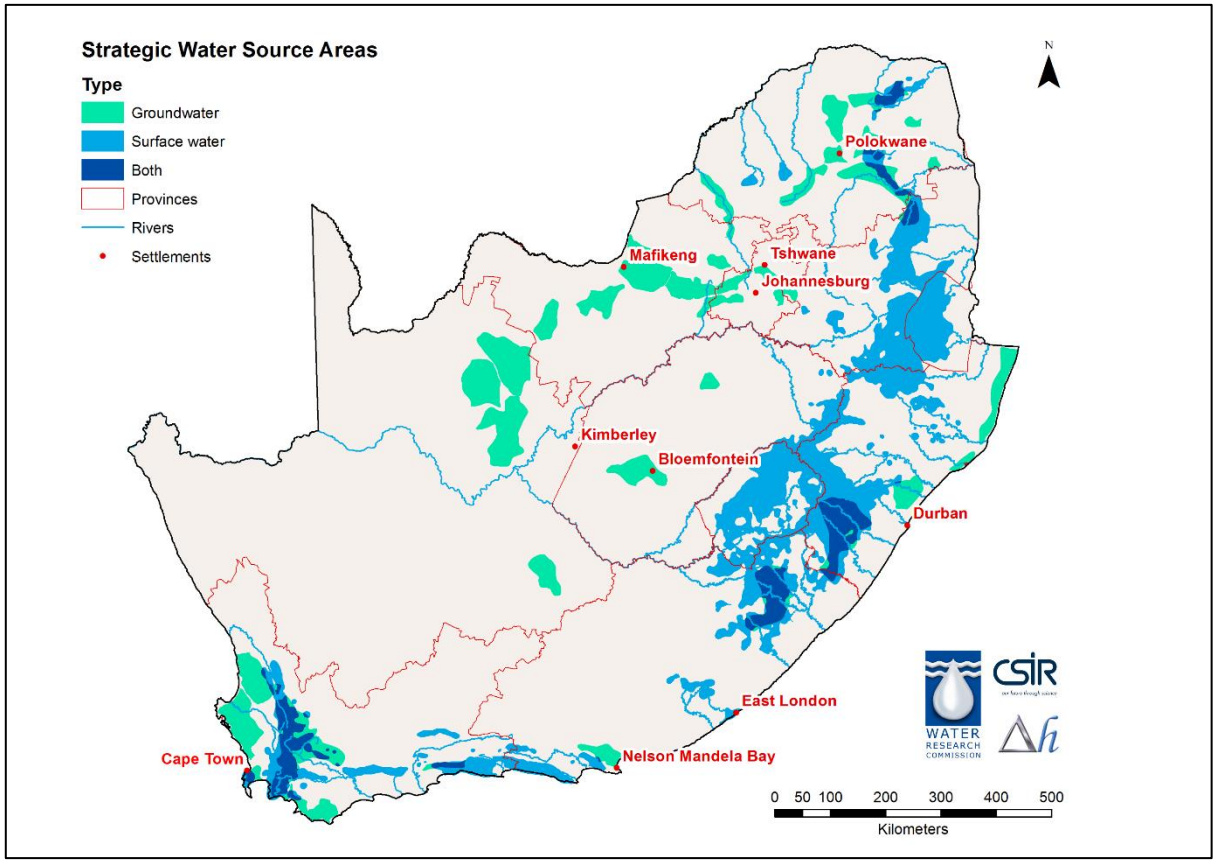


Figure 9.1. Strategic Water Source Areas (SWSA) for surface water (sw) and ground water (gw) (map based on Le Maitre *et al.* 2018).

The costs of ecological management of SWSAs (e.g. clearing of invasive plants) must be priced into the Water Tariffs for each area ('User pays principle'). For example, water users pay a Water User Tariff for management of the catchment areas that supply water to critical dams. If this principle is adopted and implemented, the pricing is correct and funds are ring-fenced, adequate funding for implementation and monitoring can be generated.

National Freshwater Ecosystem Priority Areas

As with Ramsar wetlands and SWSAs, the national network of systematically identified and spatially explicit freshwater ecosystem priority areas (FEPAs), established by the NFEPA project (Nel *et al*. 2011a;b), was a significant response to the systemic pressures outlined in Section 9.4. NFEPA was South Africa's first systematic conservation plan for inland aquatic ecosystems, and successfully generated attention, awareness and focus in responding to the pressures on inland aquatic ecosystems. The NFEPA project proposed a number of priority actions to be developed and implemented. Table 9.4 summarises progress on NFEPA priorities since it was published in 2011. Overall, there has been good application of FEPAs in inventory, biodiversity planning and land-use planning and decision-making processes. However, there has been limited improvement in monitoring, management and improved conservation of these areas. This is

partly due to the ongoing absence or reduction of scientific staff in key national, provincial and local institutions.

Table 9.4. Evaluation of progress with respect to the priorities listed by the National Freshwater Ecosystems Priority Areas (NFEPA) project and priorities listed in the National Biodiversity Assessment of 2011 (NBA 2011).

NFEPA / NBA 2011 priority action	Status
Employ sufficient numbers of aquatic ecologists and technicians in provinces, Catchment Management Agencies (CMAs) and municipalities to address the needs of freshwater ecosystems. 'Employ aquatic ecologists in provinces, local municipalities and CMAs. A concerted effort is required to improve management of freshwater ecosystems if we are to halt and reverse the 'water crisis' in South Africa. A solid understanding of aquatic ecosystem functioning is needed. Three provincial agencies do not even have a single aquatic ecologist, and very few have more than one. This lack of capacity is ill-placed in a country where water is a national limitation to growth and development.' (Nel *et al*. 2011b:23). This lack of capacity is ill-placed in a country where water is a national limitation to growth and development.	Ongoing reduction in staff at provincial conservation agencies (Impson 2016b).
Strengthen freshwater inventory and monitoring programmes.	The extent of inland wetland representation was improved since the National Freshwater Ecosystem Priority Areas (NFEPA) and National Biodiversity Assessment (NBA) 2011 projects. National Wetland Map version 5 (NWM5) has increased the representation of inland wetland types by 123%, and reduced errors in misrepresentation and typing of ecosystems (Van Deventer *et al.* 2018a; b; in review). The water quality monitoring network has been severely underfunded during the 2018–2019 years, with < 40% of the surface and groundwater monitoring sites samples analysed (DWS 2018a). Very limited monitoring of FEPA's and Important Fish Areas has been done since NBA 2011. A project funded by the Water Research Commission (WRC), authored by Wilkensen *et al.* (2016), set a framework for further prioritisation and implementation of the National Wetland Monitoring Programme (NWMP), which remains to be implemented. At present there are over 2 000 flow-gauging stations in the country representing 148 river ecosystem types. However, many are in a state of disrepair, preventing vital flow data from being collected. In addition, some large river systems have very few gauging weirs (see Section 9.7 and Figure 9.8). Recently, in 2019, the site has ceased operating owing to a lack of funding for the 2018–2019. Inland aquatic ecosystems will be included in the proposed SANBI National Monitoring Programme.
Set up mechanisms to support uptake of FEPA maps.	FEPA maps have been successfully incorporated into biodiversity spatial plans in all Provinces. The national status and trends on biodiversity (distribution and population status of species) in FEPAs cannot be reported on due to insufficient capacity (staff, operational funds, and lack of

	monitoring).
Use FEPA maps in assessing land and water resource development processes, e.g. Environmental Impact Assessments; classification of water resources; ecological reserve determinations; resource quality objectives; water use authorisations; and the development of Catchment Management Strategies.	The river FEPAs are being used in most provinces to address these needs. There is a lower confidence in the wetland FEPAs, as a result these were often not used in projects. This is primarily attributed to errors encountered and poor representation of inland wetland extent. Consequently, an update of NFEPA using the updated NWM5 would be crucial.
Use FEPA maps in evaluating applications for mining and prospecting. Applications for mining and prospecting in FEPAs and associated sub-quaternary catchments should be subject to rigorous environmental and water assessment and authorisation processes.	FEPA maps are used in most applications.
Pilot formal mechanisms for the management and protection of FEPAs, including the use of biodiversity stewardship programmes and other fiscal incentives.	No major progress but some FEPAs, especially a small number of Important Fish Areas (previously 'fish sanctuaries') have been incorporated into biodiversity stewardship programmes since 2012. Progress is underway through a suite of projects under Global Environment Facility (GEF) 5 and GEF6 funding.
Review general authorizations of the National Water Act in relation to their impact on FEPAs.	FEPA status is considered in authorisations but there has been no systematic review of the impact.
Strengthen collaboration of the former DWA and DEA around managing and conserving freshwater ecosystems. NFEPA provides tools on which to focus such combined ventures (e.g. geographic focus areas, maps, data, guidelines, policy mechanisms). The NFEPA stakeholder engagement process was also very successful at developing the necessary relationships between stakeholders in respective water and conservation sectors (e.g. between South African National Biodiversity Institute [SANBI] and Department of Water and Sanitation [DWS]; between provincial agencies and catchment managers). The Inter-Departmental Committee on Inland Water Ecosystems is also a good example of a step in this direction.	The Inter-Departmental Committee on Inland Water Ecosystems convened by DWS, with representation by the Department Environmental Affairs, DWS, SANBI, the South African National Parks, the Catchment Management Agencies, the former Department of Agriculture, Forestry and Fisheries, the Department of Minerals and Resources, and provincial conservation agencies, remains in place as an intergovernmental liaison platform, and the Freshwater Ecosystem Network (FEN), convened by SANBI since 2012 provides a platform of interaction across levels and government and civil society. There is increased appreciation of the need for cooperative governance.
Use FEPAs in water resource development processes, including water resource classification, development of catchment management strategies, water use license applications, resource quality objectives, ecological reserve determination.	FEPAs have been used in the development of Resource Quality Objectives for Water Management Areas by DWS (e.g. Olifants, Berg and Breede).
Revive the Mountain Catchment Areas Act to protect our water supply areas.	SWSAs for surface and groundwater have now been broadly demarcated (Le Maitre *et al.* 2018) and a next phase has started in which several of the provincial implementation agencies have assessed methods of practical implementation of these areas at ground level. The Centre for Environmental Rights (CER) through a comprehensive legal review has identified and prioritised the best legal mechanisms for securing the long-term protection of these areas.
Strengthen and expand scope of River Health Programme (RHP) to include wetlands and to actively target FEPAs as new monitoring sites.	The severe budgetary constraints that DWS has suffered since January 2018, resulted in a significant decline of operational budget available to facilitate travel, certification and analysis costs related to the River Eco-status Monitoring Programme (REMP), which replaced the RHP (the latter had been in operation between 2002 and 2017). Similar constraints at collaborating agencies resulted in the collapse of this established network and successful collaboration effort. DWS (2018) reported a declining trend in the availability of surface water monitoring results from 2016 (67%) to 2017 (62%) and 2018 (33%), whereas the groundwater monitoring points declined from 47.6% to 49.3% and 7.9% during the same years.

Despite the momentum that NFEPA generated, the impetus seems to have declined between 2016–2018, primarily as a result of declining funds at national and provincial departments. This negative trend in funding had a negative impact on staff appointed to do the implementation and monitoring, as well as operational costs to facilitate monitoring. This NBA 2018 did however, used the updates of the river monitoring available till month of 2017, during the time when monitoring was still credible and reliable. The RECC should evaluate and recommend the use of the REMP data of these years for next NBA 2018 or provide alternative suggestions for surrogate of these years.

Following the improvement of the NWM5 (Van Deventer *et al*. 2018a; in review) and the extended red list assessment of a number of freshwater species in this NBA 2018 (Chapter 7), the update of the NFEPA atlas is recommended. Particularly considering the concern a number of institutions have raised about the lack of confidence of the wetland FEPAs, these need to be a key priority for the NFEPA II update. The river FEPAs have, in contrast, been quite reliable in NFEPA I. However, longer term priorities include refining the river ecosystem types by exploring new techniques of river ecosystem classification (e.g. Generalised Dissimilarity Modelling [GDM] and riparian zone mapping) and ecologically meaningful lumping of the longitudinal zones (i.e. extend the analysis by Dallas & Day [2007] to fish, etc.) as well as the maintenance and update of ecological condition data. With regards to the latter, sub-quaternary catchment planning units should be developed that take account of ecological condition changes. Considering the loss of the status of some free-flowing rivers, NFEPA II can further assist in the rehabilitation of rivers to their best attainable ecological condition.

Classification of Water Resource Areas

Chapter 3 of the National Water Act, 1998 (NWA, Act 36 of 1998) lays down a series of measures which are together intended to ensure the comprehensive protection of all water resources. The NWA outlines three measures for protection of the water resources which are:

- Classification of water resources
- Reserve and
- Resource Quality Objectives (RQOs)

Section 12 of the NWA requires the Minister to establish a WRCS. The WRCS was formally prescribed by Regulation 810 dated 17 September 2010 (Government Gazette 33541). The WRCS provides procedures for determining water resource classes, Reserves and RQOs. This system provides guidelines and procedures for determining the three protection measures mentioned above. Soon after the WRCS was prescribed, the Department of Water and Sanitation (DWS) embarked on a process to determine water resource classes and RQOs for significant water resources in the country. Figure 9.4 below is a map showing all the water management areas where classes and RQOs have been determined as well as those that are still in progress. The set classes and RQOs are gazetted in a government gazette in terms of Section 13 of the NWA, once these are gazetted they are binding on all authorities and institutions when exercising any power or performing any duty under the NWA. To date, eight river systems have water resource classes and RQOs determined (shown in grey in Table 9.5) and a further seven have been gazetted for public comment.

Table 9.5. Overview of significant water resources for which proposed water resource class and resource quality objectives have been determined.

WMA	Catchment	Drainage Region	River System	Gazette date	Gazette No.
Breede-Gouritz	Breede	G40-G50, H10- H70 Tertiary Drainage Region	Breede, Riviersonderend, Overberg, as well as other smaller coastal rivers.	2019	42053*
	Gouritz	H80-90, J10-J40, K10-K70 Tertiary Drainage Region	Gouritz, Buffels, Touws, Groot, Gamka, Olifants, Kammanassie, and smaller coastal rivers	2019	42053*
Berg-Olifants	Berg	G1, G2 Secondary; G40A Quaternary	Berg, Greater Cape Town, West Coast small rivers	2019	42451*
	Olifants / Doorn	E Primary; G3 Secondary, F6 Secondary	Olifants, Doring, Papkuil, Verlorenvlei, Langvlei, Jakkalsvlei, Sandlaagte, Brak and Sout	2016	39943
Inkomati-Usuthu	Inkomati	X Primary	Komati, Crocodile, Sabie-Sand, X4	2016	40531
	Usuthu	Not yet gazetted			
Limpopo	Crocodile West and Marico	A10, A21-24, A31-32, A41-42 Tertiary	Mokolo, Matlabas, Crocodile (West), Marico	2017	41310*
	Letaba	B8 Secondary	Letaba	2016	40531
	Limpopo	Not yet gazetted			
Mzimvubu-to Tsitsikamma	Fish to Tsitsikamma	Not yet gazetted			
	Mzimvubu to Keiskamma	T3 Secondary	Mzimvubu, Mzintlava, Thina, Kinira, Tsitsa and Inxu (Wildebees) rivers, and the Mzimvubu estuary	2018	42053*
Olifants	Luvhuvu	Not yet gazetted			
	Olifants	B Primary	Olifants	2016	39943
Orange	Lower	Not yet gazetted			
	Upper	Not yet gazetted			
Pongola-Mtamvuna	Mhlatuze	Not yet gazetted			
	Mvoti to Umzimkulu	T40 Secondary, T52 Secondary	Mvoti, uMngeni, uMkhomazi, Umzimkula, Mtamvuna	2017	41306
	Thukela	Technical classification process due to commence			
Vaal	Lower	C Primary	Vaal	2016	39943
	Middle	C Primary	Vaal, Renoster, Vals, Schoonspruit, Koekemoerspruit, Sand and Vet	2016	39943
	Molopo	D41A Quaternary	Molopo	2017	41310*, **
	Upper	C Primary	Vaal, Wilge	2016	39943

** Gazetted for public comments. **Quaternary Drainage Region D41A previously formed part of the Crocodile West Marico WMA. When the Water Management Areas (WMAs) were re-published in 2013, this area fell under the Vaal WMA.*

The Reserve consist of two parts, the basic human needs Reserve and the ecological Reserve. The basic human needs Reserve is the water required to provide for the essential needs of individuals served by the water resource in question, and includes drinking water. The ecological Reserve relates to the water required to protect the aquatic ecosystems of the water resource. Reserve refers to both quantity and quality in the water resource, and will vary depending on the class of the resource. If a class has not yet been determined, a preliminary Reserve may be determined. Once the class is determined, then the Reserve can also be gazetted in terms of Section 16 of the NWA. Like the classes and RQOs, once the Reserve is gazetted, it is binding on all authorities and institutions when performing any duty under the NWA. Figures 9.5 and 9.6 respectively projects the status of Reserve determinations for both surface and groundwater.

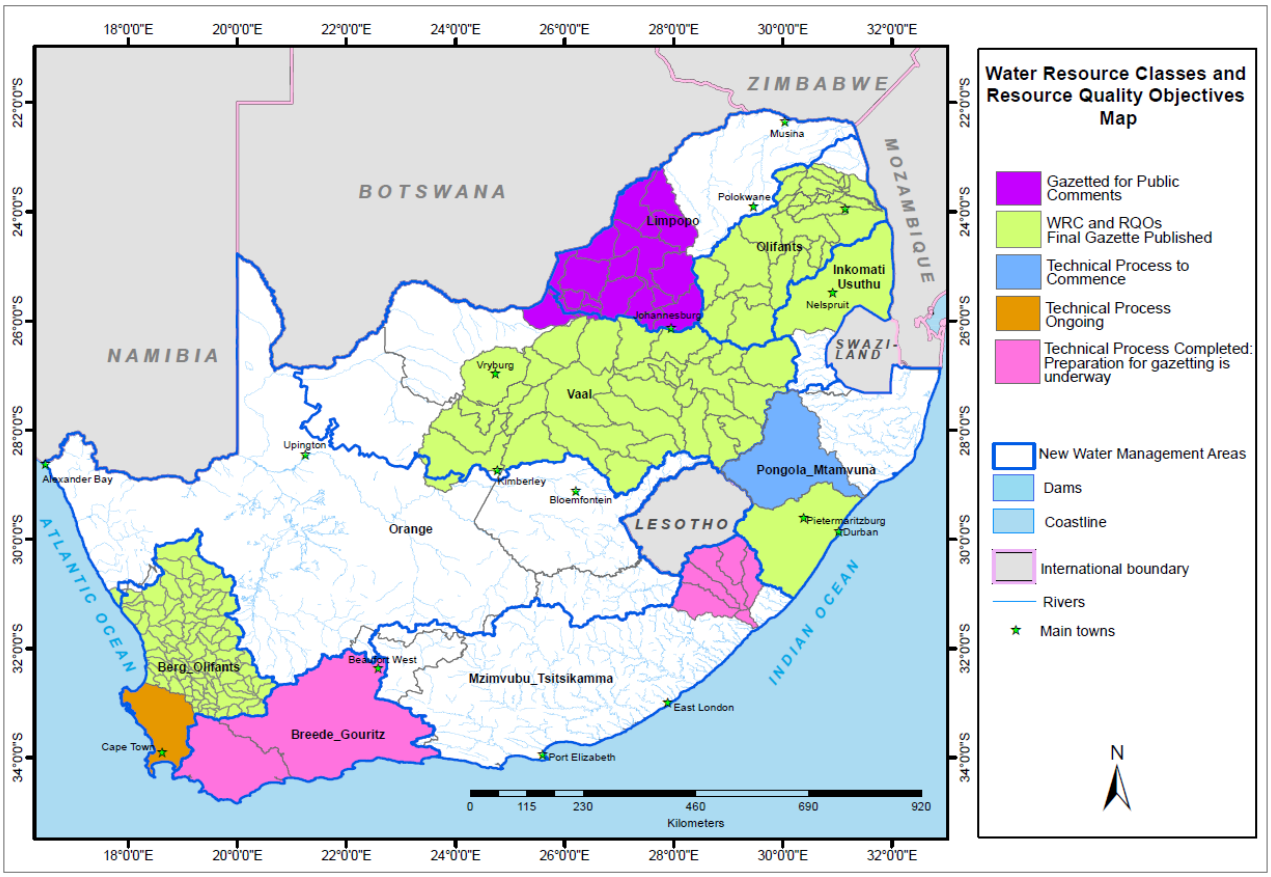


Figure 9.2. Current status of Water Resource Classes and Resource Quality Objectives determined by the Department of Water and Sanitation (DWS), up to date (DWS 2018a). *WRC = Water Resources Classification; RQOs = Resource Quality Objectives.*

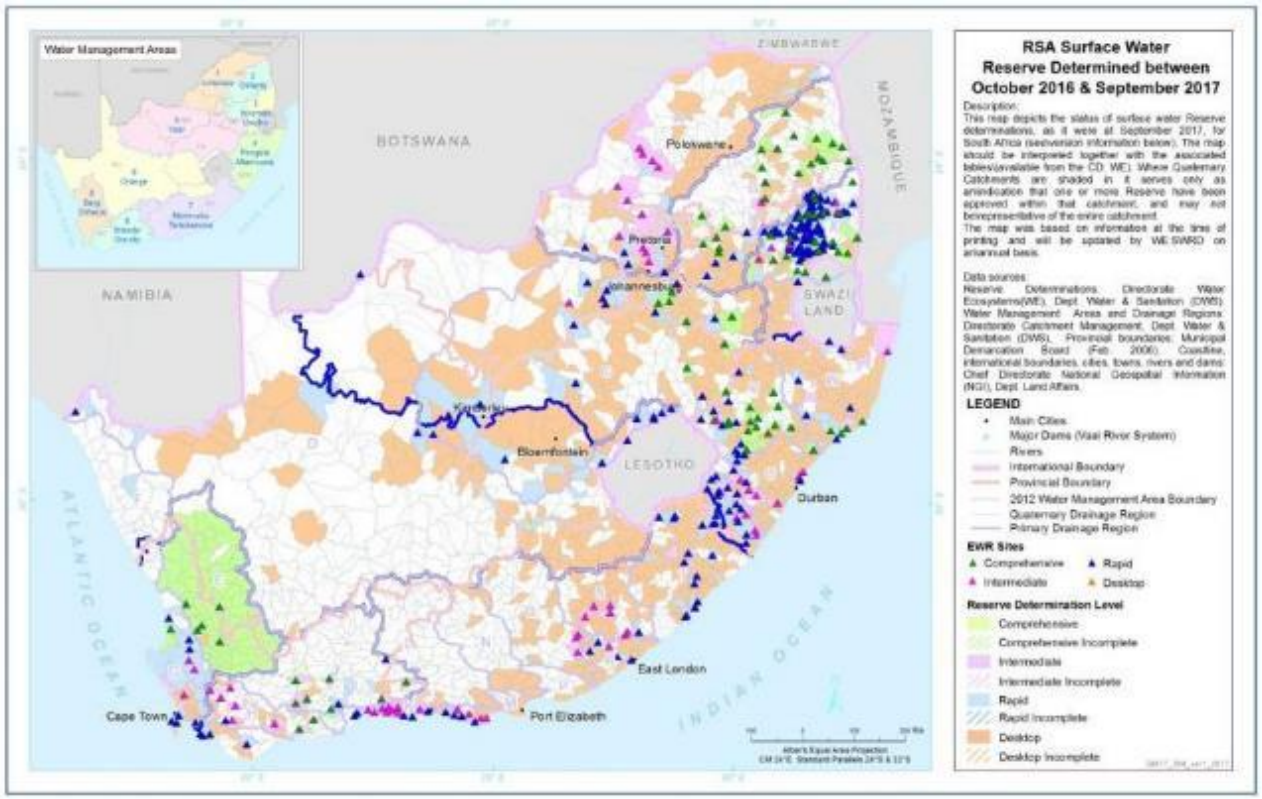


Figure 9.3. Status of surface water reserve determination implemented by the Department of Water and Sanitation (DWS) by September 2017 (DWS 2018f).

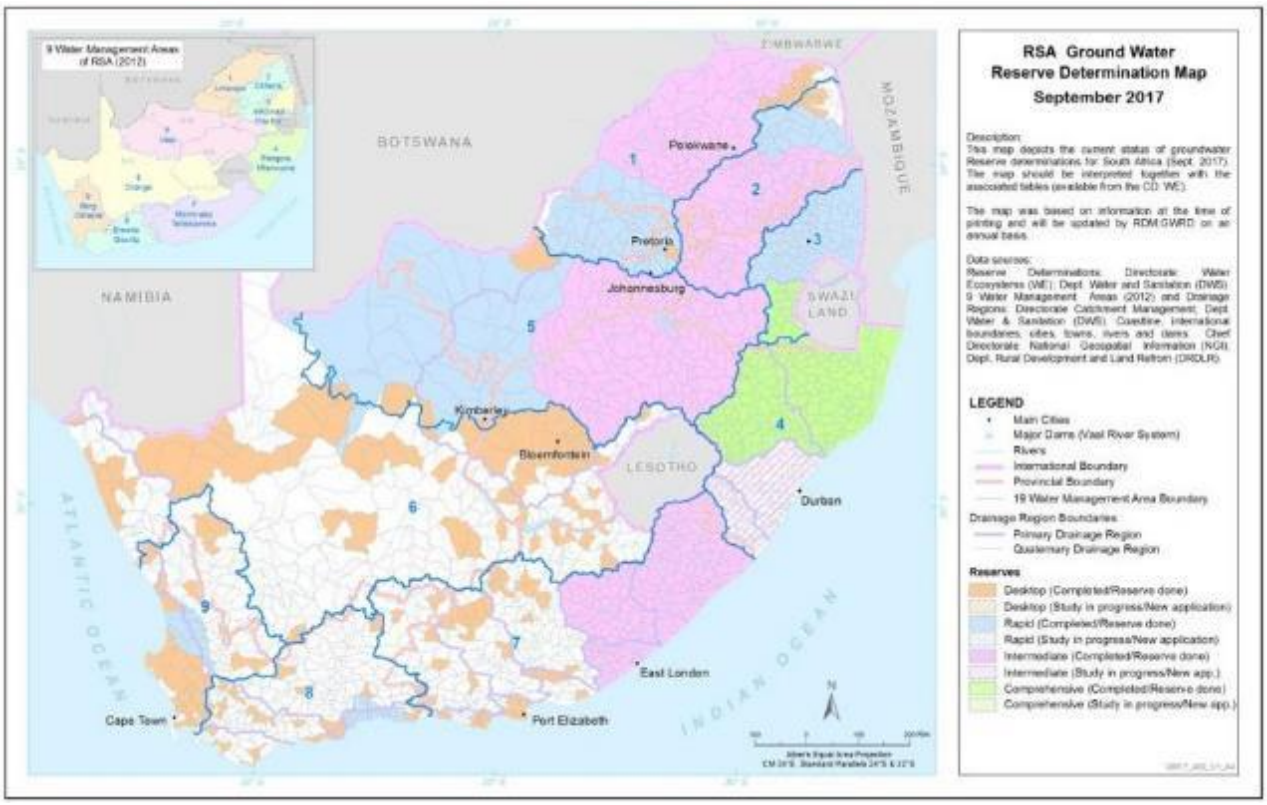


Figure 9.4. Status of ground water reserve determination implemented by the Department of Water and Sanitation (DWS) by September 2017 (DWS 2018e).

Provincial freshwater biodiversity priority areas or Critical Biodiversity Areas (CBAs)

Through a systematic biodiversity planning process, every province in South Africa has generated a CBA map which identifies provincial priority areas required to meet biodiversity targets for ecosystems, species and ecological processes (Table 9.6). CBAs and Ecological Support Areas (ESAs) support the persistence of a viable representative sample of all ecosystem types and species, as well as the long-term ecological functioning of the landscape as a whole. The most recent provincial updates took place in 2017 for three provinces, namely, the Northern Cape, Eastern Cape and Western Cape provinces. NFEPA has provided a preliminary base dataset for provinces that do not yet have an improved wetland layer, however, Mpumalanga, KwaZulu-Natal and the Western Cape provinces have each developed an updated provincial wetland layer combining modelled data with specialist input, while a new modelled wetland layer is in progress for the Free State Province. The KwaZulu-Natal Province has developed an updated aquatic ecosystem classification system (Rivers-Moore & Goodman 2010). Three metropolitan areas, City of Cape Town, Nelson Mandela Bay and eThekwini municipality have also developed their own wetland maps at a finer spatial scale than the provincial map.

Table 9.6. Summary of freshwater representation in provincial Biodiversity Sector Plans.

Province *	River ecosystem types	Inland wetland ecosystem types	Freshwater species	Connectivity /corridors / climate change refugia	SWSAs	Targets for rivers and wetlands
EC	Main stem rivers of high irreplaceability plus a 32 m buffer, includes fish sanctuaries and free flowing / flagship rivers	Umzimvubu Wetland Complex, Karst/Limestone wetlands, additional oxbow wetlands, dune and dune bypass wetlands	Not specified beyond fish sanctuaries	Climate change refugia and ecological corridors – main rivers and 32 m buffer which fall within fish corridors and other selected catchments (wetland clusters) to achieve connectivity	Provincial Strategic Water Source Areas and groundwater Karst-Limestone landscape	Have listed aquatic CBA but not specific targets
FS		Modelled wetlands				
GT	1:50 000 rivers from DWS	Pans	YES	Landscape corridor network	No	No
KZN	NFEPA Perennial rivers only	Beggs' Priority KZN wetlands NFEPA wetlands Rivers-Moore *et al*.	Wattled Crane Eels	Local and landscape Corridor network which comprise of flagship NFEPA rivers	High Water Production areas	Yes
LP	NFEPA	NFEPA		Climate change refugia and landscape connectivity corridors		Yes
MP	NFEPA	NFEPA	Yes dragonflies, damselflies, crabs	Corridors	Provincial Strategic Water Source Areas high rainfall areas	Yes
NC	NFEPA	NFEPA Intact riparian vegetation	No	Rivers landscape corridors	Not specified	Yes
NW	NFEPA	98 NFEPA types Peat wetlands Dolomitic eyes Modelled pans Instream wetlands and riparian areas	Yes	Provincial level critical biodiversity corridor linkages which include freshwater priority areas	Provincial scale - Important karst recharge areas	Peat and lakes 100%; alluvial 31%; salt pans and freshwater wetlands 24%
WC	NFEPA and 1:50 000 Rivers	NFEPA and natural wetland classes from the Western Cape's land cover product	Yes	Climate adaptation corridors	Water recharge areas; Water source areas (SWSAs + high yield sub-catchments)	Yes

** Provinces: FS = Free State; GP = Gauteng; KZN = KwaZulu-Natal; LP = Limpopo; MP = Mpumalanga; NC =Northern Cape; NW = North West; WC = Western Cape*

Several of the above-mentioned strategic planning outputs have been used to support a recent process of national prioritisation for wetland rehabilitation (Box 9.1).

Box 9.1. Working for wetlands strategic planning in South Africa

by Farai Terarai, DEA: Working for Wetlands and Kate Snaddon, Freshwater Consulting Group

The South African Department of Environmental Affairs (DEA) is home to the national wetland restoration initiative called the Working for Wetlands Programme. The growing need to enlarge the wetlands conservation footprint, highlighted by the NBA 2018 report, and the need to enhance restoration outcomes, has necessitated new strategic thinking when planning for wetland rehabilitation. The ensuing catchment-scale planning undertaken by the Working for Wetlands Programme in 2019 seeks to promote integration of restoration/rehabilitation interventions to achieve ecosystem-scale outcomes, long-term custodianship, and embedding of rehabilitation in broader local institutions and frameworks, thus fostering sustainability. The 2019 Working for Wetlands strategic planning process has been conducted at a provincial level in order to allow for varying levels of data availability in each province. The Working for Wetlands Provincial Strategic Plans will be developed over an ongoing 5-year cycle by incorporating improved and/or emerging new datasets. They are data-driven, with stakeholder validation, and they follow a multi-criteria analysis (MCA) approach.

Figure 1: Five-year strategic rehabilitation plan showing the data driven and stakeholder validation components.

The spatial planning unit used in the MCA analysis is the sub-quaternary catchment. To assess the relative to importance of each sub-quaternary for wetland rehabilitation, the following criteria were used: rehabilitation potential (soil erodibility and wetland ecological condition); ecosystem service value (wetland area, surface- and groundwater strategic water source areas, potential for ecosystem-based climate adaption (EbA) areas, the presence of peatlands, water quality enhancement, sediment retention and flood attenuation), and livelihoods (household vulnerability; environment-population growth conflict). Emerging priority catchments are then filtered for potential partnerships in the form of protected areas, historical rehabilitation sites, broader natural resources management priorities, and potential co-funding from landowners, other institutions, organisations and individuals. This potentially enlarges the restoration footprint of the often limited government funding, and ensures sustainability of interventions, as well as sustained ecosystem service provision.

The uptake of CBAs and ESAs into land use decision making anecdotally appears to be very successful as most practitioners are aware of and make use of the products. All Biodiversity Sector Plans are accompanied by land use guidelines advising restricted use in priority biodiversity areas and guiding other land uses to more appropriate areas. Other than anecdotal evidence, there have been few in depth analyses to assess the impact of these products on preventing habitat loss and other pressures to freshwater biodiversity. A preliminary review in the Western Cape Province's State of Biodiversity report (Duffell-Canham *et al.* 2017) revealed a decrease in land use change applications in CBAs, suggesting a positive effect of applicants avoiding land use change in these areas. More monitoring and analysis is needed across the country to track the full impact of these tools, supported by an annual assessment at provincial level of partial or complete loss of CBAs due to land-use change, using Google Earth, for example.

With a view to limiting habitat fragmentation and promoting inland aquatic ecosystem connectivity across the landscape, all provincial biodiversity sector plans have identified conservation corridors which incorporate river and inland wetlands (Table 9.6). Box 9.2 showcases successfully embedding and connecting rivers and inland wetlands into their surrounding terrestrial landscape through an integrated set of corridors.

Biodiversity Management Plans for inland aquatic ecosystems and freshwater species

Under the Biodiversity Act (No. 10 of 2004), Biodiversity Management Plans (BMPs) may be developed and gazetted for species and ecosystems which have been identified as threatened through the Red Listing process and NBA (Government Gazette 34809 of RSA 2011). To date, no BMP has been prepared for a river or inland wetland ecosystem types. A number of BMPs were, however, developed for freshwater species, including the Barrydale redfin (*Pseudobarbus burchelli)*, the Clanwilliam sandfish (*Labeo seeberi)*, and the Pickersgill's Reed Frog (*Hyperolius pickersgilli*), but not all have been signed off to date.

The Pickersgill's Reed Frog is only found at 25 sites along KZN's unique coastal wetlands. In 2016 it was listed as Critically Endangered, but through efforts to restore habitat, and a captive breeding program with the Johannesburg Zoo and Ezemvelo KwaZulu-Natal Wildlife, the status of this frog has been down listed to Endangered. Box.9.3 showcases the value and success of such work done by the Endangered Wildlife Trust (EWT) to successfully improve the status of this species.

Conclusion

Overall, South Africa has a very comprehensive suite of spatial planning tools, but there remains a gap between the tools, implementation and a measureable impact in alleviating the key identified pressures. National-scale products such as the SWSAs and NFEPA output layers are by nature coarse-scale products used for planning and assessment at a country-wide scale. Tools and methods are required to translate these national scale products and their resultant priority areas to a provincial or fine-scale level for implementation. The process of translating these national-scale products to finer scales, has been relatively well done for NFEPA rivers, inland wetlands, FEPAs, Important Fish Areas, but not yet for Water Resource classes, RQOs or the recently published SWSAs (Le Maitre *et al*. 2018). The reconciliation of the overall class of a catchment and the local scale information is a critical step for future plans. Management plans and best management practice are a critical bridge between planning and implementation. Future NBAs could include an indicator to track direct loss of prime conservation assets such as CBAs, as well as a measure of their management effectiveness.

Box 9.2. Ecological Networks supporting biodiversity conservation

by Prof Michael J. Samways, René Gaigher, James Pryke, Department of Conservation Ecology and Entomology, Stellenbosch University

South Africa is immensely rich in biodiversity. Conserving this vast variety of life, much of which is still scientifically undescribed, requires a broad-brush approach towards its conservation. One highly effective approach, and one where South Africa has become a world leader, is to set-aside large areas of natural land in and among production areas, especially plantation forestry. These set-asides are in the form of significant conservation corridors and nodes. The corridors and nodes connect with each other, as well as with protected areas, and all together, are called large-scale ecological networks (ENs). They not only conserve current biodiversity, but also future-proof biodiversity by providing resilience against climate change. To date, over 500 000 ha have been set-aside to conserve biodiversity and maintain ecosystem function.

ENs have been researched, developed, and improved by the Mondi Ecological Networks Programme (MENP) at Stellenbosch University. The programme won the NSTF/GreenMatter Award for its influential contribution towards conserving South Africa's rich biotic heritage. ENs are effective for a whole range of organisms from plants to invertebrates and vertebrates. These ENs are so effective at conservation that they are equivalent of protected areas, while also spatially extending the value of protected areas. The significance is that instigating ENs enables optimal production while maximizing on the conservation of biodiversity and ecological integrity for the benefit of future generations.

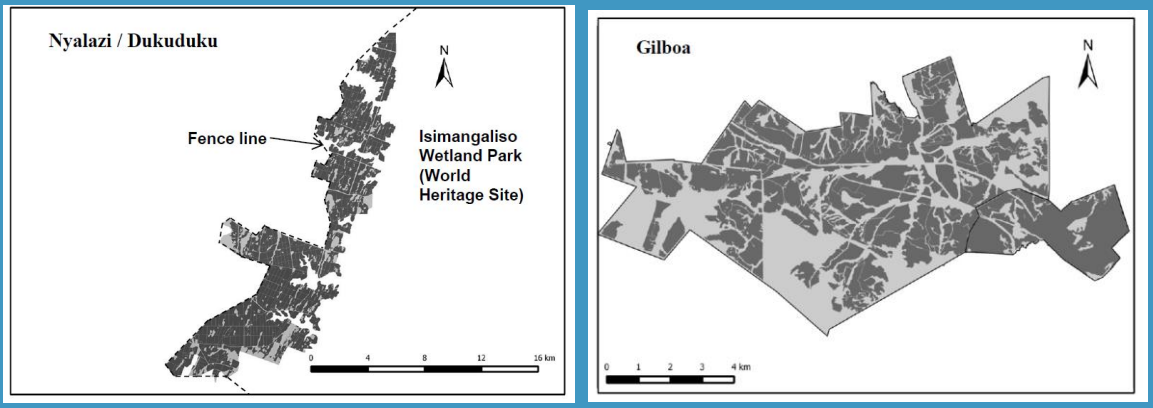


Figure 1. Maps of two plantations with large-scale ecological networks (ENs) in South Africa. The dark areas are timber compartments, while the light areas are the ENs. The plantation/EN on the left (Nyalazi/Dukuduku) is adjacent to a large protected area, with the park now extended as corridors into the plantation area, allowing many large and significant mammals to wander freely among the timber plantation compartments. The matrix surrounding all these plantations/ENs is composed variously of other plantations/ENs, and other agriculture and protected areas.

(a) (b)

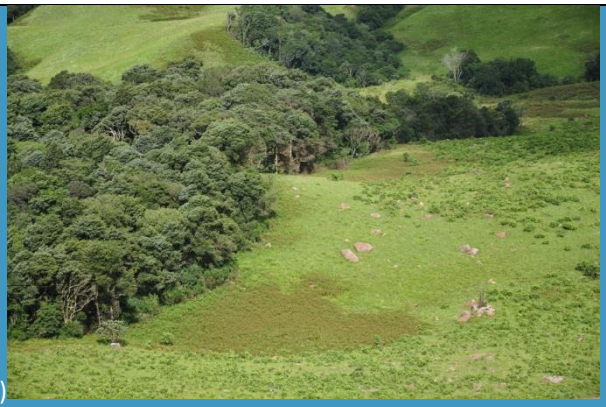
(c) (d) 

Figure 2. (a) An ecological network (EN) with wide and narrow conservation corridors, as well as varied topography. In the far upper left is a protected area adjacent to the EN. (b) These ENs must enable the local ecosystem processes to continue, and this is particularly important for hydrological processes. (c) The operational scale of the mesofilter (features of the landscape) is a major component of these ENs, with rocks, bare ground and pools (seen here) being conserved alongside vegetation heterogeneity. This particular pool is home to one of the world's largest dragonflies, the black emperor *Anax tristis*. (d) These ENs aim to maintain as much natural heterogeneity as possible. While principally conserving grassland, they importantly also conserve the natural forest patches associate with the variable topography.

(a) (b)

(c) (d)

Figure 3. (a) Dung beetles, along with elephants, are conserved in the ecological networks (ENs). (b) A white rhino grazing in an EN. (c) Elephants use the ENs, causing only minimal damage to plantation trees. (d) Megaherbivores are an essential component of the African landscape, and are also a management component of the ENs, keeping them in a historically natural condition.

(a) (b)

Figure 4: (a) The ENs must provide for the local human communities, and this involves grazing of cattle, among other activities. Where there is less density of megaherbivores than in the past, cattle serve as grazing substitutes which then maintain historic biodiversity. (b) Management of the ENs using artificial fires involves on the one hand, mimicking natural conditions, and on the other, protects the timber crop.

Figure 5: A plantation/Ecological Network (Gilboa) with highly varied topography and one which has very high conservation value.

Box 9.3. Initiatives to support the successful breeding of endangered freshwater species

Putting the action into Conservation Action Plans for a threatened frog species

By Jeanne Tarrant, Threatened Amphibian Programme, Endangered Wildlife Trust, South Africa

The Endangered (IUCN 2016) Pickersgill's Reed Frog (*Hyperolius pickersgilli*) is endemic to South Africa and restricted to the KwaZulu-Natal coast. The natural habitat of Pickersgill's Reed Frog is limited to fragmented patches of coastal reed-bed wetland, the majority of which continues to undergo transformation and degradation caused by urbanisation, agriculture, mining and forestry. A Biodiversity Management Plan was developed for the species to address these threats in a collaborative manner through multiple role players. The Plan was gazetted on the 2nd June 2017 (Tarrant & Armstrong 2017). Ezemvelo KwaZulu-Natal Wildlife (EKZNW) was appointed as the lead agent for its implementation, with the Endangered Wildlife Trust (EWT) as the supporting implementing agent.

In the first year the following actions have been implemented, the Pickersgill's Reed Frog Forum was constituted at its inaugural meeting on 20 April 2018, with 22 members and alternate members representing 15 entities. King Cetshwayo District Municipality has included wetlands containing the species into its Environmental Management Framework (EMF). Priority areas for Pickersgill's Reed Frog within the eThekwini Metro are included in the Durban Metro Open Space System. Approximately 1 000 ha of alien invasive plants have been cleared and 1 000 indigenous plants planted by EWT at Pickersgill's Reed Frog sites since 2015 in the eThekwini Metropolitan Area through the creation of 75 local jobs. One wetland site has been rezoned to 'Conservation Reserve' status. Four youths have been trained as local Nature Site Guides and two have been employed as 'Biodiversity Protection Officers' at one of the sites.

Genetic analysis indicated that the species has a single genetic population. Its life cycle has been elucidated and documented through captive-breeding of the species and a captive assurance population established at Johannesburg Zoo. The first 200 captive-bred individuals were released back into the wild in September 2018. Various monitoring techniques, including passive acoustic monitoring and the use of visual implant elastomers to monitor success of colonisation of captive-bred frogs. Testing for the chytrid fungus in the species in captivity and in the wild has been carried out. A database of distribution records for Pickersgill's Reed Frog has been created to assist with conservation decision-making. Awareness activities include over 150 television and online documentaries, print and online articles, and the annual Leap Day for Frogs, coordinated by EWT.

Figure 1: Pickersgill's Reed Frog (photo by Nick Evans).

Success story for Pickersgill's Reed Frog in KZN

The Pickersgill's Reed Frog is only found at 25 sites along KZN's unique coastal wetlands. In 2016 it was listed as Critically Endangered, but through efforts to restore habitat, and a captive breeding program with the Johannesburg Zoo and EKZNW, the status of this frog has been down listed to Endangered.

This conservation success means that 200 of these tiny but important frogs will be released into the restored Mount Moreland site today. Once released we will be able to monitor and track them with an innovative bioluminescence technique. *Facebook posting Endangered Wildlife Trust 17 Sept. 13:51*.

9.3.3 Recommendations

Together with a high level of regulatory compliance (Section 9.4), strategic planning to inform management of inland aquatic species and ecosystems is key in responding in an efficient, far-reaching, collaborative, and financially feasible manner to the full suite of pressures identified in Section 9.4, but in particular, to directing development away from the most critical biodiversity areas. A catchment and landscape approach is ideal, combining protected areas, biodiversity stewardship (securing critical ecological infrastructure), identification and conservation of ecological corridors (e.g. riparian buffers which include flood zones) and identification of critical biodiversity areas embedded within allocated water resource area use classes and resource quality objectives, supported by regulation and stipulated best management practice. A catchment approach is critical to ensure impacts to aquatic ecosystems are identified and addressed.

Further key gaps and recommendations include:

- **Increase listing of unique and threatened river and inland wetland ecosystem types through Ramsar nomination. In particular, the free-flowing rivers could be considered;**
- **Updating FEPAs and Important Fish Areas as part of NFEPA II is a top priority to incorporate the improvements on the NWM5 and formal assessment of freshwater species;**
- **Catchment-level planning and management are crucial to ensure cooperative governance** so that the diversity, functionality and connectivity of inland aquatic ecosystems are maintained; and
- **The value and importance of SWSAs must be popularised, recognised, and adopted as essential to ensure the sustainable future water supply and water security in South Africa**. The DWS, the newly formed Department of Environment, Forestry and Fisheries (DEFF) and the WRC should adopt and champion the concept of SWSAs and a programme should be developed and promoted to ensure that these become part of public consciousness.

9.4 Regulation

9.4.1 Overview

Policies and regulations help ensure that land use does not damage or degrade optimal function and ecosystem service delivery of rivers and inland wetlands now and into the future. Regulation of land and water use activities to minimise pressures in and adjacent to rivers and inland wetlands is further informed by preferred spatial land use categories identified during biodiversity assessment and planning, spatial planning tools and water resource classification. These, in turn, are strengthened by the quality of available foundational information.

9.4.2 Status

South Africa is considered to be one of the international leaders in environmental law (King & Pienaar, 2011). Project applicants are required to pursue approval for activities that may impact inland aquatic ecosystems, by means of EIAs and subsequent Records of Decision (RoD), or through a Water Use License, and the mitigation sequence (avoid, minimise, offset) is entrenched in the Constitution and national regulations. In most instances, activities identified in Chapter 4 as pressures impacting inland aquatic ecosystems are governed by specific legislation of key institutions and multiple mechanisms available in South Africa to intervene in the planning and management of water security and our ecosystems. However, a review of the status of water resource protection in South Africa by Riemann *et al.* (2017) has noted severe delays in implementation of legislation.

The Mabola Protected Environment near Wakkerstroom, Mpumalanga, is an example of the application of an important regulatory tool for inland aquatic ecosystem protection. The area was declared under the Protected Areas Act in 2014 by the Mpumalanga provincial government as part of the declaration of more than 70 000 ha of protected area in the Mpumalanga grasslands region. This followed years of extensive research and planning by a number of government agencies, including the DEA, SANBI and the Mpumalanga Tourism & Parks Agency (MTPA). In 2016, without public consultation, Ministerial permission was granted for a coal mine to be built inside the Protected Environment. The Court set aside the permission and referred the decision back to the two Ministers for reconsideration on the basis that the Ministers did not take their decisions in an open and transparent manner or in a manner that promoted public participation, and that the decisions were therefore procedurally unfair. In November 2018, the North Gauteng High Court set aside the 2016 decisions of former Mineral Resources Minister Zwane and the late Environmental Affairs Minister Molewa to permit a new coal mine to be developed in the Mabola Protected Environment and subsequent permission to appeal was refused twice, in January 2019 and April 2019 (CER 2019). The case was brought by the coalition of eight civil society organisations challenging a range of authorisations that have permitted an underground coal mine in a strategic water source area and a protected area.

South Africa's Alien and Invasive Species Regulations have also successfully led to approximately R1.5 billion per year since 1994 being spent on the control of terrestrial and inland aquatic alien and invasive plant species (Van Wilgen & Wilson 2018). This is considered an underestimate as it only includes funding from the DEA and not from other government or semi government entities or the private sector. Although the regulations have not been in place for long (less than three years), overall, the authors concluded that a lack of adequate planning remains an obstacle to the control of biological invasions in specific areas. High levels of non-compliance with some regulations, a shortage of capacity within the DEA to ensure compliance (although the magnitude of the shortage has not been assessed); the apparent absence of a strategic approach to implement the regulations in a capacity-constrained environment; and contestation of the desirability of regulations for particular species were noted as part of the recent status assessment of biological invasions in South Africa (Van Wilgen & Wilson 2018).

Pressures addressed through regulation include habitat loss in and adjacent to rivers and wetlands and water over-abstraction and pollution. Poor compliance with existing laws is a key identified challenge to effective regulation. The need to improve compliance with existing laws is an over-riding concern. Regulatory authorities currently have varying and limited capacity to ensure compliance and to enforce the conditions of permits, and applicants often do not ask for permission from the outset. Compliance is ultimately linked to capacity and budget in departments to monitor compliance with and enforce relevant environmental laws (e.g. laws prohibiting poaching and the clearing of indigenous vegetation, as well as

those governing fishing methods and quotas, the protection of threatened ecosystems, water quality and water abstraction).

The DWS verification and validation process on existing lawful water use, particularly in the agricultural sector, is still underway with significant work still to be done. Water use per property and per large user is not yet sufficiently correlated with the water resource (Riemann *et al*. 2017) and the cumulative impact on ecosystems and the water resource is, therefore, not adequately considered. This helps explain why several rivers are completely over-utilized, with a number of perennial rivers now non-perennial. Overall, the connectedness of rivers and wetlands to each other and to the broader landscape, and the reality of them spanning management jurisdictions, calls for inclusive partnerships at appropriate catchment scales (Roux *et al*. 2006). This has not yet been effectively achieved (Riemann *et al.* 2017).

9.4.3 Recommendations

Key gaps and recommendations include:

- **Adopt the policy objective of no net loss of remaining inland aquatic ecosystems and reinforce the importance of avoidance and minimisation**, particularly in areas identified to be important through systematic biodiversity planning;
- **Strengthen compliance monitoring and enforcement** through adequate budget and staff complements with appropriate skill sets, ensure that permit conditions are enforced and violations are addressed to ensure river, riparian and wetland protection, and that there is consistency in the extent of the penalty;
- **Promote coordination among authorisation and commenting authorities**. Increase capacity in coordination, numbers of staff and training to review applications and ensure that RODs are complied with, and continue to explore multi-institution permits and coordination between authorities for projects requiring multiple permits. In an environment of limited regulatory capacity, the bureaucratic burden of excessive legislation needs to be addressed and laws streamlined without compromising the natural environment;
- Foster cooperation among authorities and stakeholders in developing catchment-based strategic plans with explicit links to legislated activities and sensitive areas;
- **Review institutional mandates for efficiencies**, gaps and cooperative governance opportunities;
- **Support best practice when undertaking wetland delineation**, and river and wetland assessments, with the onus on the practitioner to show scientific rigour when presenting an appropriate body of evidence to support their determination in the face of natural variation within wetlands, with citations and scientific references to support reasoning;
- **Support more effective uptake of biodiversity management plans** for ecosystems and freshwater species; and
- **Strengthen budget and capacity** for evaluating EIAs, implementing environmental authorisations, and monitoring compliance with the conditions of environmental authorisations (RoDs).

9.5 Protected areas

9.5.1 Overview

New protected areas to safeguard water resources can be formally declared through the Protected Areas Act (No. 57 of 2003; RSA 2003), either by the state or through the biodiversity stewardship mechanism, which involves voluntary commitments (in the form of legal agreements) from private or communal landowners to protect and manage land of high biodiversity importance. Within the biodiversity stewardship model, further options to support improved biodiversity management include agreements in terms of contract law or in terms of the Biodiversity Act (No. 10 of 2004; RSA 2004). Biodiversity stewardship therefore provides a powerful tool for extending into the catchment landscape, securing new protected areas, as well as beyond formal protected areas to place critical biodiversity on privately or communally owned land under greater protection and improved management, whilst recognising the rights of landowners and communities to live on and benefit economically from the land.

9.5.2 Status

The status of inland aquatic ecosystem protection levels has been reported in Section 6.2 showing the rivers and inland wetlands are inadequately protected in South Africa's protected area network. The issues are two-fold: (i) Firstly, the protected area network was not established through systematic conservation planning of all ecosystems types. Systematic conservation planning was only introduced in the 2000 (Margules & Pressey 2000) and pioneering in the terrestrial ecosystems. Systematic conservation planning for rivers and wetlands lagged behind. Evidence in South Africa showed that rivers inside the protected area newtork were less degraded compared to those outside (Nel *et al*. 2007), proving the benefit of formal protection for inland aquatic ecosystems in South Africa. The first freshwater conservation plan was published in 2011 (See discussion of NFEPA in Section 9.3.2), incorporating both priorities for formal protection (FEPAs) and support areas. (ii) Secondly, ecosystems within the protected area network may also be degraded as a result of pressures outside the reserve or within the cathment, and therefore, a protected area boundary does not guarantee protection of inland aquatic ecosystems. In particular, river ecosystems had often been used as a boundary of a reserve or country, and not adequately protected.

The 2016 PAES included river and inland wetlands of NFEPA from across all provinces, with some provinces selecting to improve on the quality of NFEPA datasets for inclusion in the PAES in 2016. The 2016 PAES is currently being gazetted (DEA 2016), and have targeted 403 900 ha of inland wetlands to meet the 20% biodiversity target for South Africa. However, with the update of the NWM5, this makes up only 15% of the extent of inland wetlands in the NWM5. Improvements in the NWM5 as well as new ecosystem types should be reflected in an updated NPAES. However, it is proposed that an updated and improved NWM6 should best inform any NPAES updates for wetlands.

One of the shortcomings of assuming that terrestrially planned protected areas would be suitable for inland aquatic ecosystems, is that these do not incorporated the interconnectedness and interdependency of surface and groundwater in the broader landscape or catchment. Very few protected areas in South Africa support an entire upstream catchment or extensive inland aquatic ecosystems, however, some exceptions are worth mentioning, including the multiple small headwater systems within the Kruger National Park, multiple headwater seepage wetlands within the Mountain Zebra National Park in the Eastern Cape Province, the Matlabas system within Marakele National Park (Limpopo Province), the headwaters of the

Olifants and Doring rivers within Cederberg Wilderness Area in the Western Cape Province, and the Verloren Vallei Nature Reserve and Ramsar site in the Mpumalanga Province.

The use of biodiversity stewardship as a mechanism for protection across landscapes or complete catchments, has been steadily increasing since 2003, allowing for the declaration of new protected areas on privately and communally owned land. Over the past eight years approximately 10 000 km^2 has been added to the protected area estate of South Africa, mostly through biodiversity stewardship agreements (Skowno *et al.* 2019). In another example, the Kruger-to-Canyons Biosphere Region initiative links biodiversity stewardship, conservation corridors, communities and protected areas and is an example of ongoing work which acknowledges the longitudinal and interconnected nature of rivers and landscape and the challenge of protected area design.

Formal protected areas are typically the most secure mechanisms for conserving species and ecosystems, with the intention of protecting well-functioning and critical ecosystems against current and future pressures, including habitat loss. However, inland aquatic ecosystems and their ecological processes typically operate over large areas, extending into the broader landscape and catchment beyond the protected area footprint. Impacts that take place outside park boundaries (e.g. new fish invasions) can, therefore, still have negative consequences for freshwater biodiversity within a park (Nel *et al*. 2007; Barendse *et al*. 2016). For this reason, inland aquatic ecosystems, especially rivers, require the full suite of response tools to be applied. A catchment and landscape approach is ideal, combining protected areas, biodiversity stewardship (securing critical ecological infrastructure), identification and conservation of ecological corridors (e.g. riparian buffers which include flood zones) and identification of critical biodiversity areas embedded within water resource classes, supported by regulations and stipulated best management practice.

The spatial identification of inland wetlands, river and riparian areas, characterisations to identify their key drivers, pressures and the species they support, and the incorporation of this information into management plans does not always take place in sufficient detail for biodiversity stewardship sites and protected areas. Many protected areas are undergoing updated management planning and are incorporating measures to increase management effectiveness and adaptive management, providing an opportunity for increased focus on more detailed freshwater management planning.

9.5.3 Recommendations

Key gaps and recommendations include:

- **Substantially increase the representation** of river and wetland ecosystem types within the protected area network through first conservation planning of NFEPA and then active increase of the protected areas network in an PAES;
- **Prioritise under-protected species** for consideration in protected area expansion efforts, especially those that are both endemic and threatened. Freshwater fish are an obvious group for prioritisation. Protected areas should aim to incorporate climate refugia, future biodiversity hotspots, and habitats for species that are particularly vulnerable to climate change (such as amphibians) or that are of high conservation value;
- **Prioritise** protection and improved management of water ecological infrastructure (particularly through the biodiversity stewardship approach) in **Strategic Water Source Areas**;

- **Incorporate sufficiently detailed management plans** for aquatic ecosystems and aquatic species, based on their mapped extent and an understanding of their specific functions, drivers and pressures, into protected area and biodiversity stewardship management plans;
- **Apply a suitable monitoring, management effectiveness assessment and adaptive management system** to realise the full potential of protected areas and biodiversity stewardship sites for inland aquatic species and ecosystems. The protection level representation indicator for ecosystems should be complemented by an indicator of protected area effectiveness for each ecosystem type in future, which will require multi-stakeholder collaboration for data gathering and expert opinion; and
- **Support ongoing monitoring and control measures** within the protected area network, particularly with regards to invasive species, as well as other pressures impacting species.

9.6 Rehabilitation

9.6.1 Overview

Rehabilitation is located partway along a restorative continuum from reduction of degradation pressures through to the full recovery of an ecosystem (McDonald *et al*. 2016). The continuum includes stabilisation (when the degradation of a wetland is greatly slowed down or halted); rehabilitation (moving a degrading system towards its original state and allowing the system to recover some of its lost functions and values); and restoration (when a system is returned all the way to its original state). Rehabilitation of rivers, riparian zones and inland wetlands aims to improve ecosystem function and promote the recovery of the natural biota (including control of biological invasions through pathway management). Rehabilitation includes the process of assisting in the recovery of an ecosystem and ecosystem service delivery by reinstating the natural ecological driving forces or halting the decline in condition (Russell *et al*. 2009). The key principles of aquatic ecosystem rehabilitation are to first reinstate the hydrological regime. Geomorphology, including sediment movement, is also considered a first order control on ecosystem functioning, especially within the southern African landscape (Ellery *et al*. 2016; Tooth 2018). Ecosystem recovery ideally requires key processes (hydrology, geomorphology, and physicochemistry) to be re-instated such that they are self-sustaining and do not require maintenance into perpetuity. However, this is not always achievable and it is often most pragmatic to rehabilitate to a functional state and not an ideal natural state. Maintenance is, therefore, a mechanism to secure investments in natural infrastructure.

Rehabilitation includes the re-instating a buffer zone of vegetated land (e.g. indigenous riparian zone) designed and managed so that sediment and pollutant transport carried from source areas via diffuse surface runoff is reduced to acceptable levels (Castelle *et al*. 1994; Verhoevenn *et al.* 2006; McFarlane *et al*. 2015). Buffer zones may reduce disturbance impacts on aquatic ecosystems from adjacent land uses, may contribute to channel bank stabilisation and may provide habitat for a range of semi-aquatic and terrestrial species that make use of aquatic ecosystems for water, food or shelter (Houlahan *et al*. 2006; McFarlane *et al*. 2014). However, buffers are not able to mitigate flow impacts to the wetland from an altered catchment, these are best addressed at a catchment landscape scale.

Rehabilitation addresses pressures of impacts to reverse habitat loss and degradation and fragmentation of ecosystems. Practically, the rehabilitation of wetlands can include the deactivation of erosion that has been accelerated or exaggerated by anthropogenic activities or infrastructure, and the plugging of drainage systems and human-induced erosion gullies, and active revegetation. All of these types of interventions are intended to re-establish the wetland hydrology, geomorphology and plant community dynamics. The

interventions to rehabilitate hydrology and geomorphology commonly include engineered structures such as weirs, chutes and diversions as well as bioengineering (the use of plants to influence the movement of sediment and water). Rehabilitation measures to manage biological invasion in South Africa are critically important as invasive species have been identified as one of the most significant pressures on aquatic ecosystems and species.

9.6.2 Status

Several rivers and inland wetlands in South Africa have benefitted from rehabilitation projects (Figure 9.5). Since 2004, the Working for Wetlands programme of the DEA has invested just 1.1 billion rand in the rehabilitation of more than 1 511 wetlands and the creation of approximately 25 000 jobs (DEFF 2019). In addition, the DEA Working for Ecosystems programme is aimed not only at restoring natural resources, but also at enhancing the social and financial capital of rural communities (DEFF 2019). The Department of Agriculture's LandCare section has provided extensive support to farmers across the highly invaded Western Cape Province. Well-known success projects include clearing of the upper Breede River of invasive plants led by LandCare in co-operation with riparian landowners, and the Berg River Improvement Project, led by the Western Cape Department of Environmental Affairs and Development Planning (WC DEADP). Civil society and NGOs are increasingly contributing their support to rehabilitation initiatives across the landscape.

There are excellent manuals to guide river (Rountree *et al.* 2016) and inland wetland (Russell 2009) rehabilitation both internationally and within South Africa, and these include developing a vision, goals and objectives for each project. Ideally, a reference site in the catchment should guide rehabilitation efforts (desired end goal).

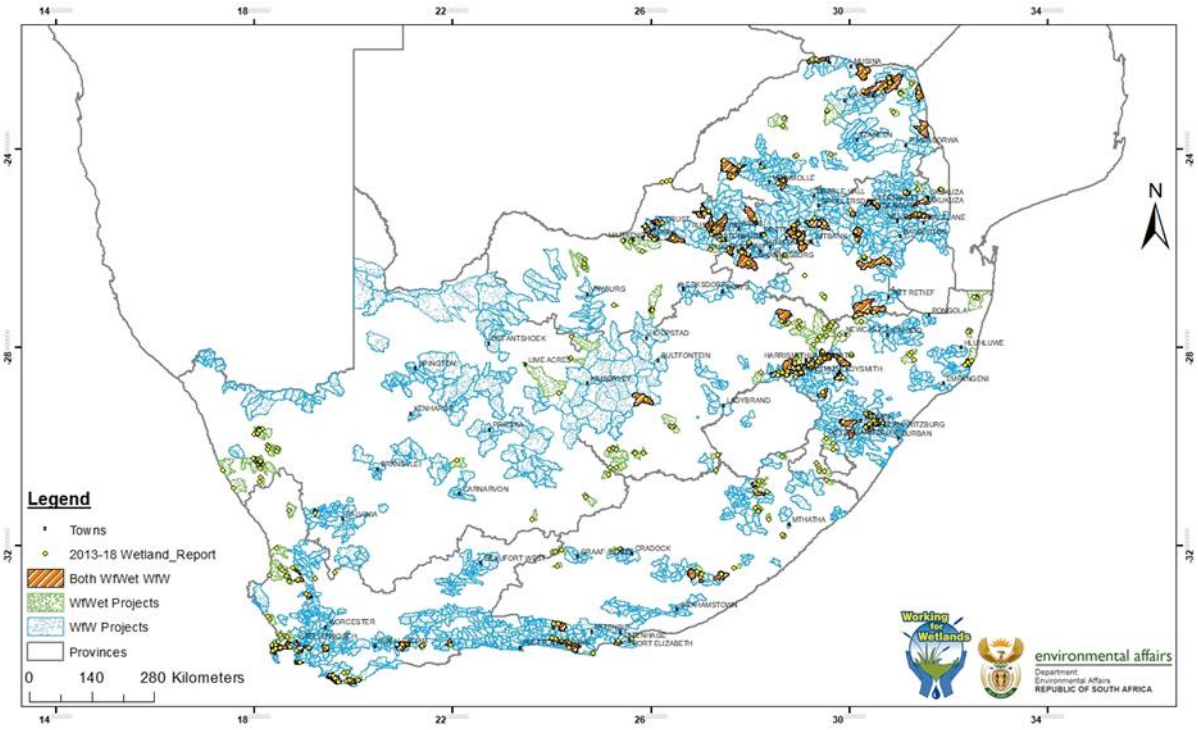


Figure 9.5. Integrated catchment approach by NRM – the map shows the sub-quaternary catchments (SQ4s) where both Working for Water (WfW) and Working for Wetlands (WfWet) have worked collaboratively, and the SQ4s where each worked separately.

Invasive species

Invasive fishes have been successfully controlled by the chemical rotenone (smallmouth bass in Rondegat River, carp in a dam in the Oorlogskloof catchment) and via mechanical (spotted bass in Thee River) methods during the reporting period in cooperative projects between DEA, WRC, CapeNature and the Northern Cape Department of Environment and Nature Conservation (NC DENC) (Box 9.4). Invasive faunal species are one of the critical pressures on our most threatened taxa, the freshwater fish, as assessed in Chapter 7 of this report, compared in the Synthesis Report against the other realms (Skowno *et al.* 2019). Hence, the effective intervention of reducing pressures on the habitat and populations of freshwater fish is critical to reduce the threats to these species.

Box 9.4. Rehabilitation of Critical Biodiversity Areas for freshwater fish in South Africa: The Rondegat River pilot project, Western Cape Province

By Dean Impson, Scientists, CapeNature

South Africa has an estimated 118 native freshwater fish species, including genetically distinct taxa, of which a remarkable 58 are endemic, but an alarming 42 species are threatened (D. van der Colff, SANBI, *pers. comm*.). These are very worrying high levels of threat for a taxonomic group. Threats to fishes and associated ecosystems are varied and include physical, chemical and biological categories of threats. The key physical threats are over abstraction of water, bulldozing and canalisation of river beds and banks, sedimentation (through poor land use management) and construction of weirs and dams (which create barriers and thus fragment the aquatic habitat). Chemical threats include inappropriate use of pesticides and herbicides, excessive use of fertilizers in agricultural lands next to rivers, and increasing levels of pollution from malfunctioning waste water treatment plants that discharge into rivers. Biological threats include invasive animals and plants.

The threat of invasive plants is countrywide, with Australian Acacias dominating many watercourses and degrading the riparian zones of rivers and substantially reducing the dry season base flow of rivers. In the summer rainfall areas, the prime threats to fish are arguably pollution, over-abstraction of rivers during the dry season and sedimentation. In the winter rainfall region, where the Cape Fold Aquatic Ecoregion (CFAE) is found, the prime threat is invasive fishes through predation and competition, and also the negative effects of carp (*Cyprinus carpio*) which can substantially increase turbidity levels in rivers and dams and hence degrade habitat.

The CFE has South Africa's largest concentrations of threatened endemic fishes and, not surprisingly, has the highest percentage of fish Critical Biodiversity Areas (CBAs) in South Africa. In the CFE, the highest concentrations of fish CBAs are in the Olifants-Doring River System, where a remarkable eight of the 10 currently described species are endemic, the highest percentage endemicity for a river system in South Africa. Here the greatest threat to native fishes, most of which are small cyprinids, is predation by two bass species – Smallmouth Bass (*Micropterus dolomieu*) and Spotted Bass (*Micropterus punctulatus*). Over-abstraction of water, especially during the critical dry summer period, when fish are breeding and recruiting, is another major threat.

The Rondegat River is a fish CBA in the Olifants-Doring River system (Figure 1), and was chosen by CapeNature as a pilot project to determine whether the piscicide rotenone could be used to rehabilitate the river. This would involve the removal of invasive smallmouth bass from 4 km of the lower river between an upstream waterfall barrier and a downstream weir. The project started in 2003 through the Cape Action for People and the Environment (CAPE) Programme, and looked at invasive fish control in four rivers in the CFE. Initially, funding from the Table Mountain Fund was used to quantify the serious impact of smallmouth bass on the lower river, which had resulted in local extirpation of two small cyprinids in this part of the river (Figure 2a; b). An Environmental Impact Assessment (EIA) was undertaken in 2007/8, at the request of CAPE, to determine whether rotenone was acceptable for use and under what conditions. This phase was characterised by some opposition to the project, especially from flyfishermen that targeted invasive trout, as one of the four rivers chosen (Krom River, Cederberg) had Rainbow Trout (*Oncorhynchus mykiss)* in it. The EIA recommended the project proceed, with the Rondegat as the first pilot, and generous funding from the then Working for Water (WfW) allowed final planning and river treatment to take place between 2011 and

2013. Funding was also provided by WfW to clear invasive plants from the riparian zone of the Rondegat River. Additional funding from the Water Research Commission (WRC) enabled independent biological and chemical monitoring of the project to take place at the same time.

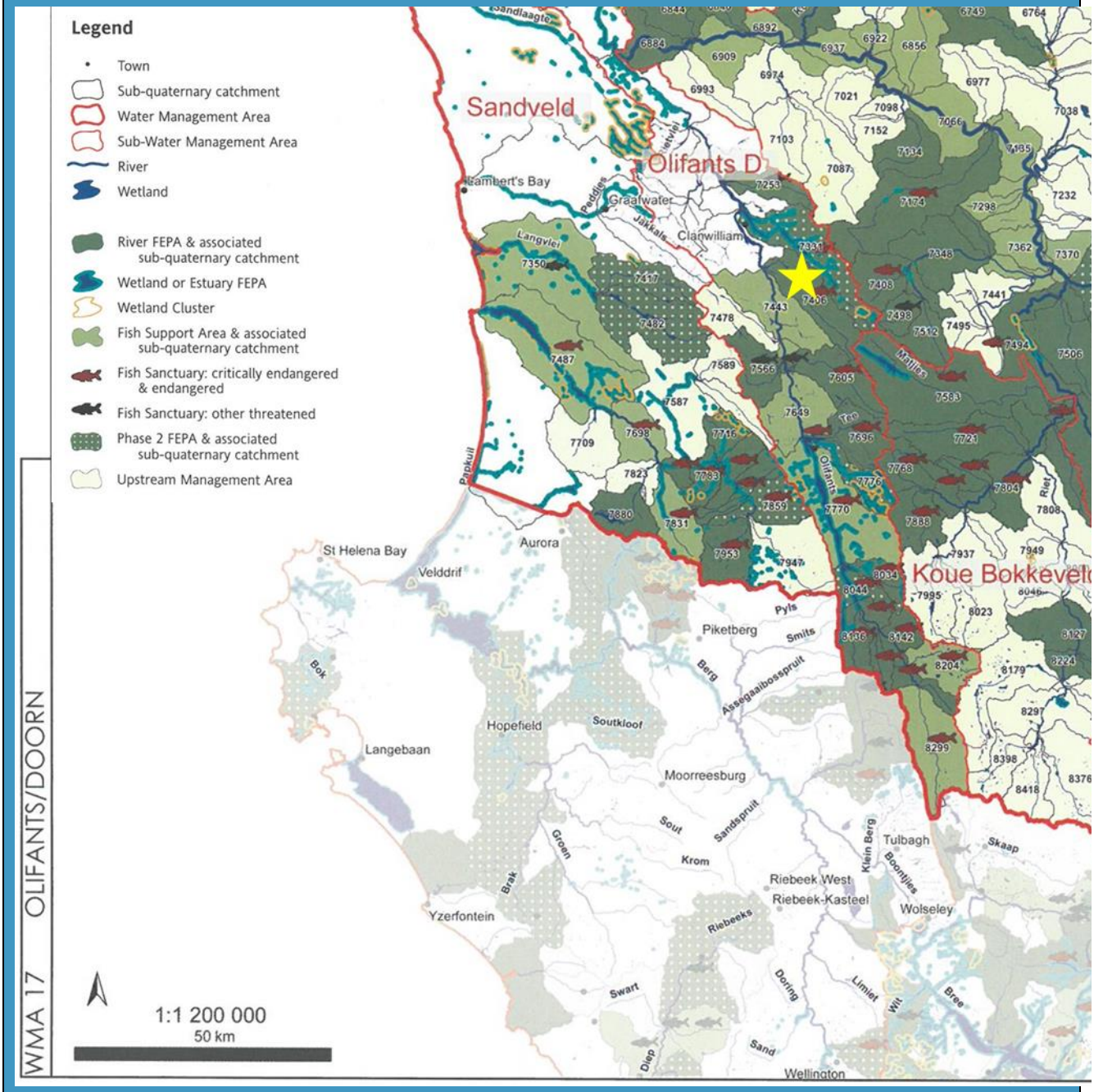


Figure 3: Map of the Olifants-Doring River system showing the high concentration of Fish Critical Biodiversity Areas (red fish = Endangered species, black fish = Vulnerable species) and the location of the Rondegat River (see yellow star on map) near the town of Clanwilliam, Western Cape Province. Map adapted from Nel *et al*. 2011a.

CapeNature treated the Rondegat River with rotenone on 29 February 2012 and 13 March 2013, with the treatments observed by a wide range of stakeholders including angling organisations, the media, university students, regulatory agencies and local water users. Biological monitoring, led by the South African Institute for Aquatic Biodiversity (Marr *et al.* 2012; Weyl *et al.* 2014), has confirmed via a high volume of peer reviewed science that the project has been a major rehabilitation success, with smallmouth bass removed from the treatment section, followed by strong recoveries of threatened endemic fishes (Figure 3) and associated aquatic fauna. Invasive plants were also removed from most of the river, and thus the Rondegat River is the first river in South Africa to have had integrated control of invasive fishes and plants at the same time. The Fish Index used by CapeNature has changed from an E category

(Poor) in the treatment area prior to the use of rotenone to a B category (Largely Natural) currently, which is a huge improvement. In addition, there has been good recovery of the native riparian zone in areas cleared of invasive trees.

(a)

(b)

Figure 2: (a) Clanwilliam redfin (*Pseudobarbus calidus* – NT) and (b) a mixed school of Fiery and Clanwilliam Redfins (*Pseudobarbus phlegethon* – EN and *Pseudobarbus calidus* – NT, respectively). These species benefitted from the Rondegat project. Photos from Dean Impson, CapeNature.

Following this positive outcome, CapeNature in 2017 used rotenone to successfully rehabilitate two small off-stream dams, one in the Oorlogskloof River catchment invaded by carp and the other in the Krom River catchment invaded by Bluegill Sunfish (*Lepomis macrochirus)*. All carp and bluegill were killed in the treatments, which took one day each. Fortunately, CapeNature has received further funding from DEA: Natural Resources Management Programmes in 2018 to enable the removal of invasive fishes from several other fish CBA's in the CFE during the next NBA reporting period.

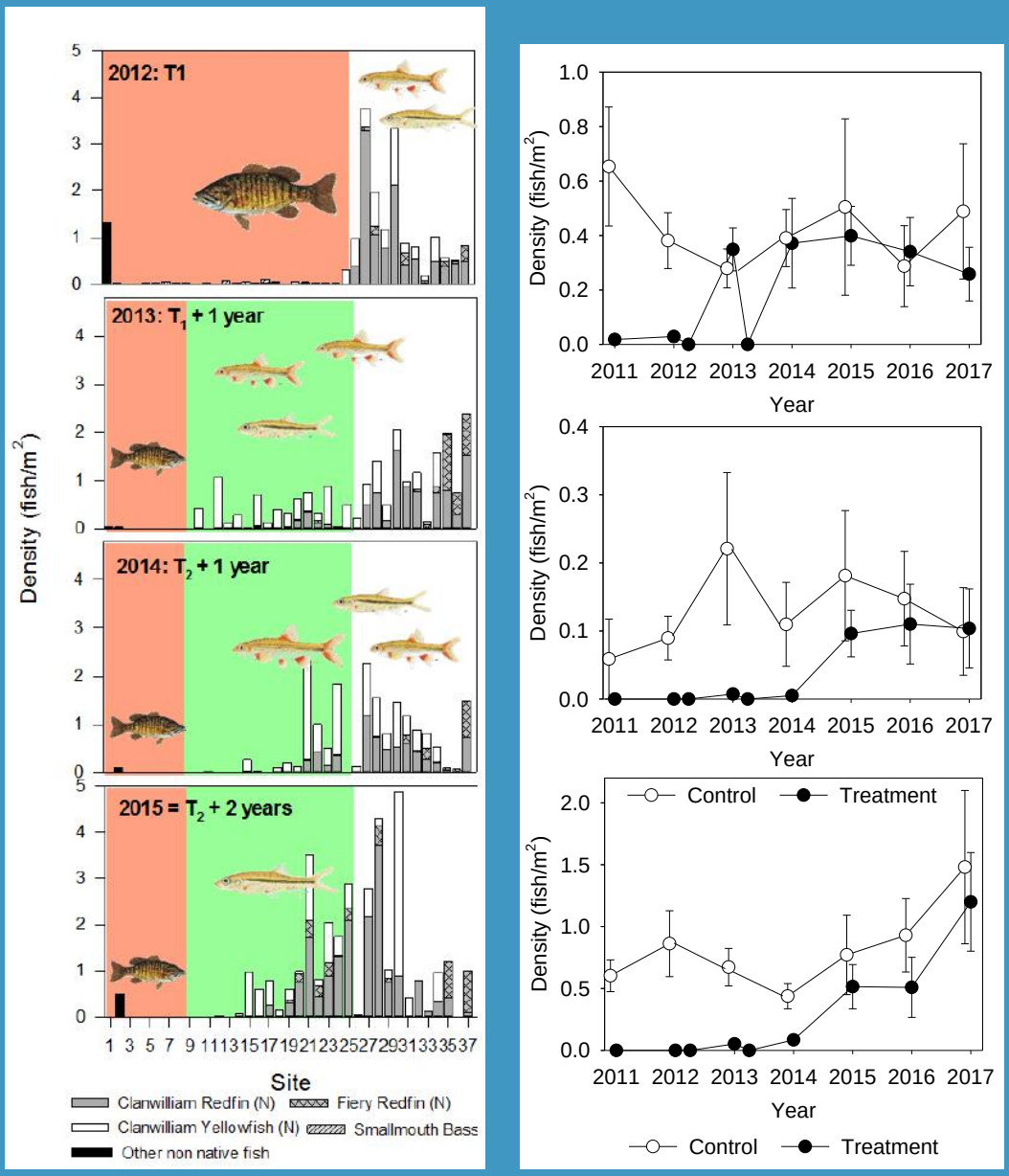


Figure 3: Recovery of the native fish community in the Rondegat River, Western Cape, South Africa, after rotenone treatments in 2012 and 2013 to eradicate smallmouth bass on 4 km of the lower river. Red = invaded zone, green = treatment zone, T1 = river at time of treatment one (adapted from Weyl *et al*. 2016).

Recent work by Van Wilgen & Wilson (2018) presents a theoretical framework for reporting on biological invasions at a national level. The framework explicitly considers biological invasions in terms of pathways, species (taxa), sites and interventions (separated into inputs, outputs and outcomes). These indicators were used as the main framework in the first National Status Report on Biological Invasions in South Africa (Van Wilgen & Wilson 2018). The report assesses the main aspects of invasions, as well as the effectiveness of control measures, and of the regulations at a national level (Van Wilgen & Wilson 2018). The status report assigned values to 21 indicators across the aspects of pathways, species, areas, and interventions effectiveness (Figure 9.6). In addition, the report proposed four high-level indicators for use in reporting on the state of the environment at a higher level (Figure 9.6).

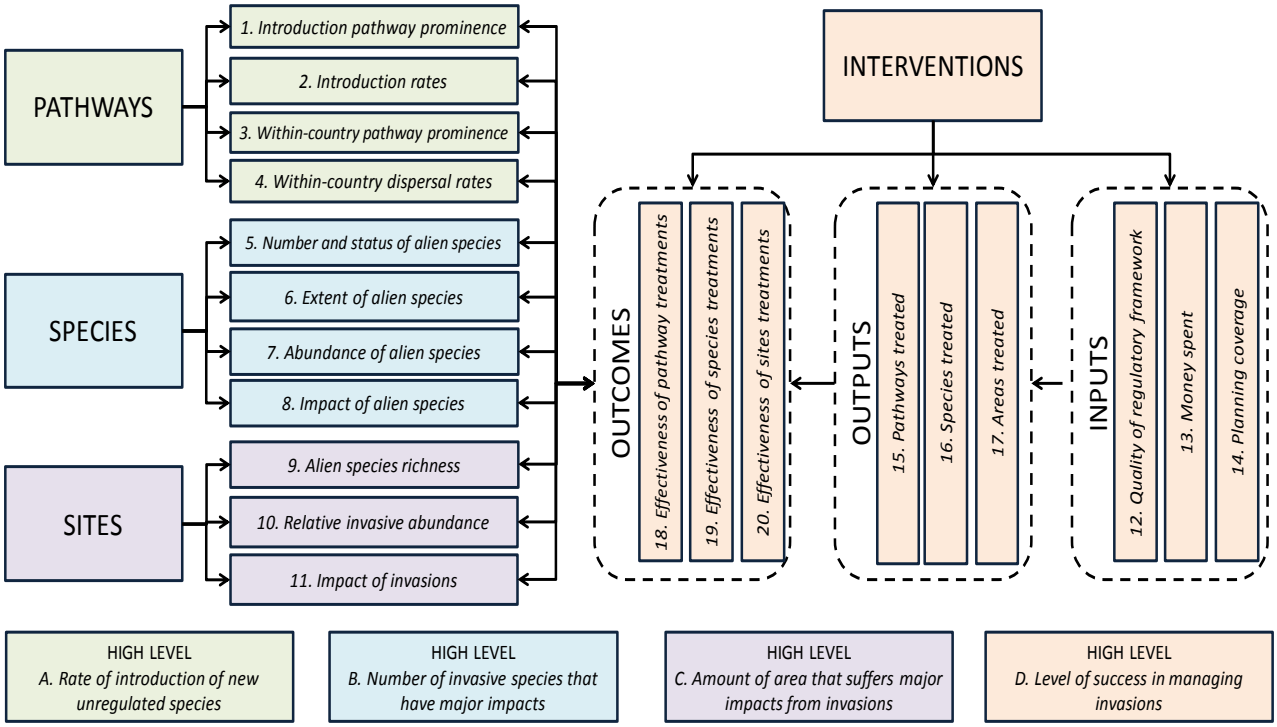


Figure 9.6.The 20 indicators and four high-level indicators that have been proposed for monitoring and reporting on the status of biological invasions at a national level. (Adapted from Van Wilgen & Wilson 2018).

As the indicators have only recently been developed, it is not yet possible to assess trends that should become clearer over time, although some preliminary trends have been identified (Van Wilgen & Wilson 2018) (Table 9.7).

Table 9.7. Preliminary identified trends based on the four high-level indicators that have been proposed for monitoring and reporting on the status of biological invasions at a national level (Adapted from Van Wilgen & Wilson 2018).

Indicator	Value	Trend	Level of confidence	Notes
Rate of introduction of new species	**7 per year**	Increasing	Low	Rate has been increasing for several decades, but if the regulations can effectively reduce the deliberate introduction of high-risk species, the rate could be reduced. Unintentional introductions, however, are expected to increase with increasing trade. Information on introduction dates are not available for many species, and consequently the level of confidence in the indicator value is low.
Number of species with major impacts	**107**	Increasing	Low	The number of species that cause major impacts is expected to increase as more species become invasive. The number can be reduced, however, through effective management (e.g. effective biological control). The value of this indicator is based largely on expert opinion rather than on formal assessments of impact, and the level of confidence in the indicator value is consequently low
Percent of area experiencing major impacts	**1.4%**	Increasing	Low	The area that experiences major impacts is expected to increase as invasive alien species spread. The value of this indicator is based on very few reliable assessments of impact, and the level of confidence in the indicator value is consequently low.
Effectiveness of control measures	**5.5%**	Stable	Low	This is the average of estimated effectiveness for pathways, species and areas. If management eliminated all the problems caused by biological invasions (i.e. managed all pathways, species and areas, everywhere, and effectively across the board) the score would be 100.

9.6.3 Recommendations

Key gaps and recommendations include:

- **Rehabilitation of rivers and inland wetlands should be prioritised in the SWSAs and Important Fish Areas** (particularly the management of invasive plants, afforestation in SWSAs, excessive abstraction, and invasive fishes) and thereafter in areas for the threatened ecosystems and species;
- Ongoing rehabilitative **management** (aftercare) of the rivers, inland wetlands and riparian zones by landholders is a critical component to ensure the long-term success of rehabilitation;
- **Build a comprehensive monitoring and reporting programme to guide research and implementation efforts on biological invasions**. The first national report, *The Status of Biological Invasions and their Management in South Africa*, has created an excellent foundation for this. Improved project-level planning for prevention and management, and enhanced spatially explicit data on the extent and severity of invasions could greatly increase efficiency of control measures;
- At the moment **invasive species management plans** are limited to a small proportion of the current occupancy range of invasives due to limited resources, and there is inadequate monitoring; and
- Alien species not legally in the country must continue to be screened for invasive potential before introduction (Nel 2004). Emerging invaders must be monitored very closely and are excellent candidates of pre-emptive measures such as biocontrol and chemical or physical eradication in terms of Early Detection and Rapid Response. Such lists help select species for modelling their rates of spread, where to focus management actions, and improved scenario development for management of biological invasions. Part of compliance should be appointing officials to do regular checking of the internet (doing searches for species of high risk for sale e.g. Prohibited species, Category 1a or 1b species) and then following up with people offering such species for sale.

9.7 Monitoring

9.7.1 Overview

Investment in existing and future strategic and co-operative freshwater biodiversity monitoring programmes is essential to strengthen our ability to detect and report on trends, plan accordingly and manage effectively. Monitoring of the ecological condition of rivers and inland wetlands is necessary to substantiate or adjust current assumptions, and to inform decisions and policy. Monitoring of the pressures on freshwater biodiversity listed in Chapter 4, including changes to the hydrological regime, water pollution, habitat loss, alien invasive species, fragmentation that result from these pressures and climate change, is crucial to strengthen biodiversity risk assessments, informed planning and conservation action.

9.7.2 Status

Department of Water and Sanitation national monitoring programmes

Section 137 of the National Water Act (Act No 36 of 1998) mandates the Minister of Water and Sanitation to establish national monitoring systems that monitor, record, assess and disseminate information on water resources. To comply with this requirement of the Act and with Chapter 3 of the National Water Resources Strategy (DWS 2013), the DWS developed and implemented a series of national monitoring programmes (Table 9.8). These programmes mostly monitor surface water quality in rivers and dams and produce long-term trend reports and visualisations of, for example, chemistry (NCMP), eutrophication (NEMP), microbiology (NMMP) and ecosystems (National Aquatic Ecosystem Health Monitoring Programme [NAEHMP]). The results are stored on the Water Management System (WMS) database. The WMS database is a suite of computer programmes developed for the DWS to provide information for water resource monitoring and management in South Africa. This national water quality monitoring database includes long-term records of several physical and chemical water quality variables in surface- and groundwater (e.g. rivers, boreholes, dams, wetlands, estuaries, etc.). The data are primarily from Resource Quality Information Services (RQIS) laboratories with contributions from a 100 other institutions. The NEsMP, NWMP and desktop DWS ecological category assessments all form part of the NAEHMP while the oldest component is the REMP which evolved from the RHP in 2016 (Table 9.8).

Table 9.8. Summary of monitoring programmes of the Department of Water and Sanitation (DWS) for rivers, dams, and inland wetlands.

Monitoring programme	Rivers/Dams/Lakes	Inland wetlands
Sedimentation	• Extensive river suspended sampling occurred from 1920–1970. Thereafter infrequent sampling leading to discontinuous records for rivers. • Decisions were made by the then Department of Water Affairs (DWA) to focus on reservoir sedimentation and sediment yields. Surveys are carried out typically every 10 to 15 years at most of the DWS reservoirs in the country with some critical reservoirs surveyed more frequently (Msadala *et al.* 2012).	Not implemented yet
National Eutrophication Monitoring Programme (NEMP) (originates from the former Trophic Status Project)	• Aimed at monitoring seven catchments, selected because of their high nutrient export load. Monitors sites (mostly dams) throughout South Africa, providing reports on trophic status, algal growth, cyanobacterial blooms and excessive water plant growth. • Chlorophyll and total phosphorus data used for six-monthly summer and winter reports (1978–2019) The Cyanolakes website has a series of chlorophyll-*a* and cyanobacterial analyses (2002–2012) for 103 large	Not Applicable

	reservoirs in the country. Since 2018 funding restraints resulted in information in information restriction on the site (DWS 2018d).	
River Eco-status Monitoring Programme (REMP), formerly the River Health Programme (RHP)	• The REMP focuses on the monitoring of the ecological conditions in river ecosystems as they are reflected by the system drivers and biological responses (instream and riparian). • Sites from the previous RHP were actively monitored until at least 2011 (year of the last State of Rivers Report published on DWS website). • The technical report list shows Eco-status for the Komati River catchment in 2014 and the RHP continued in the Crocodile West WMA until 2015. • The DWS (2018b) reported a declining trend in the availability of surface water monitoring results from 2016 (67%) to 2017 (62%) and 2018 (33%), whereas the groundwater monitoring points declined from 47.6% to 49.3% and 7.9% during the same years. These declines are attributed to a lack of funding primarily, which had impacted the number of personnel to execute the tasks and running cost to travel and analyse the samples. • Currently, the Freshwater Research Centre (FRC) in partnership with SANBI and DWS is implementing the Freshwater Biodiversity Information System (FBIS) that will house all previous Rivers database information from the RHP. The information system will be used for evaluating long-term change in river biodiversity in South Africa's Cape Fold Ecoregion (CFE), and for freshwater fish throughout South Africa. FBIS will potentially go operational in 2019.	Not Applicable
National Wetland Monitoring Programme (NWMP)	• Not Applicable.	• The WRC completed the NWMP design 2016 • Not implemented yet
National Chemical Monitoring Programme (NCMP)	• Provides data and information on the chemical water quality of South Africa's surface water resources (rivers, lakes, and dams). • A national dataset of inorganic chemical data of surface waters (rivers, lakes, and dams) in South Africa also exists developed in collaboration with the North-West University). The dataset comprises more than 500 000 samples from 1972 up to 2011 from more than 2 000 sample monitoring stations in South Africa (CWSM 2019).	Not implemented yet
The National Estuaries Monitoring Programme (NEsMP)	• Monitoring of water quality, physico-chemical and biological aspects for determining long-term trends and changes in the condition of South African estuaries. • Established in 2008 and monitoring is still continuous.	Not Applicable
Present Ecological State, Ecological Importance & Ecological Sensitivity (PES, EI & ES: Desktop PESEIS assessment)	• Information obtained from the RHP and REMP are to be used as first level desktop assessments for purposes of ecological reserve determination and for Ecological Water Resource Monitoring. • The National PES assessments were completed in 2011 by DWS (DWS 2014) These desktop data were updated with data that became available between 2011 and 2017 from Reserve or Ecological Water Requirement (EWR) and Water Resource Classification System (WRCS) studies and had been used in the assessment of river ecosystem types of this report, Chapter 5 and 6 (Van Deventer *et al.* 2018a;b). • Updating continues as more EWR and WRCS studies become available.	Adequate
National Toxicity Monitoring Programme	• To measure, assess and report on a regular basis the status and trends of the nature and extent of, first, potentially toxic substances in South African water resources (watercourses, groundwater and estuaries), and, secondly, the potential for toxic effects to selected organisms.	Not implemented yet

South Africa had developed one of the most advanced monitoring systems for river biodiversity, the RHP. The programme adopted the EcoClassification/EcoStatus approach and was forward-thinking in considering both the pressure (stressors) and resilience of ecosystems and species to the pressures (Strydom 2003; Strydom *et al.* 2006; see Box 4.1). The DWAF initiated the formal design of the RHP in 1994 to monitor the health of rivers in South Africa. A phased approach was adopted for the design of the monitoring programme. The main purpose was for the programme to serve as a source of information regarding the

overall ecological status (i.e. integrated state) of riverine ecosystems (Roux *et al.* 1999). The focus was mainly on biological characteristics as indicators of river health, e.g. macroinvertebrates, fish communities and instream and riparian habitat. While the RHP was coordinated at a national level by the DWAF, DEAT and WRC, implementation activities largely took place at the provincial level by provincial champions and implementation teams (DWAF 2008). As part of the pilot application of the RHP on the main rivers of Mpumalanga, the first complete monitoring exercise of this nature was on the Crocodile and Elands Rivers, during late 1996 and early 1997 (DWAF 1998; Roux *et al*. 1999). The RHP was in operation until 2015.

A substantial number of State of River (SOR) and technical reports (17 SOR reports listed on DWS website with 43 accompanying technical reports) were completed across South Africa, based on an intensive monitoring effort by DWS personnel supported by provincial government departments, conservation agencies, water boards and academic institutions. The RHP was an excellent example of cooperative governance, where various national, provincial and local institutions shared an objective to monitor the ecological condition of rivers across the country. It is estimated that more than 25 organisations had been involved during this decade in the RHP, monitoring approximately 800 reaches along mainstem and tributary rivers. The RHP data were also stored in a Rivers Database (Version 3, DWAF 2007). Currently, the Rivers database is operating with severely reduced functionality as it too became inoperable in 2015. However, monitoring sites from the Rivers Database are being migrated into the Freshwater Biodiversity Information System (FBIS). Existing RHP sites were also used as far as possible in the REMP to be able to make comparisons. Reference and impacted monitoring sites are included which represent the entire country at a high level. The updated REMP constitute 847 monitoring points (Figure 9.7 and Table 9.9). These points cover at least 102 number of river ecosystem types, leaving 120 not being monitored at all (Table 9.9 and Annexure G).

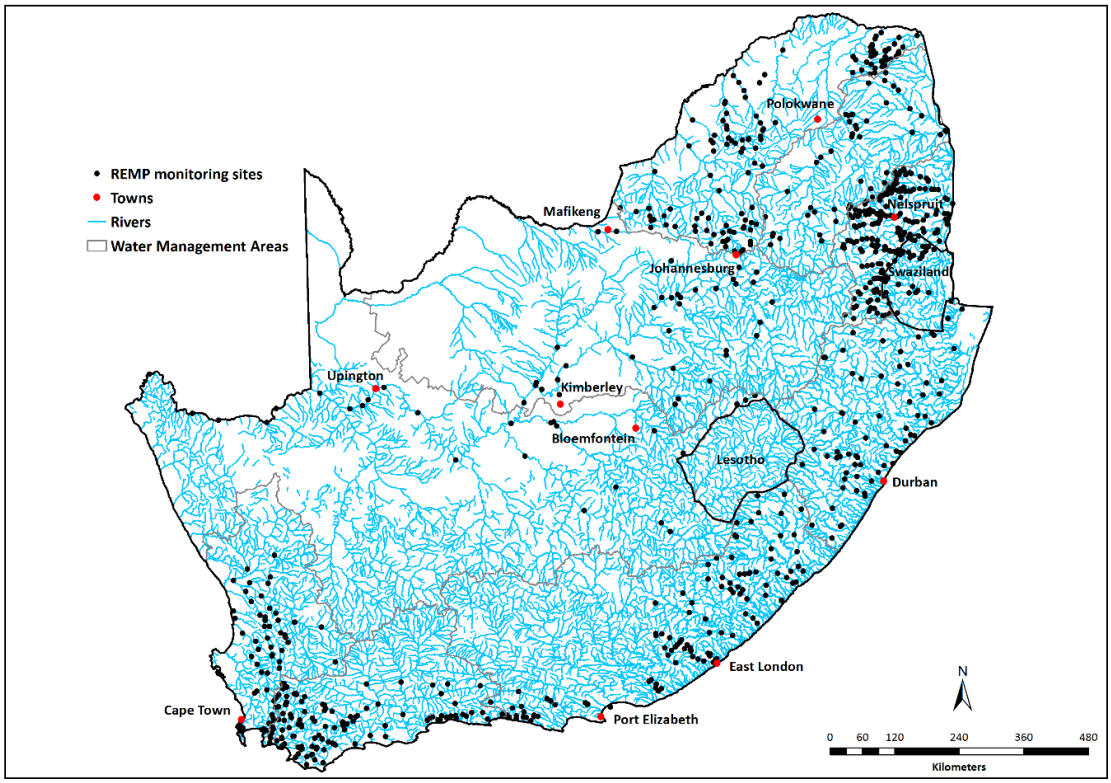


Figure 9.7. River Ecosystem Monitoring Programme (REMP) monitoring locations of the Department of Water and Sanitation (DWS) and partners.

Table 9.9. Summary statistics for the river ecosystem types and the Department of Water and Sanitation (DWS) monitoring sites.
Note: *Excluding records with no start date and end date*; river data extracted from the Water Management System (WMS) database. REMP = River Eco-Status Monitoring Programme.*

Statistics	REMP	Flow	Water quality
Number of monitoring points	847	2831*	3722*
Number of river ecosystem types monitored	102	148	145
Number of river ecosystem types not monitored	120	74	77
River ecosystem type with the most monitoring points	3_P_L (58)	11_P_L (158)	11_P_L (314)
River ecosystem type with highest overall monitoring points	11_P_L (505) & 11_P_F (292)		
Number of river ecosystem types with overall no monitoring points	58		
Number of river ecosystem types with lowest overall monitoring points	13 (1)		
Highest data deficiency (% of river type extent)	26_N_L (30.5%, total points 15) & 26_N_U (28.7%, total points 8)		

The DWS's river monitoring programmes such as the NEMP (Figure 9.7) contributed significantly to assessments and plans for river ecosystem types across the country. Flow monitoring had been done at weirs, whereas water quality were measured historically at the monitoring points of DWS. The first gauging structures constructed specifically to measure river flow were completed in 1904 in the former Transvaal Province 1960 (Wessels & Rooseboom 2009). Gauging weirs have been built on a substantial numbers of rivers. At present there are over 2000 flow-gauging stations in the country representing 148 river ecosystem types (Figure 9.8, Table 9.9 and and Annexure G). The oldest flow gauging station still operating is on the Mooi River near Potchefstroom in North West (GCIS 2018). However, many are in a state of disrepair, preventing vital flow data from being collected. In addition, some large river systems have very few gauging weirs (e.g. Olifants-Doring, Figure 9.8).

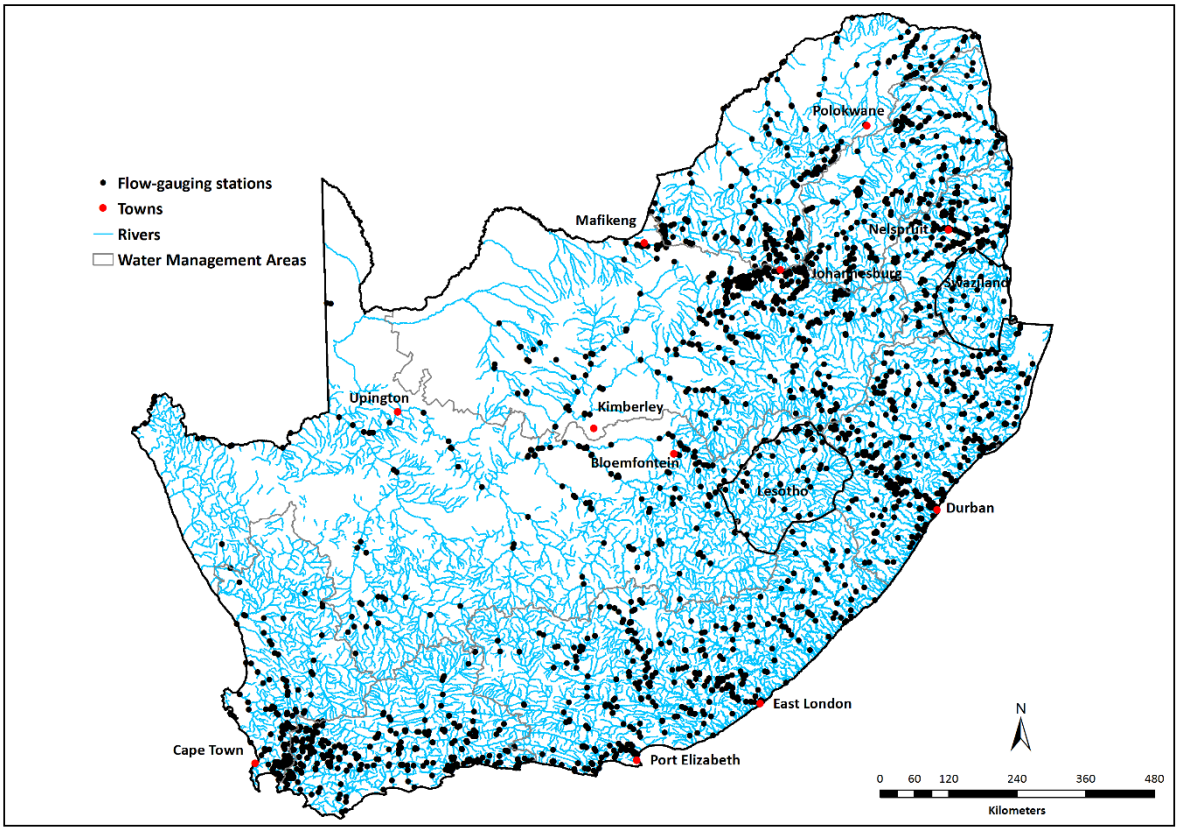


Figure 9.8. River flow monitoring weirs of the Department of Water and Sanitation (DWS).

Figure 9.9 represents an example of the water quality data points for rivers which were extracted from the WMS database. Summary statistics are provided in Table 9.9. Annexure B includes a summary of the compliance status of the WWTW of South Africa between 2011 and 2018 (DWS 2018c) while Annexure C provides a list of 103 of the 105 large water bodies that are monitored by the DWS NEMP.

When comparing all three datasets (i.e. REMP, flow and water quality) 58 river ecosystem types are not monitored at all while > 50% data deficiency is linked too only two river ecosystem types. There is a need to select variables to represent the ecological condition of these river ecosystem types. From the analysis it is also clear that the water quality dataset has the most records as well as the highest number of monitoring points per river ecosystem type.

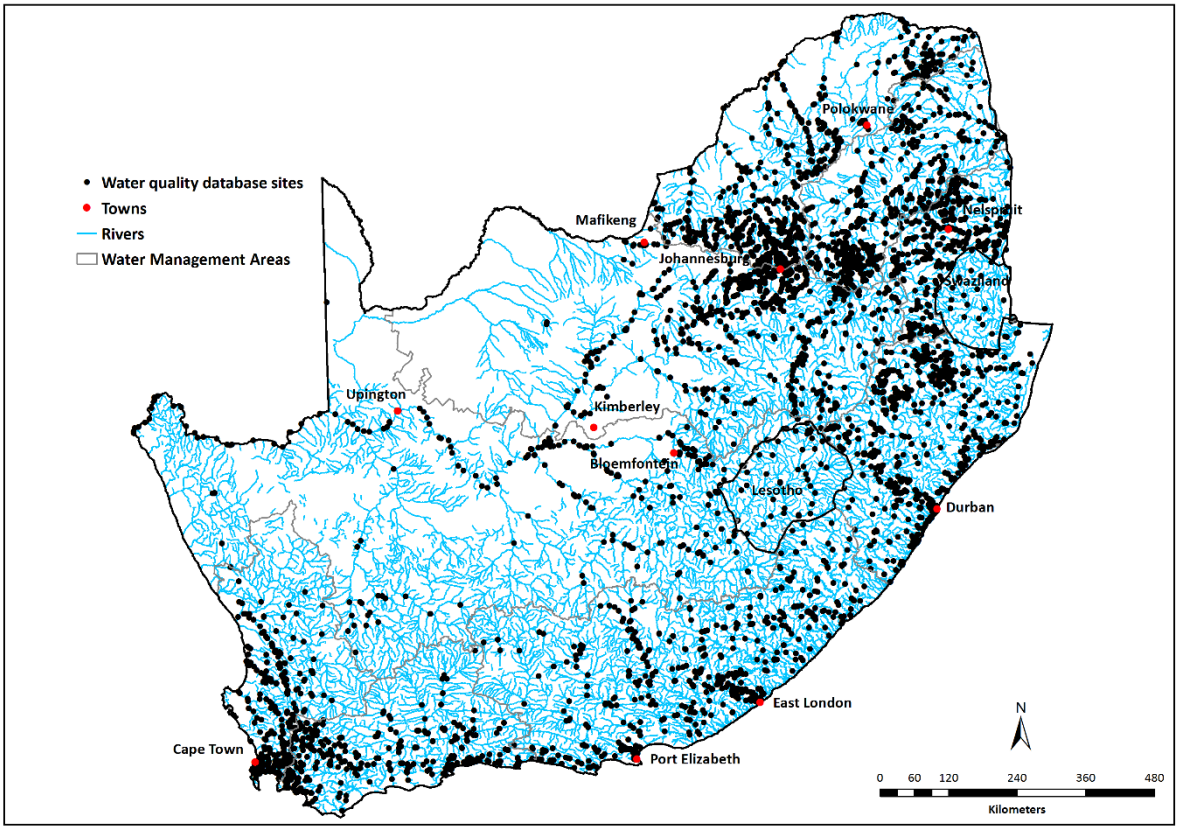


Figure 9.9. Location of the Department of Water and Sanitation (DWS) water quality monitoring sites, Water Management System (WMS) database.

Within the past 3–7 years, there has been a decline in the resources allocated to monitoring programmes such as NEMP (Figure 9.10) as a result of less funding being allocated for this purpose and a decline in staff, and some of South Africa's key monitoring datasets are very outdated while others are not secure. In addition to the monitoring initiatives discussed above, another primary source of hydrological data are rainfall data. Both rainfall and river flow measurement have exhibited a decline over recent years and the situation with rainfall is particularly serious, where our monitoring network has declined from a high in the 1970s to a current situation where the network is described as more similar to that in the 1920s (Pitman 2011). This is a very worrying statistic for a water poor country such as ours. A critical challenge for South Africa is to get national hydrological monitoring of rivers 'back on track' and implement the National

Wetland Monitoring Programme (NWMP) and this can only be done by recruitment of suitable personnel and the allocation of adequate funds (Pitman 2011; Impson 2016b).

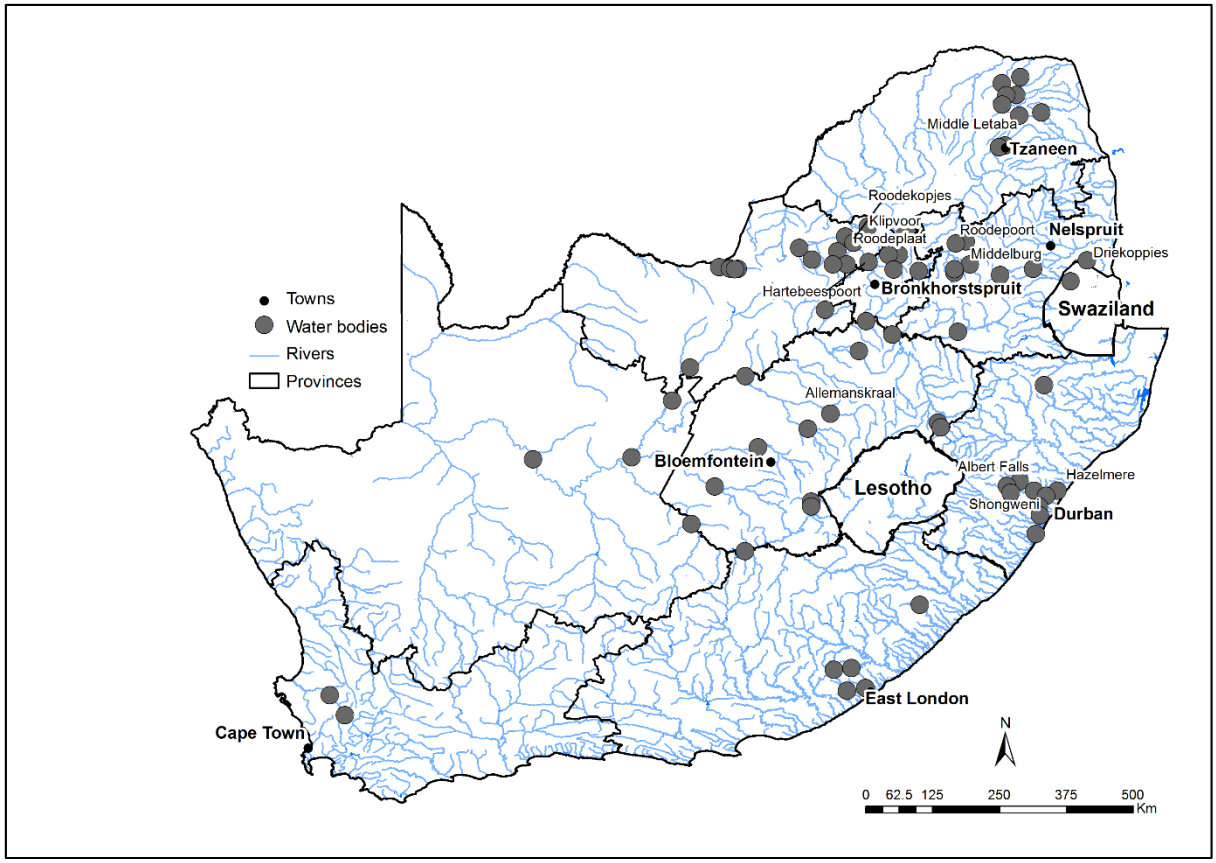


Figure 9. 10. Location of the large open waterbodies monitored by the Department of Water and Sanitation's (DWS's) National Eutrophication Monitoring Programme (NEMP).

There is currently no systematic national monitoring programme in place for wetlands but a NWMP desktop component has been initiated as part of the first phase outlined in the framework developed by Wilkinson *et al*. (2016) as part of a Water Research Commission-funded project. Owing to a complete lack of any measured data on the ecological condition of inland wetlands, the ecological condition for this NBA, similar to the first assessment in 2004, was modelled based on available datasets primarily reflecting the location or extent of pressures (Chapter 5); however, no information on the duration, magnitude or severity of these pressures were available. This introduces considerable uncertainty in this assessment that will hopefully be reduced for future assessments as the NWMP becomes operational and reliable in situ monitoring data becomes available. The first step in moving the NWMP forward, is workshopping the variables for monitoring and priority sites with Interested and Affected Parties.

Provincial conservation agency monitoring programmes

To measure trends in the state of biodiversity it is necessary that baseline data on the distribution, conservation status, and in the case of freshwater species of conservation concern, population data, is obtained through appropriate surveillance and monitoring. At the provincial level this is the mandate of the conservation agencies and requires that they be fully equipped to collect, collate and store this information and make it available for analysis and monitoring.

Many provinces have few if any freshwater ecologists and technicians, and frequently key monitoring devices are lacking or not working. Impson (2016) reviewed provincial monitoring of important fish areas or provincial CBAs that support threatened fish species (Table 9.9). Ideally, they should be surveyed at least every five years, while fish CBAs supporting endangered species should be more frequently surveyed, every one to two years. The surveys of CBAs should report on presence of the threatened fish species and associated native species, status of the threatened fish species (common, uncommon, recruiting), threats to the native fish community such as invasive fishes, invasive plants, over-abstraction, sedimentation, pollution, other impacts, and contact details of key riparian land-owners must be obtained (Impson, 2018). This information can then feed into NBA, IUCN Red List, conservation planning through review and update of fish CBAs, and invasive species maps. Of all the provinces, only two, the Mpumulanga and Limpopo provinces, have functional programmes which enable them to report on trends. The Limpopo Province has consistently monitored 216 sites on eight rivers, every three to four years.

Table 9.10. Status of provincial monitoring and management of rivers supporting Critical Biodiversity Areas for fish.

Provincial body	River	Status
Mpumalanga Parks & Tourism Association (MTPA)	Tributaries of the Olifants, Sabie, upper Usuthu, Crocodile, Komati, upper Vaal rivers.	All monitored, except upper Olifants and upper Vaal rivers. Data sufficient to report on trends.
Ezemvelo KwaZulu-Natal Wildlife (EKZNW)	Several rivers listed.	No monitoring of fish Critical Biodiversity Areas (CBAs) by EKZNW. The Aquatic Ecosystem Research Programme of the University of KwaZulu-Natal (UKZN) has monitored 12 fish CBAs.
CapeNature	Several rivers listed.	Some fish CBAs monitored, especially in Nature Reserves. Data can confirm if threatened species still present, but not status.
Gauteng Department of Agricultural & Rural Development (GDARD)	Magalies, Bloubankspruit rivers.	Three large catchments monitored quarterly but the not upper Crocodile River where fish CBAs are.
Limpopo Department of Economic Development, Environment and Tourism (LDEDET)	Shingwedzi, Luvuvhu, Letaba, Mokolo, Lephalala, Mogalakwena, Nwanedi rivers.	42 of 79 fish CBA's monitored. 216 sites on eight perennial rivers monitored every 3–4 yrs. Can report on trends.
Free State Department of Economic Development, Tourism and Environtal Affairs (FS DESTEA)	Orange, Riet, Vals rivers, and tributaries of the Wilge River around Harrismith.	No monitoring of fish CBAs (awaiting CBA update to be released in 2019). Excellent monitoring of fish communities in dams (Barkhuizen 2015).
Northern Cape Department of Environmental and Nature Conservation (NC DENC)	Orange, Sak, Oorlogskloof rivers.	Ten sites on the Orange River, but no fish monitoring since 2015 as the equipment had been damaged and not been replaced since.
North West Department of Economic Development, Environment, Conservation and Tourism (NW DEDECT)	Mooi, Tributaries of upper Crocodile and Marico rivers.	No current monitoring of fish CBAs.
Eastern Cape Department of Economic Development and Environmental Affairs (EC DEDEA)	Several rivers listed.	No monitoring of fish CBAs. Some fish CBA's surveyed by the South African Institute for Aquatic Biodiversity (SAIAB), but not for the purpose of monitoring trends.

There needs to be a national prioritisation of the capacity required to adequately monitor, assess and manage of inland aquatic ecosystems. This is dealt with in more detail in Section 9.9. The quality of reporting on the ecological state of our rivers and inland wetlands, particularly in terms of current status and trends observed in NFEPAs is lacking. The prime reason is the shortage of posts and associated skills in

the freshwater ecosystem sections at provincial level to provide the answers the country needs to manage these priority areas for biodiversity (Impson 2016a). See later section for audit on current status of officials in place on the ground to undertake monitoring in the provinces

Other monitoring initiatives

SANBI's Freshwater Ecosystem Network (FEN) which meets annually, provides an excellent platform for collaborative discussion on monitoring in general. Accurate measurements within an improved hydrological monitoring network are needed. More information is currently needed on the current functioning of different ecosystem types and the consequences of certain land uses, to inform management decisions that will protect the long-term potential of river, riparian and inland wetland ecosystems to deliver benefits to society. In addition, threats to biodiversity and human livelihoods such as climate change cannot be realistically understood unless there is continuous long-term monitoring of relevant data at appropriate sites, including temperature and rainfall. The continuous increase in the demand of water in South Africa requires ongoing monitoring and careful management to prevent ecosystem degradation and collapse.

The South African Environmental Observation Network (SAEON) was established in 2002 to provide long-term, in situ, biodiversity observation and an information management system with the capacity for spatial analytics. The SAEON network established the Expanded Freshwater and Terrestrial Environmental Observation Network (EFTEON), a modular research infrastructure to support the investigation of coupled ecological-social systems in South Africa. SAEON is actively monitoring climate and hydrology for 465 sites in 67 quaternary catchments. Of these, 126 sites collect meteorological data and a further 339 sites collect hydrological data (Figure 9.11).

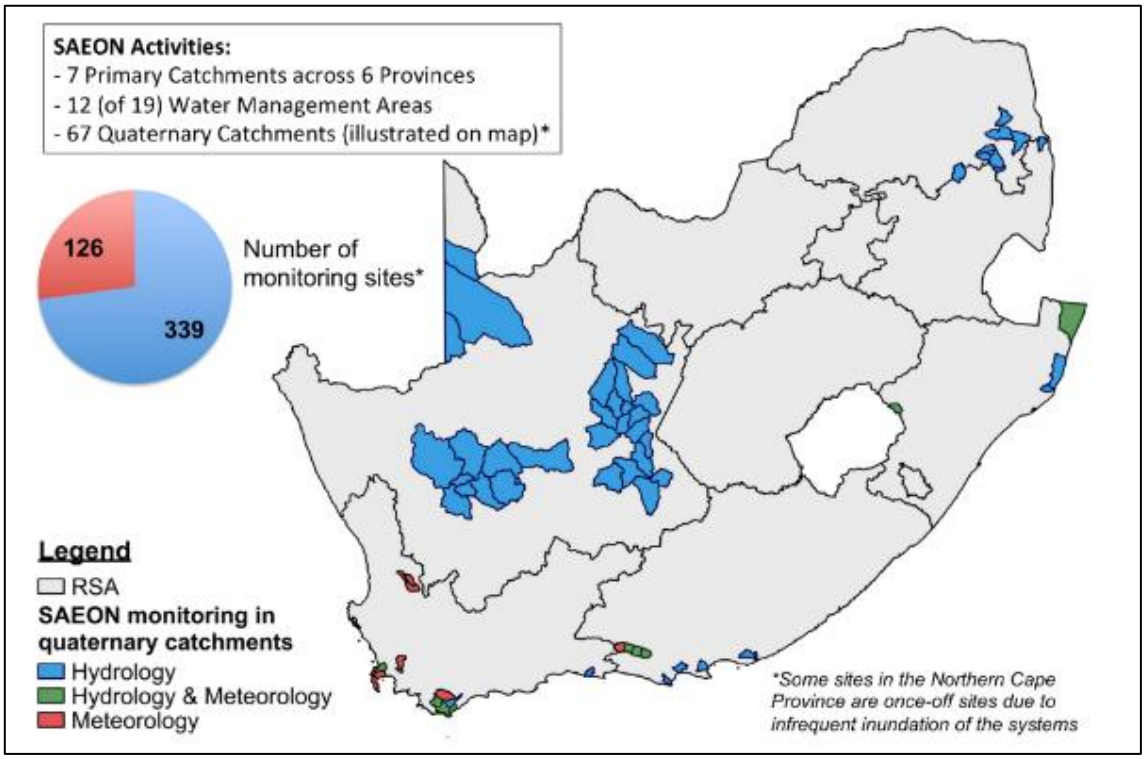


Figure 9.11. Location of quaternary catchments with SAEON long-term monitoring sites.

Table 9.11 consolidates key monitoring initiatives. In summary, while South Africa has some robust biodiversity and advanced monitoring programmes, many are dependent on state funding and capacity to execute. A new trend globally, as well as in South Africa, is to involve citizen scientists, to complement the state-funded monitoring programmes, however, it is critical that gaps in monitoring sites and variables at key sites of species populations, ecological condition and community composition are filled (e.g. implementation of the NWMP). Existing monitoring programmes (e.g. National Aquatic Ecosystem Health Monitoring Programme, which is focussed on rivers) need to be refocused and capacitated. These efforts should be linked with international efforts to identify Essential Biodiversity Variables (EBVs; Pereira *et al*. 2013; a set of variables which collectively capture biodiversity change at multiple spatial scales and within time intervals that are of scientific and management interest), and should take advantage of new methods and innovative technologies.

As critical as ensuring the continuation of the current suite of monitoring programmes, is the need to analyse and incorporate this information into focussed management and implementation plans, which are able to interpret, respond and adapt to the latest monitoring results as they come available. Monitoring is essential for detecting change and to address uncertainties, particularly with the increased impacts resulting from climate change. Cooperative governance, research and citizen science are key elements of successful inland aquatic ecosystems monitoring.

We cannot monitor each catchment through *in situ* measurements, and therefore complementary modelling would be critical for determining the ecological condition of rivers and inland wetlands, because they are connected to what happens in the landscape.

Additional climate change vulnerability assessments and focussed monitoring of species and ecosystems are required to enhance the detection, quantification and attribution of climate change impacts on freshwater ecosystems, species and genes. Additional research and monitoring is needed to track and understand climate change impacts on inland aquatic ecosystems, including their interaction with other pressures and the effectiveness of measures taken to minimise the impacts. Importantly, we need to maintain, enhance and expand time-series monitoring efforts and improve our understanding of change to enable effective adaptation measures.

In addition to the formal national monitoring of rivers and inland wetlands, rehabilitation interventions on these ecosystems that are implemented to manage and conserve biodiversity are often not monitored, which makes adaptive management of the activities near impossible. This includes Environmental flows from many public dams (e.g. the Berg River Dam). Given the numerous interventions in place and the complexities of implementation, gauging success, failure or impact of any particular intervention requires a broad evaluation protocol. The protocol should contain a suite of indicators that measure the effectiveness of the interventions against biodiversity objectives like species and ecosystem conservation, as well as socio-economic objectives like improving human wellbeing and cost efficiencies. Strengthening capacity for adaptive management needs to be addressed to make progress in this arena.

Table 9.11. Overview of key monitoring programmes for inland aquatic ecosystems which could inform a strategic integrated monitoring implementation plan for the country.

Programme	Implementing Agency*	Frequency			Ecosystem and attributes or characteristic				
		Year	Month	Desktop	Field	River	Wetland	Gw**	Description and notes
General ecological condition of ecosystems									
National River Eco-status Monitoring Programme (REMP)	DWS, Partnerships	x			x	x			Selected river reaches, SASS*, fish presence, riparian vegetation
River Eco-status Monitoring Inkomati-Usuthu Water Management Area	IUCMA		x		x	x			Selected river reaches, SASS*, fish presence, riparian vegetation
River Eco-status Monitoring Gauteng	GDARD		x		x	x			Selected river reaches, SASS*, fish presence, riparian vegetation
Present Ecological State, Importance & Sensitivity	DWS	5 yr		x		x			All mainstem and some tributaries
Gazetted Resource Quality Objectives	DWS, Partnerships	x		x	x	x	x	x	Gazetted river and inland wetland sites, not yet active
National Wetland Monitoring Programme (NWMP)	DWS								Selected wetlands, field component not yet active
Table Mountain Group Aquifer selected sites	City of Cape Town		x		x		x		Selected wetlands
Ramsar sites	DEFF				x		x		Not yet active
National Freshwater Priority Areas	DWS, DEFF								
Important Fish Areas	DEFF								
Provincial Freshwater Critical Biodiversity Areas									
Wetland Rehabilitation Intervention Sites	DEFF: Working for Wetlands	3 yr			x		x		19 wetlands, expanding to more
Long-Term Monitoring Programme	SAEON								
Specific to water quantity									
Groundwater Levels Monitoring Programme	DWS				x			x	
Table Mountain Group Aquifer selected sites	City of Cape Town								
River monitoring	DWS				x	x			Flows, rainfall gauges, stream gauges
Ecological Reserve					x	x	x		Not monitored
Specific to water quality									
National Groundwater Quality Monitoring	DWS								Selected groundwater sites
National Eutrophication Monitoring Programme									Dams
National Chemical Monitoring Programme									Dams
National Toxicity Monitoring Programme									Dams
Sedimentation									Dams
River monitoring	DWS								Flows, rainfall gauges, stream gauges
River water quality	DUCT, Citizen scientists		x		x	x			School rain gauges, phone app

** DUCT = uMsunduzi-Umgeni Conservation Trust; DWS = Department of Water and Sanitation; DEFF = Department of Environment, Forestry and Fisheries; SAEON = South African Environmental Observation Network; IUCMA =* Inkomati Usuthu Catchment Management Agency

***Gw = groundwater;*

Remote sensing in support of monitoring

Several aspects of rivers and inland wetlands can be derived from remote sensing images, including land transformation in the catchment, the inundated part of wetlands, water quality indices of large open water bodies (Matthews & Bernard 2015); species diversity, abundance and indices of vegetation health and vigour (for example, Naidoo *et al.* 2019), and potentially soil moisture of the saturated parts of wetlands (Gangat *et al.* in review). In situ field observations are essential for developing accurate and reliable products from remotely sensed imagery, but once this investment has been done, remote sensing can provide a regional view of how features on earth change, even reporting on aspects that cannot be detected visually. Consequently, remote sensing becomes an excellent complementary tool to in situ monitoring and citizen science, and form part of an integrated monitoring system and site and landscape scales. Historically, remote sensing images have been costly to acquire, however, since 2008, the United States Geological Survey (USGS) have received their Landsat Archive free of charge to the public, enabling wide use of nearly 30 years of imagery for the benefit of the public (Wulder *et al.* 2016). More Space Agencies are also considering the free availability of imagery for public good, considering the huge benefits these had for improved decision making. For example, the European Space Agency (ESA), has launched the Sentinel suite of sensors since 2015 with free access to the public. The optical Sentinel–2 sensors improves on the number of bands and the spatial resolution (10–20 m) of monitoring, which increase the number of indices and products that can be derived as well as their accuracy, compared to the former coarse-scale sensors, such as Landsat (30 m spatial resolution). A WRC project K5/2545 is currently under way, titled '*Establishing remote sensing toolkits for monitoring freshwater ecosystems under global change*' which will review and document in more detail how remote sensing can contribute to the monitoring of inland wetland ecosystem types and is due to complete in March 2020 (Van Deventer et al. in draft). This project also evaluates the advantages of finer spatial resolution satellite imagery, such as the Sentinel–2 sensor, in detecting small wetlands in a semi-arid country such as South Africa. A few examples of the potential are, however, discussed here briefly.

The extent of open waterbodies can be monitored with remote sensing and since January 2016, the ESA Sentinel–2 sensor has been used to derive the Mzanzi-Amanzi open water dataset for South Africa (Thompson *et al*. 2018). This product this is an acceptable IUCN measure for inferring changes to the hydrological regime, and can be used to inform the Red Listing of Ecosystems (RLE) (Bland *et al.* 2017). The most recent open water monitoring data of Pekel *et al.* (2016), derived from historical Landsat for example, is a global product that will be used for reporting as a Tier 1 product on the open water body extent to SDG 6.6, unless more detailed information can be provided by a country as Tier 2 (Mr Dickens, *pers. comm.*, 2019). The Amanzi-Mzanzi proprietary product, derived from the 20-m Sentinel–2 images, can therefore serve South Africa in future reporting of the SDG 6.6 indicator. These time-series datasets can further be used to derive the hydroperiod of the inundated parts of inland wetlands for describing the biodiversity characteristics of such wetlands as per the *Classification System for Wetlands and other Aquatic Ecosystems in South Africa* and other work (Ollis *et al.* 2013; Van Deventer *et al*. in review).

The monitoring of water quality indices of 103 large dams have also been done using remote sensing imagery (Matthews & Bernard 2015). Two indices, the total dissolved solids and chorophyll *a* indices, gives an indication of the variation of water quality across these open waters of the dams. The system has been implemented by the DWS as part of the National Eutrophication Monitoring Programme and reported on the Cyanolakes website, though with the recent decline in funding, ceased to operate.

In addition to the open water indices, soil moisture indices can potentially contribute to better understanding of where soil moisture remains high during dry seasons or varies across hydroperiods,

serving as early detection for global change monitoring. Globally, several satellites have previously been used to predict soil moisture of primarily terrestrial areas (see review of Gangat 2019). In South Africa, research is still in its infancy, though show promise of using the freely available ESA Sentinel sensors for the detection, quantification and thresholding of soil moisture for mapping and monitoring wetland saturation extents (Gangat *et al*. in review). Globally, a soil moisture product is being developed for similar purpose, lead by Mr Marc Paganini from ESA, to also inform on SDG 6.6's palustrine wetlands, using the ESA data (Mr Dickens, *pers comm.*, 2019). In situ data is, however, essential to ensure that globally-developed products represent South African palustrine wetlands adequately, and hence, further research funding should be investigated to evaluate these products for our use.

A key threat to rivers, riparian areas and inland wetlands is invasive alien plants (IAPs) which alter hydrology as well as nutrient accumulation and cycling in riparian areas and inland wetlands. In South Africa, invasive alien plants account for a reduction in streamflow per year of about 1 444 million m^3 (Le Maitre *et al.* 2016). Hence, substantial control and invasion management efforts are required. With respect to inland wetlands, traditional field survey approaches are highly accurate but limited to a small subset of wetlands due to intensive labour and other associated costs. It is logistically challenging to access remote areas. Monitoring at a broader scale using remote sensing technology is advantageous because it is cost effective and offers timely information over a larger area. However, the detection of IAPs in wetlands depends on scale, and the ability of the remote sensing data to discriminate between plant species in the field. Previous studies on wetlands vegetation species mapping using remote sensing have demonstrated high accuracy with hyperspectral and high spatial imagery such as WorldView–2 data but these data are expensive to acquire and small in coverage and are, therefore, not practical for monitoring infestations at a broader scale. Alternatively, species mapping using multispectral data such as Landsat is hampered by lack of high spectral and spatial resolution and mixed pixels among plant species. The 10 m Sentinel–2 Multispectral Instrument (MSI), has allowed mapping distribution of plant species. The efficacy of the Sentinel–2 image data for discriminating IAP from native species in the riparian zone was evaluated by Masemola *et al.* (2019). The study demonstrated spectral separability between A*cacia mearnsii* and *A. dealbata*. For both silver wattle and black wattle, the minimum detection threshold is 20 to 50 % cover during peak productivity in South Africa. This is sufficient during senescence and the dry season, however, mapping wetlands invasion can be hampered by the presence of surface inundation. Kaplan & Avdan (2018) classified species with an overall accuracy of more than 89% by fusing Sentinel–1 and Sentinel–2 and achieved an overall accuracy of more than 89% in the Balikdami wetlands along the Sakarya riverbed in Turkey. Masemola *et al*. (2019) also demonstrated substantial increase in discrimination accuracy (an overall accuracy of 90%) with fused data between silver wattle, black wattle and indigenous species. However, this hypothesis still needs to be validated in various wetlands with different species across South Africa.

The former Department of Science and Technology and the WRC has started several Communities of Practices (CoP) for encouraging interaction, discussion and research on the use of remote sensing technology in various sectors of application. To date, a Water CoP has been initiated in 2016, showcasing the advances and listing further research needs. These two institutions remain some of the key funders in South Africa, of remote sensing research and derivative products.

Conclusion

SANBI's FEN which meets annually, provides an excellent platform for collaborative discussion on monitoring in general. Accurate measurements within an improved hydrological monitoring network are needed. More information is currently needed on the current functioning of different ecosystem types and the consequences of certain land uses, to inform management decisions that will protect the long-term potential of river, riparian and inland wetland ecosystems to deliver benefits to society. In addition, threats to biodiversity and human livelihoods such as climate change cannot be realistically understood unless there is continuous long-term monitoring of relevant data at appropriate sites, including temperature and rainfall. The continuous increase in the demand of water in South Africa requires ongoing monitoring and careful management to prevent ecosystem degradation and collapse.

9.7.3 Recommendations

Key gaps and recommendations include:

- **Reinstite the cooperative governance and monitoring of river ecosystem types** that has collapsed over the past three years;
- Allocate funding for a detailed study on how the various monitoring systems related to inland aquatic ecosystems and freshwater species can be **optimised and integrated**, into, for example, the Freshwater Biodiversity Information System. This project requires urgent attention and is seen as a top priority;
- Workshop and Implement the **National Wetland Monitoring Programme**, following agreement on variables to monitoring and pilot sites to test;
- Secure and implement sustained funding for evaluating globally-derived **remote sensing products for monitoring and reporting and the development of remote sensing monitoring systems** for rivers and inland wetlands;
- **Coordination** of monitoring and reporting between departments and organisations should be encouraged through the FEN and provincial networks (e.g. Freshwater Forum of the Department of Environmental and Development Planning, Western Cape Province);
- Monitoring of species populations is an enormormous task, which can be assisted by online **citizen science platforms** that allow people across the country to contribute to the effort, Citizen Science apps should be developed and where gaps for rivers and inland wetlands exist, programmes must be launched to involve and coordinate the passion of South African citizens in being the eyes and ears on the ground for inland aquatic ecosystems and freshwater species;
- **Monitoring of Important Fish Areas** needs to be undertaken regularly (every four years, and every two years for those areas that have endangered species), and should at least include variables such as flow, water quality and habitat condition. An examination of the effectiveness of Important Fish Areas in terms of preventing biodiversity loss is urgently needed; and
- A similar assessment needs to be undertaken for **freshwater CBAs and ESAs**. Habitat deterioration and loss indicators must be used to track whether rates of loss for threatened ecosystem types that are CBAs are reduced compared to those outside CBAs.

Long-term, focussed monitoring of biodiversity at specific sites should be incorporated into the five-year action plan for the National Biodiversity Monitoring Framework, and the annual plans of research and monitoring institutions, including the establishment of long term ecological research and

observation stations, to enable researchers to tease apart the effects of the threats climate change and biological invasions on specific species populations, and to track these over time to monitor ecosystem functioning. Regular monitoring for specific species, especially threatened and highly range restricted species, not only provides information about species distribution and abundance patterns crucial for use in species Red List assessments, but also gives important feedback to researchers on where to expand searches for species that are only known from a few previous records and may also reveal completely new species discoveries. Site based monitoring of the impacts of various pressures on biodiversity (e.g. invasive species, mining, residential and commercial development, transport corridors, intensive agriculture) is needed to inform better understanding of these pressures on ecological condition and species populations.

Continued and improved monitoring of water quality and pollution sources in rivers, inland wetlands, estuaries and the inshore marine environment is crucial to gain a better understanding of these pressures on biodiversity in these sensitive systems. The monitoring of impacts of abstraction and recharge of groundwater on ecosystems and species is urgently required. Groundwater is the main or only source of water for numerous towns or settlements across the country so protecting the capture zone, specifically for municipal supply well-fields, the recharge area, and the integrity of the aquifers is important.

It is vital that existing established and useful monitoring programmes (such as the ecological condition monitoring of rivers) receive the support and funding to continue. Establishing new monitoring programmes is far more difficult than sustaining existing programmes, and would be fruitless expenditure, considering the amount of effort that has gone into the design, implementation and coordination of expertise in existing monitoring systems. South Africa is at a point where funding could effectively leverage these systems into an integrated and holistic, well-coordinated system of sytems, given sufficient investment.

9.8 Sustainable financing and cooperative governance

9.8.1 Overview

The management of ecological infrastructure such as rivers and inland wetlands that underpins the benefits and services to people cannot take place in silos. Biodiversity patterns and processes are connected in complex ways that cross human-constructed boundaries and realms. To deal with this interconnectedness, cooperative governance and cross-sectoral planning and decision making are essential, and our research, monitoring, data management and intervention efforts should be integrated. The National Development Plan 2030 directs us with: ‘South Africa belongs to all its people and the future of our country is our collective future. Making it work is our collective responsibility’. Examples of cooperative governance, such as the REMP (formerly the River Health Programme) and the cooperation of the new departments of departments of Agriculture, Land Reform and Rural Development, as well as Environment, Forestry and Fisheries: Working for Wetlands and DWS, demonstrate what is possible through collaboration and when sufficient resources are available.

Biodiversity and ecosystem services are central to South Africa’s national objectives of increased economic growth, job creation, and improved service delivery and wellbeing for all its citizens. A clear priority action is to ensure that all sectors better integrate this understanding into their policies and practices. The environmental sector cannot work in isolation, and environmental and resource protection efforts will be more successful if mainstreamed and financially supported by all sectors. For example, if correctly priced

and the revenues collected, an Ecological Infrastructure Levy included in the Water User Charge for all users could fund many of the activities proposed in the NBA, as well as capacity needs.

9.8.2 Status

To achieve the suite of seven response areas requires the key mandated agencies to have in place a competent complement of aquatic staff. For DWS, this is REMP work / water resource monitoring. Impson (2016b) determined provincial conservation agency capacity needs based on consideration of the work that is needed, what is currently working at a regional level, and the availability of funding, distinguishing between coastal and inland provinces, as coastal provinces include estuaries, which require an additional skill set for appropriate management. They recommended a required minimum capacity of eight dedicated staff per coastal province and six dedicated staff per inland province (Table 9.12). These aquatic teams would further benefit from the ready availability of additional support staff when conducting field work.

Table 9.12. Proposed minimum staff for a freshwater section in a provincial conservation agency.

Provincial group	Section leader	Scientists (MSc, PhD)	Technical support	Total
Coastal province	Assistant Director (Aquatic)	Fish scientist Wetland scientist River scientist Estuarine scientist	3 staff with BSc or diplomas	8
Inland province	Assistant Director (Aquatic)	Fish scientist Wetland scientist River scientist	2 staff with BSc or diplomas	6

Table 9.13 presents the number of dedicated aquatic staff currently deployed in provincial conservation agencies (Impson 2016b). Only one agency, the MTPA, comes close to meeting the suggested minimum requirement, but still has two less staff than suggested. Two other provinces have half the suggested minimum requirement (CapeNature and EKZNW), while other provinces have very few or no (Eastern Cape Province) dedicated aquatic staff. Based on their review, Impson (2016b) suggest that South Africa has a crisis in terms of aquatic capacity in the provincial conservation agencies, and that the quality, extent and breadth of field-based reporting on the ecological state of our rivers and wetlands, particularly in terms of current status and trends, for example of the NFEPA areas in this NBA is a reflection of this crisis.

Table 9.13. Current capacity (2018) in the freshwater sections of the provincial conservation agencies.

Province and provincial body		Section leader	Scientists (MSc, PhD)	Technician	Total (suggested minimum)
Eastern Cape	Department Of Economic Development and Environmental Affairs	0	0	0	0 (8)
Free State	Department of Economic Development, Tourism and Environtal Affairs	0	2	0	2 (6)
Gauteng	Department of Agricultural and Rural Development	0	2	2	4 (6)
KwaZulu-Natal	Ezemvelo KwaZulu-Natal Wildlife (EKZNW)	0	3	1	4 (8)
Limpopo	Department of Economic Development, Environment and Tourism	0	1	1	2 (6)
Mpumalanga	Mpumalanga Tourism and Parks Association (MTPA)	0	4	0	4 (6)
North West	Department of Economic Development, Environment, Conservation and Tourism	0	2 (1 filled)	0	1 (6)
Northern Cape	Department of Environmental Affairs and Nature Conservation	0	1	0	1 (8)
Western Cape	CapeNature	1	2	1	4 (8)
Totals		**1**	**16**	**5**	**22 (62)**

While Tables 9.12 and 9.13 have outlined capacity needs and, by implication, the associated funding, for provincial conservation needs, the overall needs to achieve effective and focussed monitoring for the overall sector are clearly even more extensive.

9.8.3 Recommendations

The following recommendations are highlighted for implementation as soon as possible:

- The DEFF, through SANBI, should identify by 2020 minimum capacity needs at provincial level for ecological management of inland waters. The report by Impson (2016b) can serve as a guideline. This must address budgetary requirements to appoint sufficient appropriate personnel at regional level and equip staff to do their work (mileage, accommodation, equipment, conference attendance, analysis etc.);
- DEFF, through SANBI, to submit motivation to national treasury in 2020 to obtain ring-fenced funding to address capacity needs. It is proposed that water user charges must include ecological infrastructure maintenance and rehabilitation, which will then enable capacitation.
- DEFF, through SANBI, to identify by 2019, an appropriate number of monitoring sites per ecosystem types, geographically dispersed across the country and regions, as well as methodologies and equipment required for monitoring purposes. The FEN should be used to achieve this objective. These monitoring sites should be chosen based on a range of key criteria e.g. reference sites, sites to represent rare, unique, threatened and poorly protected areas, hotspot sites (high concentration of threatened / endemic biota), rehabilitation sites, IFA sites, FEPA sites etc.
- ILWELC and/ot the FEN should be used to track annual progress in achieving the above objectives, as well as enabling provincial report backs on progress with management of rivers and inland wetlands;
- Departments such as DEFF and DWS and other organisations (e.g. SAIAB, Universities, consultancies) should collaborate and co-operate in terms of sharing resources to enable the production of provincial State of River and Wetland reports, with the goal of having all reports (nine

provinces) ready by 2024 so that their results can feed into the next NBA. Reports should be completed every seven years.

- The next NBA must comprehensively report on the current ecological condition of all designated monitoring sites (including key components of the flora and fauna), the conservation initiatives with partners to enhance the ecological infrastructure of the associated catchments of such sites, as well as trends in the ecological condition of each catchment since 2019.

9.9 Summary of recommendations

Table 9.12. The seven core areas of a national conservation and management strategy are all required to comprehensively address the key pressures on inland aquatic ecosystems and associated freshwater species.

Core area	Response to pressures
Foundational information and base data	• Reconcile a stable set of catchment boundaries for the country; • Undertake a systematic process of detailed taxonomic studies on priority groups, including field collections and DNA barcoding, to enhance national species datasets. • Develop biodiversity indices; • Identify and monitor species that can serve as biological indicators for different pressures; • Revise river flow categories and hydrological indices at a sub-quaternary (quinary) scale; • Improve the spatial alignment between 1:50 000 and 1:500 000 rivers and develop a representation of rivers as (polygon) features and types; • Ground-truth inland aquatic ecosystem types in priority areas Refine riparian vegetation mapping for the country; • Wetlands remain largely under-represented and insufficiently described, and therefore, significant effort should be afforded to develop data-driven wetland ecosystem types; and • Undertake a gap analysis of NFEPA.
Strategic planning, wise use and best management practice	• Increase listing of unique and threatened river and inland wetland ecosystem types through Ramsar nomination. In particular, the free-flowing rivers could be considered; • Updating FEPAs and Important Fish Areas as part of NFEPA II is a top priority to incorporate the improvements on the NWM5 and formal assessment of freshwater species; • Catchment-level planning and management are crucial to ensure cooperative governance so that the diversity, functionality and connectivity of inland aquatic ecosystems are maintained; and • The value and importance of SWSAs must be popularised, recognised, and adopted as essential to ensure the sustainable future water supply and water security in South Africa.
Regulation	• Adopt the policy objective of no net loss of remaining inland aquatic ecosystems and reinforce the importance of avoidance and minimisation; • Strengthen compliance monitoring and enforcement; • Promote coordination among authorisation and commenting authorities; • Foster cooperation among authorities and stakeholders in developing catchment-based strategic plans with explicit links to legislated activities and sensitive areas; • Review institutional mandates for efficiencies, gaps and cooperative governance opportunities; • Support best practice when undertaking wetland delineation, and river and wetland assessments; • Support more effective uptake of biodiversity management plans for ecosystems and species; and • Strengthen budget and capacity for evaluating EIAs, implementing environmental authorisations, and monitoring compliance with the conditions of environmental authorisations (ROD).
Protection	• Substantially increase the representation of river and inland wetland ecosystem types within the protected area network; • Prioritise under-protected species for consideration in protected area expansion efforts, especially those that are both endemic and threatened. Freshwater fish are an obvious group for prioritisation. Protected areas should aim to incorporate climate refugia, future biodiversity hotspots, and habitats for species that are particularly vulnerable to climate change (such as amphibians) or that are of high conservation value; • Prioritise protection and improved management of water ecological infrastructure (particularly through the biodiversity stewardship approach) in Strategic Water Source Areas; • Incorporate sufficiently detailed management plans for aquatic ecosystems and aquatic species, based on their mapped extent and an understanding of their specific functions, drivers and pressures, into protected area and biodiversity stewardship management plans; • Apply a suitable monitoring, management effectiveness assessment and adaptive management

	system ; and • Support ongoing monitoring and control measures within the protected area network, particularly with regards to invasive species, as well as other pressures impacting species.
Rehabilitation	• Rehabilitation of rivers and inland wetlands should be prioritised in the SWSAs and Important Fish Areas (particularly the management of invasive plants, afforestation in SWSAs, excessive abstraction, and invasive fishes) and thereafter in areas for the threatened ecosystems and species; • Ongoing rehabilitative management (aftercare) of the rivers, inland wetlands and riparian zones by landholders is a critical component to ensure the long-term success of rehabilitation; • Build a comprehensive monitoring and reporting programme to guide research and implementation efforts on biological invasions; • At the moment invasive species management plans are limited to a small proportion of the current occupancy range of invasives due to limited resources, and there is inadequate monitoring; and • Alien species not legally in the country must continue to be screened for invasive potential before introduction.
Monitoring	• Reinstitute the cooperative governance and monitoring of river ecosystem types that has collapsed over the past three years; • Allocate funding for a detailed study on how the various monitoring systems related to inland aquatic ecosystems and freshwater species can be optimised and integrated, into, for example, the Freshwater Biodiversity Information System; • Workshop and Implement the National Wetland Monitoring Programme, following agreement on variables to monitoring and pilot sites to test; • Secure and implement sustained funding for evaluating globally-derived remote sensing products for monitoring and reporting and the development of remote sensing monitoring systems for rivers and inland wetlands; • Coordination of monitoring and reporting between departments and organisations should be encouraged through the FEN and provincial networks (e.g. Freshwater Forum of the Department of Environmental and Development Planning, Western Cape Province); • Monitoring of species populations is an enormormous task, which can be assisted by online citizen science platforms that allow people across the country to contribute to the effort, Citizen Science apps should be developed and where gaps for rivers and inland wetlands exist, programmes must be launched to involve and coordinate the passion of South African citizens in being the eyes and ears on the ground for inland aquatic ecosystems and freshwater species; • Monitoring of Important Fish Areas needs to be undertaken regularly (every four years, and every two years for those areas that have endangered species), and should at least include variables such as flow, water quality and habitat condition. An examination of the effectiveness of Important Fish Areas in terms of preventing biodiversity loss is urgently needed; and • A similar assessment needs to be undertaken for freshwater CBAs and ESAs.
Sustainable financing and cooperative governance	• The DEFF, through SANBI, should identify by 2020 minimum capacity needs at provincial level for ecological management of inland waters; • DEFF, through SANBI, to submit motivation to national treasury in 2020 to obtain ring-fenced funding to address capacity needs; • DEFF, through SANBI, to identify by 2019, an appropriate number of monitoring sites per ecosystem types, geographically dispersed across the country and regions, as well as methodologies and equipment required for monitoring purposes; • ILWELC and/ot the FEN should be used to track annual progress in achieving the above objectives, as well as enabling provincial report backs on progress with management of rivers and inland wetlands; • Departments such as DEFF and DWS and other organisations (e.g. SAIAB, Universities, consultancies) should collaborate and co-operate in terms of sharing resources to enable the production of provincial State of River and Wetland reports, with the goal of having all reports (nine provinces) ready by 2024 so that their results can feed into the next NBA. Reports should be completed every seven years; and • The next NBA must comprehensively report on the current ecological condition of all designated monitoring sites (including key components of the flora and fauna), the conservation initiatives with partners to enhance the ecological infrastructure of the associated catchments of such sites, as well as trends in the ecological condition of each catchment since 2019.

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10. KEY FINDINGS AND RECOMMENDATIONS

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In this Chapter, we present here an overview of the matters discussed in Chapter 1–9 of this report, followed by the key findings, key messages, knowledge gaps and related priority actions in subsequent sections.

10.1 Introduction

The biodiversity of inland aquatic ecosystems is represented by the river and inland wetland ecosystem types as well as a wide range of species diversity. The *Classification System for Wetlands and other Aquatic Ecosystems in South Africa* serves as a framework for the tiered classification of inland aquatic ecosystems and associated attributes (Ollis *et al.* 2013). In this National Biodiversity Assessment for 2018 (NBA 2018), 222 river ecosystem types have been mapped using both 856 mainstem and also tributary rivers which drain the 22 primary catchments of South Africa. Inland wetlands constitute 135 ecosystem types, covering at least 2.2% of the surface area of the country. Groundwater forms an essential and supportive function for the baseflow of these ecosystem types.

Many plant species are associated with rivers and wetlands, and more than 4 000 faunal species have been recorded to be associated with inland aquatic ecosystems. This report presents the Red List assessment and index for a sample of the plants, birds, reptiles, mammal, amphibian, freshwater fish and dragonfly species associated with inland aquatic ecosystems. Assessments for southern African species have also been disaggregated to report on threat status and protection level of species specific to South Africa.

This report offers an overview of the status of ecosystems and species associated with inland aquatic ecosystems, reporting against several headline indicators, including Ecosystem Threat Status (ETS), Ecosystem Protection Level (EPL), free-flowing rivers, Species Threat Status (STS), Species Protection Levels (SPL) and the Red List Index (RLI) of species. The results of these assessments inform and direct national reporting, such as the Environmental Outlook reports, as well as planning at various levels of government. The results further inform international reporting to the Convention on Biological Diversity (CBD), Freshwater Biodiversity Observation Network (FWBON), the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), Ramsar International and the United Nations Environment Programme (UNEP).

10.1.1 Summary of benefits of inland aquatic ecosystems

The diversity of inland aquatic ecosystem types provides a range of benefits in the form of ecosystem services. Usually ecosystems in a near-natural to a moderately modified ecological condition sustain the provision of vital ecological services to society in both urban and rural areas. Services range from provisioning to regulating and cultural services. Ecosystems with a heavily to severely or critically modified

ecological condition are at risk of collapsing, or have collapsed, with a consequent dwindling of their ability to deliver ecosystem services. A tipping point may be reached where rehabilitation is not possible anymore, and ecosystem services cannot be recovered. It is therefore crucial to ensure that all types of inland aquatic ecosystems, including their range of services and ecological condition, are mapped and managed in catchments to meet both biodiversity targets and ecosystem drivers while meeting the demands of sustainable development.

10.1.2 Climate change – changing our envelope of the known context

Climate change is a key driver of evolutionary change. Compared to historic shifts in climate that had taken place over thousands of years, the impact of anthropogenic climate change has resulted in unprecedented changes within the past 50 to 100 years. Internationally, inland aquatic ecosystems are considered the most vulnerable ecosystem type to climate change with the status of aquatic species deteriorating faster than other ecosystem types. South Africa, with its mean annual precipitation below the international average, has been identified as a water-related vulnerable 'hotspot'. Evidence of warming and subsequent increasing air temperature, number of hot days and duration of warm spells is very likely to increase evapotranspiration and impact the hydrological regime of inland aquatic ecosystems. In addition, increases in the variability of water temperature within some of Africa's large water bodies and rivers have been observed.

Rainfall is naturally highly variable in South Africa and no substantial change has been observed during the past 50 years for southern Africa. The intensity of heat waves, drought and hot days are predicted to increase which will likely lead to more intense fires, where sufficient vegetation exists to fuel the fires. Furthermore, although rainstorms and storm surges are predicted to increase, a decline in rainfall is predicted for southern Africa. The frequency of tropical cyclones, providing significant rainfall to the Limpopo Province and Maputaland Coastal Plain, is predicted to decrease, resulting in a decrease of the recharge of associated aquifers, particularly those on the coastal plain.

Healthy ecosystems which are aquifer-dependent (or Aquifer Dependent Ecosystems (ADE)) are argued or expected to be more resilient to changes in rainfall and temperature increases, compared to those that are predominantly dependent on surface-runoff and recharge. At the same time, ADE systems on the coastal Cenozoic plains have shown to be vulnerable to water abstraction, and the water level has declined since to below the level it has been the past 7 000 years. A combination of water abstraction, land use practices and droughts has resulted in 17 peat wetlands becoming desiccated or burnt since 1996. Inland systems dependent on runoff may show drastic changes in their hydrological regimes with subsequent impacts on productivity, connectivity and the life cycles of water-dependent fauna. Some of these 17 peat wetlands have collapsed and would be difficult to rehabilitate, and the burning likely resulted in turning these sinks of carbon dioxide into atmospheric sources of greenhouse gasses.

For Africa, the start of the annual growing season has been shown to be delayed, and a decline has, for example, been observed in the Blue Crane (*Anthropoides paradiseus*), a wetland-related species, as a result of change in seasonal rainfall timing and volume. South Africa's small and shallow inland wetlands and ephemeral rivers are expected to have little resilience against both climate change and current pressures, such as water abstraction, water pollution and sedimentation. Moderate to severe changes in the structure and function of habitats will result in species having to shift. A number of freshwater fish with narrow water depth and temperature tolerance levels (generally those found in mountain streams), as well as wetland-

dependent birds, frogs and mammals are experiencing climate change impacts on their habitats. If similar environmental ranges in alternative habitats are not available elsewhere, extinction would be a possibility, especially for those very range restricted species that cannot migrate from one habitat to another. Dams limit such migration of aquatic species, in particular freshwater fish. Species have adapted and evolved over thousands of years to different climate regimes, and show potential genetic markers for adaptability. The ability of species to now adapt rapidly to drastic changes in habitats, imposed by both climate changes and multiple anthropogenic pressures, however, remains uncertain. Evolutionary resilience or genetic diversity has however shown potential for species to overcome rapid environmental change (Hughes *et al.* 2008, as cited in Chapter 8). The monitoring of pressures, habitat and species should be done more frequently to address knowledge gaps and inform planning and decision making.

10.1.3 Key pressures

This report has built on the five key pressures as listed internationally by Dudgeon et al. (2006), and which had been workshopped and documented in the NFEPA atlas (Nel *et al.* 2011a). These include changes to the hydrological regime, changes in water quality, loss of natural habitat (degradation) and invasive species. Although fragmentation is associated with the first three pressures, we summarise it in this Chapter as a subsection, integrating the fragmentation aspects listed under the various key pressures in Chapter 4.

Changes to the hydrological regime

The extent and persistence, as well as the severity of anthropogenic pressures on the hydrological regime are mostly unknown for South Africa. In addition, the resilience of habitats and species to varying degrees of water abstraction, pollution, land degradation and invasive species, is often poorly understood. Most of the studies related to the impacts of pressures on ecosystems are temporally and geographically limited or narrow in scope, failing to improve the understanding of the complexity and interdependency of inland systems. A geographic focus, for example, on the Cape Floristic Region and part of the KwaZulu-Natal Province, has been tremendously helpful in highlighting the impact of both climate change and pressures on species and habitats. Further work is required across the diversity of ecosystem types and species to improve understanding of the cumulative impacts of multiple pressures on inland aquatics. The development of a framework, and particular indices and indicators for invasive species, has improved the reporting of this pressure across ecosystem types. Invasive species indicators now include the pathways of entering a system, the number of species that have major impacts, the geographic extent of the impact and the level of success in interventions. Similarly, indicators for measuring the impacts of changes to the hydrological regime, water quality and degradation are required to better monitor these impacts over time.

Evidence is presented in this report that water abstraction has caused the collapse of at least 18 peat wetlands in the country (Section 4.3.1.; Appendix C and Appendix D). Water abstraction in these systems has resulted in the drying out of substrates which had been inundated for thousands of years. The safe margins of water abstraction, which would avoid collapse of ecosystems are largely unknown. Similarly, the modification of ecosystems through the addition of water from Waste Water Treatment Works (WWTW) or interbasin water transfers that changes the thermal ranges, turbidity, oxygen and nutrient levels of aquatic ecosystems, is also largely unknown. These impacts require further study in South Africa to better understand and quantify their effects on inland water ecological infrastructure across South Africa.

While a number of Resource Quality Objectives (RQOs) are in progress, several primary catchments remains to be done. The RQOs aim to address a balance between water resource use and protection by requiring compliance monitoring against legally prescribed monitoring objectives. In addition, the DWS has identified strategies in terms of Resource Protection, and these strategies are strongly focused on ecological health of inland waters. These initiatives are a major step forward in planning for ecological resilience in the landscape. Wetlands have, however, been mapped to a medium confidence, limiting the understanding of the full extent of the water budget required for these systems to persist over time. The interaction between groundwater and surface water is furthermore poorly understood, hindering the understanding of which systems are aquifer dependent, and possibly more resilient to climate change, and which systems would likely be more vulnerable to the combination of water abstraction *and* climate change.

Water pollution

Sources of water pollution are diverse, ranging from point-source pollution, e.g. discharge from a WWTW, to non-point source via land use practices within a catchment. While the geographic extent of the source could be mapped, the distance of impact on aquatic ecosystems are difficult to determine and monitor. Traces of water quality pollution have been found up to 2 km downstream of the source, as in the case of *E. coli* in the Orange River, and 40 km downstream of a WWTW in the Olifants River (Oberholster *et al.* 2013) while in an arid, vegetated valley-bottom system, pollution was absorbed within 50 m of the pollution source (Van Heerden 2014). Ranges of impact in seasonal to ephemeral rivers, as well as inland wetlands are largely unknown. The complexities of geology, geomorphological setting, the soils, vegetation and nature of the pollution affect the ability to accurately model impacts in different inland aquatic ecosystems. In 2013, 7.3% of SA's 859 WWTW received Green Drop certification, while 30% (248 WWTW) received purple (poor) status. In 2018, samples from only 33% of surface and 7% of groundwater monitoring points had been analysed by DWS, with a general decline in the numbers sampled observed over the past three years (DWS 2018). By 1 January 2019, the former minister of the Department of Water and Sanitation (News24 2019) has declared 46 WWTW under critical review.

Water pollution is considered a key pressure on freshwater fish following their Red List assessment, which classified a large portion of freshwater fish as threatened in this NBA. Pollution events may be persistent or ephemeral in nature, but the impact may be instantaneous and severe resulting in a fish kill, or persistent over time but less dramatic (i.e. loss of pollution sensitive species or impaired recruitment) and therefore less invisible. An emerging contaminant is microplastics, which internationally has been seen as a major concern to ecosystems, species and humans since 2014, and resulted in several countries banning microplastics and labelling it a toxic substance. In South Africa a risk assessment approach is required to determine the impact of microplastics and microfibers on inland aquatic ecosystems and aquatic species. The origins of macroplastics, which degrades to microplastics and fibres, are speculated to originate from inland rivers in South Africa, however, the cause of such pollution and areas needs to be verified. The DWS has a Source-to-Sea project in place which evaluates methods of removal for at least five rivers located in the Ethikwini Municipality of the KwaZulu-Natal Province, these being the Umgeni, Umlazi, uMbila, mMhlatuzana and aManzimnyama rivers. Intervention is required at product production level, pathway and recovery levels to minimise the pollution, while research is required to assess risk to aquatic biota.

The detection and treatment of water pollution is relatively well addressed from a human consumption point of view in South Africa. It is critical that all ecosystem types, for both river and inland wetlands, are covered by effective monitoring. Treatment of pollutions is not always possible at source or a WWTW, as for example, in the case of pharmaceuticals, endocrine disruptive chemicals and microplastics. Water pollution may also be caused by poor land use practices and is more difficult to trace both temporally and

geographically. Instream monitoring of water quality is therefore critical for the protection of all users of water resources, as well as the resource base itself, that is the aquatic ecosystem.

Loss of natural habitat

The land cover dataset has served several NBAs and other projects as a surrogate for where ecosystems in a natural or near-natural ecological condition exist. The natural land cover categories provide a quick, easy-to-use and effective dataset for informing where natural, untransformed land is likely to occur, and have been used to inform the ecosystem and species threat status in this NBA. For the ecosystems, the biodiversity target requires that at least 20% of the full extent of an ecosystem needs to be in a natural or near-natural ecological condition. If less than 20% is in a near-natural ecological condition, the ecosystem type would be considered Critically Endangered.

Land cover is, however, not an index of degradation. Degradation can result from overgrazing, ploughing and sand mining in rivers and inland wetlands. These impacts are more difficult to detect remotely and therefore costly to map and monitor. Sand mining in rivers has become an emerging pressure within the past decade, destroying the ability of river ecosystems to recharge aquifers, regulate flow and provide instream habitat for biota. The pressure is often not easily or clearly visible from orthophotos or satellite imagery, particularly because these are short-lived events at a small scale.

Activities that lead to land degradation would therefore require better compliance monitoring across the extensive landscape of the country, and ultimately, would be very costly. Awareness raising, education and involvement of communities are therefore critical in the effective monitoring of degradation. Stewardship programmes combined with citizen science reporting, could provide a better alternative for intervention and rehabilitation of rivers and inland wetlands in both urban and rural areas.

Invasive species

Regardless of the improvement in the structure language and indicators in quantifying and reporting on a trend analysis of invasive species, the geographic extent of impact remains particularly difficult to detect and monitoring on rivers and inland wetlands. Remote sensing has shown advances in the detection of woody invasive species, but is limited in predicting invasive plant species for shrubs and grass species. Invasive faunal species in the aquatic environment are even more difficult to detect, since these species are very mobile across large distances and without effective surveying can easily remain unseen. In this regard, progress made in environmental DNA (eDNA) shows promise of detecting traces of certain invasive species within the aquatic environment.

Over-exploitation of species

Several river and wetland-dependent species are currently affected by over-exploitation, and although many of these are not threatened with extinction, the trade in these species must be controlled. South African freshwater species listed on Appendix II of the Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES) includes all three of South Africa's iconic crane species; Wattled Crane (*Bugeranus carunculatus* – CR), Grey Crowned Crane (*Balearica regulorum* – EN) and Blue Crane (*Anthropoides paradiseus* – NT). Freshwater species are primarily threatened by an ongoing decline in the size and condition of available habitat although over-exploitation is not at levels that threaten their existence. Nevertheless, ongoing monitoring of use and trade should be conducted to detect any change in current trends. South Africa has many species of saltwater fish that have been fished to the point of commercial extinction (e.g. White Steenbras, Red Steenbras), but as yet our indigenous freshwater fish stocks have not been affected by over-exploitation beyond the local scale. However, some freshwater fish

species may face impacts of over-exploitation due to angling and local fisheries and are due to be listed in terms of the national Threatened or Protected Species (TOPS) regulations.

Fragmentation

Although not a pressure on its own, we summarise fragmentation in this final chapter in a self-standing paragraph due to its significance in maintaining functional aquatic ecosystems. Fragmentation can result from changes in the hydrological regime, or water pollution or loss of natural habitat (land degradation) or water pollution, e.g. chemical, thermal and nutrient changes in the water as a result of effluent and land uses impacting on these systems. The construction of dams can also interrupt the longitudinal connectivity of river ecosystems, whereas land uses and transport infrastructure minimises the dispersal and migration capabilities of freshwater-dependent species. The free-flowing rivers index offer a measure for longitudinal connectivity of river ecosystem types, while the Species Threat Status takes habitat fragmentation into account for freshwater-dependent species. Further indices are required for measuring chemical fragmentation of inland aquatic ecosystems. Fences in the landscape, particularly electric fences, prohibits migration and dispersal of species, and have also been shown to kill or injure freshwater species.

10.1.4 Are we up to the challenge?

South Africa has made headway internationally in its assessment of inland aquatic biodiversity. The typing and assessment of river and inland wetland ecosystems at a country-wide scale for arid to semi-arid countries offers an example for other data-poor countries to follow (Chapter 1; Nel *et al.* 2007; 2016; 2018; Van Deventer *et al.* 2016). This report now provides for the first time a more comprehensive overview of both vertebrate and invertebrate taxa of inland aquatic ecosystems. Species records have been collected and curated by several institutions in South Africa, however, through recent funding from the Jacob Richard Schramm (JRS) Biodiversity Organisation, the Freshwater Research Centre of Cape Town and SANBI are making these records electronically available through the Freshwater Biodiversity Information System (FBIS). The South African Institute for Aquatic Biodiversity (SAIAB) has also curated and provided highly accurate data to the Global Biodiversity Information Facility (GBIF) and hence South Africa has good species occurrence data to use in assessments, especially for freshwater fish. This NBA 2018 found the first evidence that the threat status of freshwater species corresponded to the assessment of the ecological condition of their habitat or ecosystem types. Freshwater fish were found to be highly threatened, and a corresponding 67% of river ecosystem types were found to be severely modified from its natural ecological condition.

South Africa is also considered a country leading in environmental law, particularly for environmental protection and regulation (Funke *et al.* 2007). Recently a court interdict prohibited mine exploration to continue in the Mabola Nature Reserve, following sufficient evidence from multiple parties that the environmental consequences would have been dire. The South African Human Rights Commission (SAHRC), for example, has also been involved in investigating the spill of 150 megalitres of raw, untreated sewerage into the Vaal River system, which posed a health risk to many people and ecosystems, and has been responsible for a large fish kill. The SAHRC intends to provide recommendations to government on the conflict resolution. These examples illustrate the various mechanisms South Africa offers to intervene in the planning and management of water security and our ecosystems.

Monitoring is essential

It is clear that ecosystems, species, pressures and impacts require a complex set-up of indicators and institutions to ensure effective monitoring and to enable improved understanding of interactions and trends. Improved understanding is essential for better decision making and planning. Historically, South Africa had one of the most advanced river monitoring systems in the world, in operation between 2002 and 2011. Yet, progress on national assessments within the past 15 years has not always been met with equal progress in monitoring of ecosystems, species and pressures. In particular, the collapse of the river monitoring systems over the past three years, as well as no monitoring system for inland wetlands, and an insufficient water use monitoring at the time of this assessment, means that credible decision making is limited. Primarily, funding and skilled personnel needs to be allocated for monitoring to facilitate the building of solid baseline data for decision making and assessments.

Increasingly, a plethora of technologies are available to facilitate monitoring and collaboration, including *in situ* devices and remote sensing technology, as well as reporting via community platforms. The advantage of such tools is not only for data collection and subsequent modelling, but also for improved understanding by the general public, so as to allow them to be part of informed decision making. For example, access to information on water use and impacts, on a smart phone devise, can alter behaviour of the general public.

Within the past eight years, South Africa has seen a collapse of the capacity of government to monitor and respond to the pressures on the ecosystem types and species associated with inland aquatics. Despite the momentum gained with the National Freshwater Ecosystems Priority Areas (NFEPA) project, and the collaboration the project forged across institutions, a lack of sustained funding within government has resulted in debilitation of functioning to secure the quantity and quality of water resources for sustaining the agreed extent of ecosystem types. For the first time since 1994, the collaborative river monitoring programme will not be assessing the ecological condition of the mainstem rivers, due to a severe lack of funding and resources of the DWS. The River Eco-Status Monitoring Programme (REMP) has not been fully functional since 2018 as the finalization of methods is still required, and the collection of monitoring data cannot take place, although Resource Protection divisions are still in place in DWS regional offices. Collaboration established through the RHP also collapsed, especially data curation facilities. Since January 2018, the National Eutrophication Monitoring Programme (NEMP) has also been non-operational, owing to insufficient funding for monitoring. Note that the sites, covered by the NEMP and National Microbial Monitoring Programme (NMMP), have been insufficient for some time. The NWMP is, however, on the verge of implementation, a first in South Africa, following the tremendous drive generated since NFEPA and the funding from the WRC to investigate the framework and indicators for monitoring.

Effective responses would require the pro-active buy-in of every South African in protection our natural heritage.

10.2 Key findings

A number of key findings are summarised in Table 10.1. These have been developed and updated from the key findings of NBA 2011 and NFEPA projects (Nel *et al.* 2011a; 2011b; Nel & Driver 2012) and the information presented in this report (Chapters 1–9).

Table 10.1. Key findings for the inland aquatic ecosystem types and species.

The biodiversity of inland aquatic ecosystems benefits South Africans	
Benefits	• Inland aquatic ecosystems offer a range of ecosystem services, ranging from provisional services to regulating and cultural services. Those in a better ecological condition offer more ecosystem services, compared to those that are degraded. • Rivers and wetland offer connectivity in the landscape which supports the biodiversity of other realms (e.g. terrestrial species). • Inland aquatic ecosystems serve as refugia during times of drought. Rivers and FEPAs form ecological corridors for ecosystem-based adaptation to climate change (Nel *et al.* 2011a; 2011b). • The surface water SWSAs (SWSA-sw) cover about 124 075 km² (10% of the country) and provide a mean annual runoff (MAR) of 24 954 million m^3 (50% of the total MAR). The groundwater SWSAs (SWSA-gw) cover around 9% of the land surface of South Africa. They account for up to 42% of the baseflow in their areas and have a key role in sustaining surface water flows during the dry season. • Rivers and wetlands serve as ideal landscape features to serve as ecological corridors to facilitate species movement, both aquatic and terrestrial, in response to climate change.
The representation of ecosystem types are important for planning and decision making	
The rivers layer is a key dataset for planning and decision making at multiple levels of governance in South Africa	
Rivers	• A total of 222 river ecosystem types were assessed. • The river ecosystem types were most diverse in the Limpopo Water Management Area with the lowest occurring in the Vaal and Breede-Gouritz Water Management Areas. • The assessment of the extent of river length for each longitudinal zone highlighted the rare occurrence of intact lowland rivers in South African rivers. • The flow categories should be revised to include season and ephemeral flow types rather than only permanent and non-permanent. • There is a need to refine the river riparian vegegation mapping nationally.
National Wetland Map 5 (NWM5) is a key dataset for planning and decision making at multiple levels of governance in South Africa	
NWM5	• The update of the National Wetland Map version 5 (NWM5) showed that 2.2% of the country has been mapped as inland wetlands, totalling 2.6 million ha. • NWM5 has significantly improved the representation of inland wetland ecosystem types. The representation of the extent of inland wetlands has improved by 123%, whereas the incorrect representation of terrestrial ecosystems as wetlands has been reduced. • In spite of these improvements, nearly 70% of the extent of South Africa is still at a low confidence level (Van Deventer *et al.* 2018), meaning inland wetlands have not been well mapped and typed for 70% of the country. • There is general agreement that wetlands remain largely underrepresented and not sufficiently described, and therefore, significant effort should be afforded to address this gap.
The threat status of unique aquatic ecosystem types in South Africa were available for the first time	
Freshwater lakes (Limnetic wetlands)	Unique ecosystem types with restricted ranges have also been identified for the inland aquatic ecosystems. Eight freshwater lakes (limnetic wetlands) with restricted range have been identified as South Africa's only inland lakes (Van Deventer *et al.* 2018). These are permanently inundated depressions where the depth at the annual, low-water level is > 2 m (Ollis *et al.* 2013). The DWS has undertaken the verification of the depth of these systems, to ensure accuracy in reporting under the Sustainable Development Goal 6.6 to the UNEP (Mr Elijah Mogakabe, November 2018, *pers. comm*.).
Swamp forest	Attribute information on swamp forest which were derived from the topographical maps, as mapped by the former Department of Rural Development and Land Reform, Directorate National Geo-Information (DRDLR:NGI), and transferred to the NWM5, also showed potential for these inland wetland sub-types to be restricted in range. SANBI is in the process of following up on the improved mapping and potential red listing of these subtypes.

Status and protection of inland aquatic ecosystems	
River and wetland ecosystems are highly threatened	
Ecosystem Threat Status (ETS)	• This assessment found that respectively 64% and 79% of South Africa's river and wetland ecosystem types are threatened, i.e. Critically Endangered, Endangered or Vulnerable. • Wetland ecosystem types were likely more threatened than their river, coastal, marine, terrestrial and sub-Antarctic counterparts (64%, 60%, 50%, 23% and 18% of river, coastal, marine, terrestrial and sub-Antarctic ecosystem types are threatened respectively). In this assessment, estuarine ecosystem types were found to be more threatened compared to wetlands, with 86% of the ecosystem types threatened. • Wetlands in South Africa's landscape today make up only 2.2% of the country's area, yet wetland ecosystem types are mostly underrepresented in the National Wetland Map. On average, a municipality would have at least 3% of its extent being wetland.
Ecosystem Protection Level (EPL)	• Rivers and inland wetlands are Poorly Protected. This assessment found that less than a quarter of the country's river and inland wetland ecosystem types could be considered Well Protected (13% and 6% respectively). • Lowland river ecosystem types, as well as valley-bottom and floodplain wetlands, usually coincide with low-lying areas. They are subsequently predominantly developed and at the receiving end of effluent discharges. This assessment found 67% of the lowland rivers and 93% of the valley-bottom and floodplains wetlands to be Critically Endangered. Most of the inland wetlands were found to be Poorly Protected, mainly because < 5% of the extent of these hydrogeomorphic types are in a near-natural ecological condition.
River ETS	• 64% of 222 river ecosystem types are threatened. • 13% of river ecosystem types were considered Well Protected while 42% are Not Protected. • The Vaal WMA has an alarming proportion of Critically Endangered ecosystems associated with its rivers; far higher than the rest of the country (> 70% of its length contains Critically Endangered ecosystems). • Healthy tributaries and wetlands support the sustainability of hard-working rivers.
Inland wetland ETS	• About 73% of inland wetlands are threatened and unprotected (Not Protected or Poorly Protected). • Freshwater lakes (limnetic wetlands) were also found to be threatened and Poorly Protected. • The shortfall to the biodiversity target is largest for Bushmanland Depression and Mesic Highveld Grassland Valley-bottom wetlands. These systems should be prioritised for in-field integrity assessments, followed by consideration in an expansion strategy for protection. • FEPAs for wetlands should be redone once the NWM5 reach a medium confidence in the extent and typing of inland wetland ecosystem types. • SWSA play a critical role in securing our water supplies, however it is the retention capacity of inland wetlands which will sustain the provisioning and regulating ecosystem services to humans. • Priorities for protection or red listing of ecosystems should be considered, including the freshwater lakes (Lake Fundudzi, Barberpan, De Hoop, Groenvlei and Lake Sibaya requires improved protection), ecosystems which are range restricted (freshwater lakes and swamp forests), ecosystems which are critically endangered and not protected (arid depressions needs to be prioritised for in-field validation) and those with a large shortfall to the biodiversity target (the Bushmanlan Bioregion Depressions – 65k ha; and the Mesic Highveld Grassland valley bottom wetlands – 40k ha).
Flagship rivers	• 19 flagship rivers remained in a near-natural ecological condition.
Free-flowing rivers	• Fourteen free-flowing rivers have changed in status: four as a result of dams not represented in the layer used for the NFEPA project (6% of the original 62 free-flowing rivers) and ten as a result of deterioration of their ecological condition (i.e. 16% of the original 64 free-flowing rivers). • South Africa has 48 remaining free-flowing rivers.
Freshwater species are vulnerable to multiple pressures	
Highlights vulnerability in the aquatic environment	**Freshwater species show a high sensitivity to multiple pressures, the most serious being the loss of natural habitat owing to invasive alien species, pollution of river systems, agricultural and housing developments and over-abstraction of water**. More than 65% of South Africa's reptiles, mammals, birds, aquatic plants, freshwater fish, amphibian and dragonfly Taxa of Conservation Concern (ToCC) are declining as result of agricultural and housing developments. Pollution as a result of agricultural and industrial effluents are impacting more than 60% of South Africa's inland aquatic dependent birds, freshwater fish, mammal and reptile ToCC. Changes in hydrological regimes associated with the water abstraction and the building of dams is impacting more than 50% of South Africa's birds, freshwater fish, mammal, reptiles and amphibians ToCC. Over 50% of South Africa's dragonfly, freshwater fish, aquatic plants and amphibian ToCC are threatened by invasive species. These pressures are driving the increase in species threat status. Efforts should be focused to

	reduce impacts of pressures such as improved invasive species control, prevention of pollution into river systems by better management and better-informed land use decisions.
Freshwater fish are highly threatened with extinction and Poorly Protected	**Freshwater fish are South Africa's most threatened and least protected taxonomic group**. A total of 36% of all freshwater fish and 39% of endemics are threatened with extinction. Freshwater fish are experiencing rapid rate of increase in extinction risk as indicated by their low RLI value and the fact that 7% of SA's fish have increased in threat status since 2007. This group is also Poorly Protected, with none of the Critically Endangered species assessed as Well Protected and a further 18 ToCCs assessed as Not Protected.
Protected areas are not adequately catering for South Africa's inland aquatic species	**Many protected areas are not geographically located to protect South Africa's endemic inland aquatic species. Furthermore, many species occurring within existing protected areas are threatened and declining as a result of pressures present within or originating outside of protected areas, and which are not effectively managed.** A total of 90% (47 taxa) of SA's endemic freshwater fish species and 46% (21 taxa) of endemic amphibians are under protected (Moderately Protected, Poorly Porotected and Not Protected). For taxa occurring within protected areas management effectiveness is not adequate, particularly fish where 22% of South Africa's freshwater fish (21 taxa) have populations occurring in protected areas but are suffering due to invasive species impacts and were downgraded in the protection level assessment due to poor management effectiveness. Similarly, 9% of amphibians drop a category of protection due to ineffective management interventions mostly linked to invasive alien plants changing water hydrology for critical habitats and inappropriate fire management. Improved management within protected areas is required, while a catchment approach is required for impacts originating outside of protected areas, to improve effectiveness of protecting species.
Pressures in the aquatic environment are increasing	Freshwater ecologists agree that pressures in the aquatic environment are increasing, and this is supported by a much steeper RLI of species for inland aquatic species than is observed for terrestrial species. The expert opinion is supported by the River Natural Capital Accounting Report (Nel &Driver 2015), which show a decline in the expert-rated river ecological condition between 1999 and 2011. Rivers remain under sampled due to ongoing capacity constraints and many invertebrate species from the aquatic environment are underrepresented.
Invasive alien species and water pollution are major drivers of fish extinction risk	Impacts of invasive alien species and water pollution are major drivers of fish extinction risk, impacting 81% (51 taxa) and 70% (44 taxa) of ToCCs respectively in South Africa. These impacts have resulted, in species extirpations and habitat degradation and fragmention of species populations. Improved river monitoring and management is urgently needed. Successes have been observed where invasive species have been cleared or eradicated indigenous species have returned, e.g. the Rondegat eradication of invasive fish as well as the recolonization of cleared sites by dragonfly species.
27 freshwater species are Taxa of Conservation Concern (ToCC) and Not Protected	Species that are ToCC and assessed as Not Protected include 26 freshwater species: • Four fish species are Critically Endangered: Treur River Barb (*Enteromius treurensis*), Barrydale Redfin (*Pseudobarbus burchelli*), *Pseudobarbus* sp nov Krom and *Galaxias* sp nov slender; 11 taxa – Endangered (*Galaxias sp nov breede, Galaxias sp nov heuningnes, Galaxias sp nov verlorenvlei, Kneria sp nov South Africa, Pseudobarbus capensis, Pseudobarbus sp nov heuningnes, Pseudobarbus quathlambae, Pseudobarbus sp nov keiskamma, Pseudobarbus trevelyani, Pseudobarbus verloreni and Pseudobarbus afer* , two taxa - Vulnerable (*Galaxias sp nov goukou and Galaxias sp nov gourits*) and one Data Deficient (*Enteromius amatolicus*). • Four bird species: Grey Crowned Crane (*Balearica regulorum* — EN); Black Stork (*Ciconia nigra* — VU), Chestnut-banded Plover (*Charadrius pallidus* — NT) and the Maccoa Duck (*Oxyura maccoa* — NT); • Four amphibian species: Amatola Toad (*Vandijkophrynus amatolicus* - CR), the Table Mountain Ghost frog (*Heleophryne rosei* - CR), the Endangered Hogsback Caco (*Cacosternum thorini*) and the Cape Dainty Frog (*Cacosternum capense* — NT) are assessed as Not Protected; and • One mammal species the Spotted-Necked Otter (*Hydrictis maculicollis* – VU); not found in any protected area.
Intervention can be highly successful	There are many rivers and wetlands in South Africa that have benefitted from rehabilitation projects. The biggest positive impacts have come from the NRMP section of DEA and the Working for Water and the Working for Wetlands programmes. Large river areas have been cleared of invasive plants and wetlands have been rehabilitated. The former Department of Agriculture's LandCare section deserves special mention for the remarkable progress made in clearing the upper Breede River of invasive plants in co-operation with riparian landowners. Invasive fishes have also been successfully controlled by chemical means (Smallmouth bass in Rondegat River, Carp in dam in Oorlogskloof catchment) and mechanical (Spotted bass in Thee River) means during the reporting period in cooperative projects between NRMP, the WRC, CapeNature and the Northern Cape Department of Environmental and Nature Conservation.

Pressures on inland aquatic ecosystems are underrepresented and poorly understood	
The geographic extent, duration and impacts of pressures on inland aquatic ecosystems are poorly understood	• The extent and degree to which rivers and wetlands are dependent on groundwater is poorly understood, and hence the amount of water which can be reasonably extracted without having a negative impact on these ecosystems, needs to be quantified through research and comprehensive monitoring. • The geographic extent, duration and impact of water pollution currently on inland aquatic ecosystems and freshwater species is poorly understood because comprehensive monitoring is not been done at either a provincial or national level in relation to point and non-point sources of pollution. • Nearly 70% of the surface area of South Africa is used for grazing (Skowno *et al.* 2019), yet the impact of stock type and levels are unknown. • The extent of emerging pressures, including sand mining and microplastics, are unknown. • Invasive plant species, particularly woody species, have been mapped and detected in the National Invasive Alien Plant Survey (NIAPS), yet the resolution is too coarse for distinguishing river and wetland habitats from terrestrial habitats (the atlas is at a quarter degree square ranging from 22 to 28 km spatial resolution). In general the confidence for almost all estimates is low. Although remote sensing has promise to detect and monitor invasive woody speciesm, shrub, grass and invasive faunal species require *in situ* detection and monitoring which can be costly for the vast extent of the country. Environmental DNA (eDNA) shows promise for detection and surveillance of aquatic habitats in particular.
Invasive species is a major environmental driver	Invasive alien species constitute a major driver of environmental change in the environment with major environmental, social and economic impacts, thus more attention must be focused at preventing further introductions and spread of existing alien species as well as reducing their impacts, particularly in the face of climate change. Where appropriate (e.g. in 'fish sanctuaries') river rehabilitation projects should be undertaken, especially if endangered species or taxa are present and part of the area in invaded by either invasive plants or fishes or both.
65 of invasive species are considered top invasive species for inland aquatic ecosystems	A total of 191 alien species are associated with rivers and inland wetlands, and of these, 65 are considered invasive. These consist of: • 34 plant species (26 listed) • 18 invertebrate species (three listed) • 12 fish species if both alien and translocated species are included. The invasive alien species with likely the most severe impacts on indigenous biota are Carp; Rainbow and Brown Trout; Spotted, Smallmouth and Largemouth Bass; Nile Tilapia; Bluegill Sunfish and Mosquitofish. The invasive translocated species with likely the most severe impacts on indigenous biota through predation and competition are Sharptooth Catfish, Mozambique Tilapia, Banded Tilapia and Smallmouth Yellowfish. • Three amphibian species (two listed). • Four bird species (one listed) The magnitude of impacts of the invasions of these species in rivers and wetlands need to be prioritised and assessed comprehensively. Following more comprehensive surveys, trend analyses should be completed for the next NBA.
Climate change will affect habitat structure and function, causing range shifts in species	• Rivers and wetlands in a natural or near-natural ecological condition serve as refugia for species during times of drought and can therefore offer resilience to many species in the face of climate changes. • Some wetlands may be close to geomorphological thresholds and changes in sediment yield and/or runoff from catchments. Climate change may cause unchannelled valley-bottom wetlands to become incised (Garden 2008). • South Africa will probably experience an increase in temperature, which will likely result in changes of the evapotranspiration and other parts of the hydrological cycle. Rivers and wetlands may change in their hydrological regime, affecting their function and structure. Evidence has shown range shifts in species to high (and cooler) elevations, however species in the aquatic environment may have limited options in range shifts. It is critical that these trends are quantified through long-term monitoring of national sites. • Climate change exacerbates existing pressures on rivers and inland wetlands. Water abstraction is of a major concern, especially in rivers in the western parts of the fynbos biome, as these are typically low during the dry hot summers when water demand is highest. Eighteen peat wetlands have collapsed as a result of excessive water abstraction and droughts. The water level was reduced to below the level it has been for thousands of years, leaving the organic substrate to burn and turn into a source of atmospheric pollution.

Alignment between inland aquatic ecosystems (including rivers, inland wetlands and estuaries) highlighted the importance of transition zones and interdependent support functions	
Wetland transition zones	Inland wetlands in NWM5 have been aligned with the extent of some rivers and all the estuarine ecosystems in this NBA. Areas of transition zones were identified which emphasized the interdependence of function across wetlands.
Collaboration was beneficial to the inland aquatic ecosystems and maximised opportunities	
Maximising opportunities	Collaborative discussion amongst numerous wetland specialists benefitted the NBA 2018. Owing to the creation of the ecosystem classification committees and the creation of an inland aquatics reference committee, a number of meetings allowed fruitful discussion on several topics. This has allowed the report to reflect the consensus of a wide range of specialists in the field of rivers and inland wetlands. For example, a discussion on the *Classification System for Wetlands and other Aquatic Ecosystems in South Africa* allowed for correction of hierarchies and terminology, whereas the practicality of mapping some of the hydrogeomorphic units at desktop level and the shared learning, allowed for the amalgamation of some of the hydrogeomorphic units for the assessment (Appendix A). Cumulative benefits result from collaboration. The majority of the Inland Aquatic Assessment report for the NBA 2018 results from volunteered contributions from river and wetlands specialists. Their tremendous passion and determination to make things work have been inspirational. The shared goal and work ethics are a key component to this NBA.
Capacity at government level to monitor and intervene has collapsed within the past 7 years	
Government has a severe lack of scientific and technical resources for monitoring and intervention programmes	Despite the awareness and momentum built through the NFEPA project to attend to and care for inland aquatic ecosystems (rivers and wetlands), the past seven years has seen a slow and ongoing decline of the number of skilled staff and budget for monitoring and intervention of inland aquatic ecosystems. • The NFEPA project recommended to 'employ aquatic ecologists in provinces, Catchment Management Agencies and municipalities'. • Yet, within the past seven years, Impson (2016) and Chapter 9 of this report, observed a serious shortage in skills at the national and provincial agencies tasked with compliance monitoring, guidance, land use planning and decision making for inland aquatic ecosystems. Of the minimum 62 staff positions recommended by Impson (2016) and the Freshwater Ecosystem Network at provincial level, currently only 22 are filled, totalling 36% of the minimum capacity. These do not include positions required at national departments for influencing policy and decision making at higher levels, where budgets are forged. • Monitoring of water quality was seriously affected by the recession in the second semester of 2018. The DWS's chemical monitoring network and programmes such as the NEMP, for example, ceased operations following insufficient budget, and several other projects had to be put on hold. This was at a time when large numbers of WWTW were non-compliant, a very worrying trend for effective management of our working rivers.

10.3 Key messages

I. **River and inland wetlands ecosystem types represent the diversity inland aquatic ecosystems of South Africa.** The high temporal and spatial variability of rainfall in South Africa results in very variable runoff and flow regimes for rivers, as well as a diverse range of hydroperiods for wetland types. The combination of a broad range of climatic settings, high topographic variability, and variable hydrological regimes make for increased ecosystem-level diversity with high species endemism and limited geographic ranges for a number of taxa. Two layers represent these ecosystem types in the South African Inventory of Inland Aquatic Ecosystems (SAIIAE): (i) the 222 river ecosystem types with 164 018 km of mainstem and tributaries; (ii) the 135 inland wetland ecosystem types mapped in the National Wetland Map version 5 (NWM5). Inland wetlands mapped in NWM5 cover 2.2% of South Africa. Detailed catchment studies have, however, indicated that wetland coverage is far higher in other regions of South Africa. Suggesting that inland wetland ecosystem types are considerably underrepresented in NWM5. Continuous effort is required to improve the representation of inland aquatic ecosystem types in the national inventory.

II. **Water security is essential for human wellbeing and livelihoods. Ecologically healthy aquatic ecosystems supply the quantity and quality of water required for survival**. Over-abstraction of water and water pollution place these ecological infrastructure assets at risk. Freshwater is often a limiting resource for socio-economic development. Strategic Water Source Areas (SWSAs) are landscapes where a relatively large volume of runoff produces water for the majority of South Africa. The National Freshwater Ecosystem Priority Areas (NFEPA) study initially identified high water yield areas and high groundwater recharge areas. Recently, these were refined to 22 areas for surface water (SWSA-sw), covering 10% of the extent of South Africa and supplying 50% of the country's mean annual runoff. In addition, 37 areas for groundwater (SWSA-gw) were identified, accounting for 9% of the land surface of South Africa and up to 42% of the baseflow in the respective areas, sustaining flows in the dry season. Currently, only 13% of the SWSAs' extent falls within protected areas. Catchment-level planning and management is thus critical for ensuring that the ecosystem diversity, functionality and connectivity are maintained.

III. **Inland wetlands remained highly threatened and under-protected**. Nearly 80% of inland wetland ecosystem types are threatened (107 of 135; 61% Critically Endangered, 9% Endangered and 9% Vulnerable), constituting more than 2.3 million ha of > 2.6 million hectares of inland wetlands mapped in NWM5. Approximately 75% of inland wetlands are threatened and under-protected. Only 6% of inland wetlands are considered Well Protected, while 61% are Not Protected. Compared to the NBA 2011, where wetlands were found to be poorly mapped, highly threatened and Poorly Protected, the trends in ecological condition and protection level appear to be declining further. Action ought to be taken to improve inland wetland maps in planning and prioritisation, involve citizens in biodiversity stewardship programmes, improve inland wetland awareness, protection, accountability of all citizens and implement the National Wetland Monitoring Programme.

IV. **River ecosystems are declining in ecological condition. Of the 222 river ecosystem types assessed, 64% were found to be threatened (43% Critically Endangered, 19% Endangered and 2% Vulnerable).** River ecosystem types are also Poorly Protected with only 13% considered Well Protected and 42% Not Protected. The majority of rivers (67% of total river length) is degraded. Moreover, a decline in river condition (11%) has been observed from 1999–2011. Tributaries are generally less heavily impacted than main rivers with 38% of tributary length in natural condition compared to 28% of mainstems. The percentage of threatened river ecosystem types is higher for

lowland and lower foothill rivers (67%) than for the upper foothills and mountain streams (25%), which is a reflection of multiple pressures accumulating from river source to sea. Only 16% of the lower foothills and mountain streams are Well Protected while 61% of lowland rivers are Not Protected. During the NFEPA project 62 free flowing rivers were identified, but the decline in ecological condition resulted in 14 rivers losing this status. Of these 14 rivers, four lost more than half and the remainder lost all of their extent in a natural condition. Cooperative governance linked to integrated water resource management partnerships at catchment scale is required to address the decline in the ecological condition of rivers and to ensure effective river conservation.

V. **Flagship rivers have remained intact over the past seven years, and serve as an excellent example of ecosystem types from source to sea**. In the NFEPA project of 2011, 19 of the free flowing rivers were identified as flagship rivers. Despite the general decline in ecological condition of river ecosystem types, the value of effective conservation planning through the NFEPA project and implementation of these priorities at various scales ensured that the ecological condition of these rivers was maintained. It is crucial that these flagship rivers retain their free-flowing character since they provide important ecosystem service provision to the communities along their shores. The flagship rivers represent some of the few remaining examples of connected river ecosystem types that are intact from source to sea, both in South Africa and globally.

VI. **South Africa has eight unique freshwater lakes (totalling roughly 13 300 ha), all of which are Critically Endangered and under-protected.** South Africa's largest lake, Lake Sibaya (8 400 ha) on the Maputaland Coastal Plain in the KwaZulu-Natal Province, provides freshwater to communities in the vicinity. The remaining freshwater lakes include Baberspan (~1 730 ha), Chrissiesmeer (~1 300 ha), De Hoop (~950 ha), Groenvlei (~360 ha), Tevredenpan (~330 ha), Lake Fundudzi (~200 ha) and Lake Banagher (~185 ha). All eight of the freshwater lakes are considered Critically Endangered since < 20% of the spatial extent of these systems is in a natural or near-natural ecological condition. Five of the freshwater lakes are Not Protected while three are Poorly Protected.

VII. **A total of 658 indigenous freshwater taxa associated with rivers and inland wetlands, from seven taxonomic groups, were assessed for this NBA and freshwater fishes are the most threatened (36% of all taxa and 66% of endemic taxa threatened).** Amphibians, birds, odonata (dragonflies and damselflies, collectively referred to as dragonflies), mammals, freshwater fishes, reptiles and a sample of aquatic plants were assessed. Of these taxa, 160 taxa are endemic and 41% of endemic taxa are threatened with extinction. The Red List Index shows that all freshwater associated taxonomic groups exhibited a gradual decline in threat status over the assessment period, indicating that pressures are continuously impacting species in aquatic ecosystems. While freshwater fishes had the highest threat levels, freshwater mammals had the steepest decline. Based on a meta-analysis of species Red List assessments, the major pressures causing decline were invasive alien species, habitat loss and degradation due to pollution, urban expansion, poor dam and water management activities and agricultural activities. Despite multiple threats to freshwater fishes, including pollution, invasive species and over-abstraction of water no freshwater fish taxa have yet gone extinct, largely owing to active management interventions by conservation agencies. The high levels of endemism of this group (49%), and the fact that harvesting of freshwater fishes is an important food source and recreational activity for many South Africans, means that urgent interventions are required. Multiple and integrated mechanisms are essential for curbing the pressures on freshwater fishes. Successful invasive fish eradication methods trialled by CapeNature during this past assessment period need to be expanded and rolled out nationally.

VIII. **The first protection level assessment for species found that the majority of freshwater associated taxa, with the exception of freshwater fishes, are Well Protected: 100% of reptiles, 83% of birds, 65% of mammals and 74% of amphibians.** Only 18% of freshwater fish taxa are Well Protected, which can be attributed to their sole dependence on rivers and the fact that only 14% of South African river lengths occur within the protected area network. Moreover, only 43% of these rivers are in a natural or near-natural condition. Pressures not mitigated through the protected area network have resulted in 20 freshwater fish taxa (21%) and 8 amphibian taxa (8%) dropping down a category of protection. Twenty-seven Taxa of Conservation Concern were assessed as Not Protected and these should be prioritised. There is an urgent need to increase the representation of inland aquatic systems within the protected area network, prioritising rivers and inland wetlands inhabited by under-protected species. Furthermore, there is a need to bolster management interventions that mitigate threats to freshwater Taxa of Conservation Concern within protected areas.

IX. **Genetic diversity brings new value to the inland aquatic ecosystem types.** Genetic diversity is a key component of biodiversity as it represents a species' evolutionary potential to evolve and adapt within an ever-changing environment. Many species are equipped with sufficient evolutionary resilience, or genetic diversity, to overcome rapid environmental change; however, others are not, as is evident by the rapid loss of biodiversity reported globally. Risks to genetic diversity include genetic erosion through habitat fragmentation, reduced population sizes and connectivity, hybridization and inbreeding, unsustainable use, the disruption of co-adapted gene complexes and disease transmission through translocations. Monitoring changes in genetic diversity would allow for refined species assessments and the improved ability to understand and rapidly respond to population declines and the spread of invasive species, especially within an aquatic environment. New indicators to track and monitor the status of genetic diversity are being developed and can assist to identify areas critical to the maintenance of genetic diversity over the landscape for target species at risk. Safeguarding and maintaining genetic diversity is an explicit target in the Convention on Biological Diversity (CBD), and the incorporation of genetic indicators in this NBA is a first step to address South Africa's present and future commitments to the CBD.

X. Moving forward, **monitoring is critical to inform baseline information, decision making and improved governance of ecosystems, species and pressures.** For the past 15 years South Africa has made significant advances in the spatial representation and assessment of ecosystem types and species. Yet, our advanced monitoring of the flow, water quality and structure of river ecosystems have been severely curbed (35% of surface water and 7% of groundwater monitoring points were sampled in 2018) as a result of budget cuts and lack of enough skilled personnel at conservation agencies. Sufficient funding and skilled personnel should be prioritised over the next seven years to address this gap. Strategic monitoring of ecosystems, species and pressures will address uncertainties in effectiveness of protection, restoration, intervention and climate change impacts on rivers and inland wetlands.

XI. **Integrative and collaborative monitoring and management will optimise the protection of rivers and inland wetlands.** Rivers and inland wetlands are interconnected systems but small features in the larger landscape of South Africa. Owing to their varying attributes, ranging from water quantity, quality and ecological attributes, a wide range of expertise is required for monitoring and management of the ecosystems, species and pressures. Consequently, expertise is required over a wide range of organisations. Proper monitoring and effective management would therefore require an integrative and collaborative approach between a multitude of organisations at national to local

level for protecting our scarce resources. Although the key conservation agencies and national departments, such as the Department of Water and Sanitation (DWS) and Department of Environment, Forestry and Fisheries (DEFF), have critical roles to play, the value of citizens in monitoring and behaviour change should not be ignored.

10.4 Knowledge gaps and priority actions

Following the assessment of rivers and inland wetlands in this NBA 2018, we have identified the top five priorities for the next decade based on key knowledge gaps (Table 10.2). These related to the lack of sufficient baseline information for informed and improved decision making, stricter management of scarce water resources, better representation of ecosystem types, improved representation of ToCC and aquatic invertebrates and the update of protected areas and the National Conservation Plan with findings from this assessment. Regardless of the contribution and momentum built up through the national assessment and planning for rivers and inland wetlands over the past decade in South Africa, little progress has been made in general, on any of the priorities identified in the last NBA 2011 and NFEPA. In fact, evidence show a collapse in the number of skilled personnel and budget allocated for the monitoring and protection of rivers and inland wetlands, and a decline in the ecological condition of these systems. It is therefore critical that these declining trends be immediately curbed and addressed, particularly in the light of the global concerns for inland aquatic ecosystems (Finlayson *et al.* 2005; Díaz *et al.* 2019).

Monitoring informs multiple levels of decision making

Baseline data on river and inland wetland ecosystem types, freshwater species and their resilience as well as pressures is critical in the next seven years for improved decision making. Funding should be secured for the persistent monitoring of water quality, river ecosystems and the implementation of the National Wetland Monitoring Programme. It is essential that skilled personnel be appointed for monitoring and reporting. In particular the uncertainty in ecosystem representation, the relationship between habitat and species and species vulnerable to pressures and climate change should be prioritised. This would be critical for improved decision making, but particularly in developing climate change adaptation strategies which will build resilience and improve well-being.

Table 10.2. Summary analysis of knowledge gaps for the inland aquatic realm, which causes limitations to the NBA, as well as priority actions for solutions

Knowledge gap	Priority Action
National monitoring data for river and inland wetlands are incomplete and are insufficient to show trends in ecological condition and physio-checmical state. The River EcoStatus Monitoring Programme (the former River Health Programme) is in danger of failure. The National Wetland Monitoring Programme remains to be implemented.	Dedicated funding for regular **monitoring** will strengthen ability to assess ecosystem status and determine trends. The monitoring programmes should aim at a better representation of ecosystem types across the country (spatial aspect), as well as their representation over the diversity of hydrological regimes (temporal aspect).
Water use statistics are estimated which limites our ability to make informed decisions.	Water is a limiting factor for rivers and inland wetlands. South Africa as a semi-arid to arid country needs to manage water stricter as a scarce resource. **Ensure water availability for river and inland wetland ecosystem types**. South Africa has shown success here in targeting resource management within the Strategic Water Source Areas. Additional water saving mechanisms and water pricing are critical mechanisms to secure water across board.
Representation of river and inland wetland extent and ecosystem types show spatial inaccuracies and inland wetlands are particularly underrepresented in the National Wetland Maps. In particular, inland aquatic ecosystems in arid regions needs better indicators for defining and identifying and characterising these systems.	Invest in **improved representation and verification of these systems** through a combination of citizen science, expert mapping, integration in GIS and remote sensing methods. In particular, river ecosystem types need to be refined to include riparian vegetation because these not represented and could potentially be highly threatened. Develop indices for the identification of inland aquatic ecosystems in arid regions.
Freshwater fish and aquatic plants show declining trends according to the Red List Index assessments. Insufficient representation of aquatic invertebrates hampers understanding of the impact of changing ecological condition on aquatic species. Most of the groups on the RLI currently (birds, amphibians, mammals and dragonflies) are able to disperse and potentially escape pressures; and therefore, the RLI result are likely to underestimate overall threat levels and rates of decline in the inland aquatic realm.	**Additional inland aquatic invertebrate groups must be assessed** and monitored for inclusion in the next NBA, with a specific focus on endemic groups. A comprehensive database of macro invertebrates to support assessments and planning should be prioritised and budget allocated to its ongoing maintenance. Important fish areas should be included in provincial biodiversity plans. The successful interventions of Cape Nature to curb invasive fish should be rolled out to other parts of the country.
The National Freshwater Ecosystem Priority Areas (NFEPA) product nears a decade and requires an update, particularly following the assessment of freshwater species assesssed in this report, the critical state of freshwater fish and the need for updated Important Fish Areas, as well as the update done for the inland wetland ecosystem types.	**Update the Important Fish Areas and wetland FEPAs in NFEPA II** to inform planning within the next decade, while more accurate baseline information is collected in the next decade for improved decision making and planning.
The impact of climate change on inland aquatic ecosystems and freshwater species is largely unknown.	**Fund research to provide evidence of the impact of climate change** on inland aquatic ecosystems and freshwater species, to enable better planning for shifts in ranges and extinctions. Priority areas which could serve as refugea during drought or long-term ecosystem base adaptation should be developed and incorporated in conservation plans.

Implement water saving mechanisms, integrated water management and water use monitoring

Water is a limiting factor for rivers and inland wetlands. The impact of droughts and failed water infrastructure on both ecosystems and human well-being became evident in the past five years with the lack of sufficient water supply in most cities and the increasing number of peat wetlands which had started to burn or have become desiccated (17 to date). These events have emphasized that South Africa needs to implements more drastic water saving mechanisms, and better management of existing systems. Several interventions should be considered, for example:

- water use in the agricultural sector, the industry which use the most of our water budget, should avoid pivot irrigation and prioritise drip irrigation;

- water pricing should reflect the scarcity of the resource;
- implement improved land use management within our Strategic Water Source Areas;
- awareness campaigns to promote water-saving techniques, focus on the development of water efficient technology, and provide incentives for water storage and grey-water use on site;
- water-wise technology and innovations should be promoted and rewarded (certification), and water-wise products should carry unique labels for consumers to identify;
- campaigns to encourage water-wise behaviour, such as 'Every drop counts' campaign, Adopt a River campaign, 'Friends of the ….' groups and citizen science;
- awareness of the benefits if infiltration and recharging our aquifers as opposed to surface storage which are at risk of evapotransporation and eutrophication;
- improved and wide-spread monitoring of our groundwater, as it sustains baseflow of a number of rivers and inland wetlands, particularly in the dry season and during times of drought.

Improve ecosystem representation

Several priorities have already been identified in the South African Inventory of Inland Aquatic Ecosystems (SAIIAE) or inventory report (Van Deventer *et al.* 2018), particularly relating to the improvement of base datasets for the Inventory of the river and inland wetland ecosystem types. For the inland wetlands this requires, as a minimum, the following base datasets:

- A National Wetland Map that is of medium confidence representing at least 70% of all wetland extent and types (to Level 4A of the *Classification System for Wetlands and other Aquatic Ecosystems in South Africa*);
- Level 2 classification which has been derived from quantitative data;
- A health assessment of the wetlands;
- A functional assessment of the wetlands;

Given sufficient funding, **NWM can be improved to a higher confidence level before the NBA 2024**. We extrapolate this conclusion from current knowledge and experience. The South African Inventory of Inland Aquatic Ecosystems (SAIIAE; Van Deventer *et al.* 2018) aims to map a large percentage of inland wetlands in NWM5, using the principle of the maximum extent over the full range of wetland types. To date, NWM5 has mapped on average nearly 3% of the surface area of each district in South Africa as inland wetlands through desktop mapping. The latter excludes the representation of rivers and estuarine systems. In some of the districts, a maximum of 11% of their surface area constitute inland wetlands (City of Johannesburg and Ekurhuleni), mapped at a desktop level. In two other catchments of South Africa, mapped at a senary (6th) level of catchment division, inland wetlands constitute more than 15% (Hogsback) and 42% (Tevredenpan) of the surface area of the catchment, following in-field verification by wetland specialists (Van Deventer *et al.* 2017). The latter represents possible maximum values inland wetland extent that could be attained in the country. If extrapolating from these examples, it can be assumed that an average of 6% of the extent of any district, in a conservative approach, and 6% of the extent of South Africa, could be inland wetlands. Mapping and typing inland wetlands across districts to attain the target of 6% of South Africa in NWM6 would be considered a goal in reaching better representation and a NWM with a medium confidence level (Van Deventer *et al.* 2018). Such a level of confidence in the NWM6 would greatly benefit the NBA 2024 and provide a higher confidence in future assessments as well as planning outputs, such as a National Freshwater Ecosystem Priority Areas II.

To fast-track the attainment of 6% extent of South Africa and a medium-confidence level in NWM6, the following steps could be undertaken:

- Erase NWM5 from the *wetland probability map* (generated in Collins 2018);
- Merge NWM5 and the *wetland probability map*;
- Reshape and type the hydrogeomorphic (HGM) unit of the sections of the *wetland probability map* while confirming the extent and HGM unit of the polygons which originated from the NWM5.

It is estimated that 500 000 ha of inland wetlands from the *wetland probability map* (generated by Collins 2018) can be corrected and typed per month by a single person and integrated into NWM6 (estimates based on work done in the West Rand, Gert Sibande and Nkangala districts). In NWM5, at least 24 districts are considered to be at low confidence level (85 509 727 ha), 22 districts at a low-to-medium confidence level (27 903 898 ha) and six districts to be largely at a medium confidence level (8 667 635 ha). This means that a total of 122 081 260 ha of South Africa should be quality checked and improved by wetland specialists in the next five years. To achieve this target, at least four specialists needs to work at a rate of 500 000 ha per month over a period of five years to reach the target of 6% extent-representation of South Africa at a medium confidence level in NWM6. Desktop digitising, reshaping and HGM unit typing of polygons is however extremely exhausting, therefore, to curb exhaustion and the risk of increasing error as a result of it, more than four dedicated wetland specialists should be tasked with the improvement. Alternatives to desktop digitising are investigated by Dr Collins (FS DESTEA) for modelling wetland extent and HGM units, to minimise such labour. Following the improvements suggested for NWM6, further improvements to a medium-to-high confidence level could be considered, where representation reaches beyond 6% of the surface area of a region. Such targets require prioritisation of areas and in-field verification over a longer period of time to attain.

Improve species representation

The 26 freshwater species found to be Critically Endangered and Poorly Protected in this report, should also be prioritised for improved understanding of habitat requirements and resilience to current and future pressures. The improved representation of aquatic invertebrates which habituates in rivers and inland wetlands are critical for the next NBA. Similar to fish and wetland-dependent amphibians, aquatic invertebrates are likely to be more range-restricted and vulnerable to multiple pressures which cumulate in aquatic systems. Other species to consider include:

- thermal refuges for cold-adapted stenotherms and gondwanan species;
- montane assemblages are especially vulnerable to extinctions due to their isolated locations; and
- ToCCs identified in Chapter 7, endemic, Critically Endangered and unprotected, those in the Cape Floristic Region (CFR), those that are range-restricted and on the limit of their ranges; particularly the freshwater fish and amphibians.

Species listed in the climate change chapter that should be considered for Red List assessments are:

- The Natal Cascade frog (*Hadromophryne natalensis*);
- The Critically Endangered Riverine Rabbit (*Bunolagus monticularis*);
- The endemic Cape Clawless Otter (*Aonyx capensis*) and the indigenous Spotted Necked Otter (*Lutra macullicollis*); and
- Freshwater bird species such as the Blue Crane (*Anthropoides paradiseus*).

Extend protection and update NFEPA and associated Important Fish Areas

The protection of a representative sample and processes of river and inland wetland ecosystem types and their associated species are critical. Above all, freshwater fish and aquatic invertebrates are range-restricted and threatened by a multitude of pressures, it is critical that the Important Fish Areas (formerly known as the NFEPA fish sanctuaries) be revisited and updated. There is also value in updating the inland wetland FEPA's, following the update of the NWM5 which improved the extent and typing of these ecosystems and reduced error. These updates will facilitate improved management of these critically threatened systems and species within the next decade, while better baseline information is collected. The newly identified ToCC species from this report, as well as those identified to be susceptible to impacts of climate change, should now be prioritised in NFEPA II, and consideration should be given, where possible, to include climate refugia, future biodiversity hotspots, areas where a high level of ecosystem services are offered and areas which could support the Global Deal for Nature (Dinerstein *et al.* 2019).

Strategies for the prioritisation of ecosystem types which had a shortfall to the biodiversity target should be targeted for restoration, the Protected Areas Expansion Strategy of the DEFF or Ramsar listing. Further work is required to identify confidence in this assessment, shortlist priority areas and appropriate routes of restoration and prioritisation, ideally through an expert-based workshop. It is key that **the available mechanisms for protection, such as Ramsar and Protected Environments, be utilised now,** while the collection of baseline data through monitoring be harnessed in the next decade.

Research gaps

In addition to the knowledge gaps listed above, several research gaps have also been identified:

- Update and refine flow categories for river ecosystem types;
- Criteria for the identification and characterisation of inland aquatic ecosystems in arid regions;
- Collating data for the distribution of macro-invertebrate data of rivers and inland wetlands and determine their sensitivity and resilience to multiple pressures;
- Improve understanding of ecosystem types in relation to freshwater species;
- Test criteria for categorising ecological condition of rivers and inland wetlands;
- The impact of climate change on inland aquatic ecosystems and freshwater species; and
- Localities of key ecosystem services of inland aquatic ecosystems.

10.5 Limitations of this assessment

- The results of the Ecosystem Threat Status (ETS) and Ecosystem Protection Level (EPPL) results were dependent on available data and methods at the time of the assessment. In particular, the National Wetland Map version 5 is (NWM5) still considered an underrepresentation of inland wetlands, and consequently, it is difficult to get an accurate sense of the ETS and EPL for inland wetlands;
- No reference data was available on the ecological health of inland wetlands, and hence, the accuracy of the modelled ecological condition could not assessed; and
- Inland aquatic ecosystems in the arid regions are poorly understood. The rivers have indicated these as 'Data Deficient' and have not assessed these. For inland wetlands, these systems have been included as one of the four hydrogeomorphic (HGM) units assessed in the NBA 2018, yet, the criteria by which they are identified is very different from those HGM units in the wetter parts of

the country. It is therefore critical that unique identifiers should be developed to identify and characterise rivers and inland wetlands in the arid regions, and variables put in place to monitor their ecological condition, particularly in the case of rivers.

Despite these limitations, the report has been compiled with a strong expertise base from South Africa. In addition, the assessment of inland aquatic ecosystems in South Africa is in an advanced state, compared to inventories and assessments of inland aquatic ecosystems globally.

10.6 References

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APPENDIX A: LIST OF MEETINGS HELD FOR THE DEVELOPMENT OF THIS REPORT

The following meetings were held for the development of this technical report. Meeting reports are available on request.

Meeting date	Venue	Nature of meeting	Participants	Key decisions
27 July 2015	SANBI Pretoria	Wetland Ecosystem Classification Committee (WECC)	Andrew Skowno (SANBI), Boyd Escott (DEA), Bonani Madikizela (WRC), Denise Schael (NMU), Dirk Roux (SANParks), Elija Mogakabe, Farai Tererai (DEA), Genevieve Pence (CapeNature) Hannes Marais (MTPA), Heidi van Deventer (CSIR), Hermien Roux (UNIVEN), John Dini (WRC), Kate Snaddon(FCG), Kennedy Nemutamvuni (SANBI), Mervyn Lötter (MTPA), Mike Silberbauer (DWS), Nacelle Collins (FS DESTEA), Namhla Mbona (SANBI), Nancy Job (SANBI), Naomi Fourie (DWS), Nick Rivers-Moore (Private Consultant), Nicolene Fourie (DEA), Peter Ramollo (Northern Cape government).	• Inaugural meeting of WECC. • Need for guidelines and standards were highlighted, as well as registration as data custodian under SASDI Act 54 of 2003.
28 January 2016	CSIR VCs: Pretoria, Stellenbosch	WECC	Namhla Mbona (SANBI), Nancy Job (SANBI), Heidi van Deventer (CSIR), Nacelle Collins (FS DESTEA), Mervyn Lötter (MTPA), Nicolene Fourie (DEA), John Dini (WRC), Hannes Marais (MTPA), Nick Rivers-Moore (Private Consultant), Mike Silberbauer (DWS), Andrew Skowno (SANBI), Kate Snaddon (FCG), Skhumbuzo Kubheka (EKZNW).	• TOR of WECC; frq of meetings. • Availability of EIA data. • Preliminary results of the data audit. • Priorities for NWM5. • Dr Collins presented watercourse probability map. • Errors in threat status of wetlands in NBA 2011 resulted from assessment done at L4A.
23 May 2016	SANBI Cape Town	River Ecosystem Classification Committee (RECC)	Mike Silberbauer (DWS), Dean Impson (CapeNature), Mmaphefo Thwala (standing in for Lebogang Matlala, DWS), Michael Grenfell (UWC), Jeanne Nel (CSIR), Chantel Petersen (CSIR), Ashton Maherry (CSIR), Heidi van Deventer (CSIR), Lindie Smith-Adao (CSIR), Namhla Mbona (SANBI), Helen Dallas (FRC), Karl Reinecke (Southern Waters), Andrew Gordon (DWS) and Andrew Skowno (SANBI). Or	• Inaugural meeting of RECC. • Agreement to use the 1:500 000 rivers data used for the NBA 2011. • Keep river ecosystem type categories as is • Use Present Ecological State/Ecological Importance/Ecological Sensitivity (PES/EI/ES) data (DWS, 2014) to update the river condition data for NBA 2018.

			3 DWS staff members, 1 CapeNature staff member, 1 UWC staff member, 5 CSIR staff members, 2 expert consultants and 2 SANBI staff members. Representing 14 participants from 7 organisations.	
12 August 2016	SANBI VC Pretoria, Cape Town	National Ecosystem Classification Committee (NECC)	NECC members from SANBI and CSIR.	• Inaugural meeting, TOR. • Coastal ecosystems introduced. • Connectedness between aquatic ecosystems. • Mapping of islands.
27 October 2016	NWI2016	Inland Aquatic reference committee	1 CSIR, 1 SANBI, 4 Inland aquatic reference committee members, 6 interns, 1 collaborator (ICLEI) and Douglas McFarlane (Eco-Pulse Environmental Consulting Services).	• Accuracy assessment discussion. Should be taken up in future meetings. • see CSIR report no. CSIR/NRE/ECOS/IR/2016/0161/A. • Alignment with WRC prj of Dean Ollis on condition*.
26 January 2017	CSIR VCs: Pretoria, Durban, Cape Town	WECC	Namhla Mbona (SANBI), Heidi van Deventer (CSIR), Nacelle Collins (FS DESTEA), Mervyn Lötter (MTPA), John Dini (WRC), Hannes Marais (MTPA), Mike Silberbauer (DWS), Tebogo Kgongwana (SANBI), Andrew Skowno (SANBI), Kate Snaddon (FCG), Nancy Job (SANBI), Nick Rivers-Moore (UKZN), Skhumbuzo Kubheka, Erwin Sieben (UKZN).	• NBA 2018 progress on the Freshwater Component.

19 May 2017	CSIR VCs: Pretoria, Stellenbosch	RECC	Andrew Gordon (DWS), Chantel Petersen (CSIR), Christa Thirion (DWS), Heidi van Deventer (CSIR), Helen Dallas (FRC), Lindie Smith-Adao (CSIR), Michael Grenfell (UWC), Mike Silberbauer (DWS), Namhla Mbona (SANBI), Nick Rivers-Moore (Private Consultant, presented in absentia) and Patsy Scherman (Scherman Environmental)
			Or
			3 DWS staff members, 1 UWC staff member, 3 CSIR staff members, 3 expert consultants and 1 SANBI staff member. Representing 11 participants from 7 organisations.
				• Nomination of 2 RECC members for Inland Aquatic reference committee;
				• Update of the PES data for the NBA 2018;
				• Fish species atlas;
				• Nick Rivers-Moore's presentation on WRC prj modelling in-stream flow requirements;
				• Keep all detailed condition categories and do not lump;
				• Addition of 22 rivers approved;
				• Agreement that a change analysis can be done, not trends; and
				• Priorities after NBA 2018:
				  ○ Revisit the river flow categories.
				  ○ Macroinvertebrates.
				  ○ Riparian vegetation mapping on a national scale.

				○ Sub-quaternary catchments and altitude zones (NFEPA) ACTION: LS discuss with Jeanne Nel as to the motivation for getting this done. ○ If new data is generated then it should be used. ○ PES (habitat template) is the totality and features characteristics of a river and its riparian areas that can support an appropriate natural fauna and flora. Not a biodiversity assessment but an indication of the ecological condition of the resource. ○ Need biodiversity indices that speak directly to biodiversity (of which macroinvertebrates would be one, and fish, riparian vegetation, diatoms, etc.) (DEA mandate). ○
27 September 2017	SANBI Pretoria and Cape Town	NECC	NECC members from SANBI and CSIR.	• Update and integration efforts. • Vegetation map. • Coastal ecosystems. • Ecosystem map.
2–4 October 2017	SANBI Kirstenbosch	Inland Aquatic reference committee	3 SANBI, 3 CSIR, 1 WCS, 8 reference committee members (complete).	• Inventory: ○ Hydrological features which are not rivers or wetlands should be kept in the inventory geodatabase as a separate feature class and may include for example streams from the *wetland probability map* as well as washes. ○ Correction on terminology was done to align with the *Classification System for Wetlands and other Aquatic Ecosystems in South Africa*. ○ Eight unique freshwater lakes (limnetic wetlands) were identified; set target as 100% for threat status. ○ Agreement that the NWA definition of

				wetlands should be used. ○ Add information on groundwater dependent ecosystems. ○ EIA polygons are considered less suitable compared to large, catchment funded projects for mapping wetlands and updating the NWMs. ○ Citizen science may contribute, however inconsistent collection and verification not ideal. • Landforms was previously used to inform modelling of wetland types and not required when HGM wetland types have been captured at desktop-level.
24 November 2017	CSIR VCs: Pretoria, Durban, Cape Town	Inland Aquatic reference committee	3 SANBI, 3 CSIR, 1 WCS, 8 refcom members (full representation).	• Assessment: only Levels 2 and 4A should be used for assessing biodiversity pattern. • The improvements of L2 is essential using the NWVD. • A target threshold of 20% will be retained for assessing ETS until further research has been done on species responses and other outcomes which would inform other target thresholds for wetlands. • Grouping of HGM wetland types: 4 to 3 groups can be considered, but first present the results of the assessment, before the refcom will decide. • Landforms: ○ Landforms in the *Classification System for Wetlands and other Aquatic Ecosystems in South Africa* are to guide classification and doesn't reflect biodiversity of wetland ecosystem types ○ Landforms automated at desktop level is not essential for now, since NWM5 was typed at desktop level to L3 and 4A
23 January 2018	CSIR VCs: Pretoria, Durban, Cape Town	WECC	Namhla Mbona (SANBI), Heidi van Deventer (CSIR), Nacelle Collins (FS DESTEA), Mervyn Lötter (MTPA), Hannes Marais (MTPA), Mike Silberbauer (DWS), Millicent Dinala (SANBI), Happy Khumalo, Andrew	• National Wetland Map 5 progress. • SAIIAE. • Layout of NBA 2018 Assessment report. • Future planning for the SAIIAE and NWM.

			Skowno (SANBI), Kate Snaddon (FCG), Nancy Job (SANBI), Elijah Mogakabe (DWS), Skhumbuzo Kubheka (EKZNW), Erwin Sieben (UKZN).	• Wetland modelling inclusion.
23 May 2018	CSIR VCs: Pretoria, Stellenbosch	RECC	Andrew Skowno (SANBI), Chantel Petersen (CSIR), Dean Impson (CapeNature), David le Maitre (CSIR), Heidi van Deventer (CSIR), Helen Dallas (FRC), Michael Grenfell (UWC Mike Silberbauer (DWS), Namhla Mbona (SANBI), Nancy Job (SANBI) and Patsy Scherman (Scherman Environmental) Or 1 DWS staff member, 1 UWC staff member, 3 CSIR staff members, 1 CapeNature staff member, 2 expert consultants and 3 SANBI staff members. Representing 11 participants from 7 organisations.	• Agreement not to update the NFEPA rivers GIS layer with additional 1:50 000 rivers associated with estuaries. • Do not include rivers which have no PES scores, since modelling has a number of complications. • Most of the rivers are episodic / ephemeral and should be left as "Data Deficient". Not necessary to model the condition of the PES scores for the DD systems. Don't assess, display as DD on the final map. • Erosion can be natural and not induced and the current maps cannot distinguish between these, therefore do not use it to model river condition. • Do not use invasive species (e.g. *Prosopis*) to model river condition, experts are needed. • Intersect the rivers with the dam layer and type the section of a river within any of the large 92 dams as artificial and PES = F.
28 May 2018	SANBI Kirstenbosch	Inland Aquatic reference committee and authors workshop	Team members, reference committee members and co-authors to the Assessment Report. Please refer to the attendance register for more information.	• Wetland flats in most of the provinces would be depressions, since they may receive surface contribution from adjacent seep wetlands. These are not purely groundwater driven systems. Wetland flats from the C.A.P.E. project was also desktop-typed and have a low confidence. These should however be kept as wetland flats in the NWM5.
11 June 2019	CSIR VCs: Pretoria, Stellenbosch and Cape Town	Reference committee final meeting	Nacelle Collins (FS DESTEA), Althea Grundling (ARC–SCW), Piet-Louis Grundling (DEA), Farai Tererai (DEA), Heidi van Deventer (CSIR), Lindie Smith-Adao (CSIR), Chantel Petersen (CSIR), Michael Grenfell (UWC), Dean Impson (CapeNature), Dirk Roux (external reviewer, SANParks), Nancy Job (SANBI), Dean Ollis (FCG), Kate Snaddon (FRC/FCG).	The reference committee of the inland aquatic ecosystems signed off on the final report. Minor suggestions were listed and completed in follow up. A few suggestions were also made for future NBA updates.

* WRC project K5/2549, Project lead Mr D Ollis; 'Developing a refined suite of tools for assessing the Present Ecological State of wetland ecosystems.'

APPENDIX B: LIST OF FRESHWATER FAUNA IN SOUTH AFRICA

List compiled by (alphabetical order) Hamer, M., Khoza, T., Raimondo, D. & Van der Colff, D. (South African National Biodiversity Institute /SANBI). Text in bold indicates the faunal taxa assessed in this report Chapter 7.

Phylum	Class	Order	Common name	Estimated SA number	Number of SA species associated with Freshwater	Reference for association with freshwater
Annelida	Polychaeta	Echiuroidea, Amphinomida, Eunicida, Phyllodocida, Polycladida, Sabellida, Spionida, Terebellida, Scolecida	Fanworms, bristleworms	760	7	Day & De Moor 2002a
Annelida	Clitellata		Leeches	50	50	Day & De Moor 2002a
Annelida	Clitellata	Haplotaxida	Earthworms, freshwater worms	310	10	Nxele *et al.* 2015
Arthropoda	Arachnida	Araneae	Spiders	2088	20	Day & De Moor 2002a
Arthropoda	Arachnida	Astigmata, Mesostigmata = 304, Prostigmata, Oribatida, Sarcoptiformes = 106	Mites	3075	100	Day & De Moor 2002a
Arthropoda	Branchiopoda	Anostraca	Fairy shrimp	35	35	Day 2015
Arthropoda	Branchiopoda	Conchostraca	Clam shrimp	12	12	Day 2015
Arthropoda	Branchiopoda	Cladocera	Water fleas	55	50	Day 2015
Arthropoda	Branchiopoda	Notostraca	Tadpole shrimp	1	1	Vanschoenwinkel *et al.* 2012
Arthropoda	Maxillopoda	Harpacticoida, Calanoida	Copepods	unknown	38	Day *et al.* 2001a
Arthropoda	Ostracoda	Podocopida	Seed shrimp	165	121	Day *et al.* 2001a
Arthropoda	Chilopoda	Geophilomorpha, Scolopendromorpha, Lithobiomorpha	Centipedes	141	1	http://chilobase.bio.unipd.it|http://www.catalogueoflife.org/
Arthropoda	Entognatha	Collembola	Spring tails	124	10	Janion-Scheepers 2015
Arthropoda	Insecta	Coleoptera	Beetles	17 427	480	Stals & De Moor 2007
Arthropoda	Insecta	Diptera	Flies	5 883	800	Day *et al.* 2003
Arthropoda	Insecta	Ephemeroptera	Mayflies	400	400	De Moor & Day 2003
Arthropoda	Insecta	Hemiptera	Bugs	4 829	100	De Moor *et al.* 2003
Arthropoda	Insecta	Hymenoptera	Ants	721	1 (feeds on spring tails)	http://antwiki.org/wiki/Strumigenys_rakkota
Arthropoda	Insecta	Lepidoptera	Butterflies and moths	6783	800 (moths)	De Moor *et al.* 2003
Arthropoda	Insecta	Megaloptera	Alderflies	7	7	De Moor *et al.* 2003
Arthropoda	Insecta	Neuroptera	Lacewings	350	390	De Moor *et al.* 2003
Arthropoda	Insecta	Odonata	**Damselflies and dragonflies**	162	162	Samways &Simaika 2016; Tarboton 2015
Arthropoda	Insecta	Plecoptera	Stone flies	39	39	De Moor & Day 2003
Arthropoda	Insecta	Tricoptera	Caddisflies	222	222	De Moor *et al.* 2003
Arthropoda	Malacostraca	Amphipoda	Beach hoppers, scuds and well shrimps	454	37	Day *et al.* 2001b

Arthropoda	Malacostraca	Bathynellacea		5	3	Day *et al.* 2001b
Arthropoda	Malacostraca	Decapoda	Crabs, crayfish, lobster, shrimp	750	24	Day *et al.* 2001b
Arthropoda	Malacostraca	Isopoda	Pill bugs, woodlice	290	13	Day *et al.* 2001b
Arthropoda	Malacostraca	Speleogriphacea		1	1	Day *et al.* 2001b
Arthropoda	Malacostraca	Tanaidacea		19	5	Day *et al.* 2001b
Bryozoa	Stenolaemata	Cyclostomatida, Cheilostomatida	Moss animals	288	Unknown	Day & De Moor 2002a
Chordata	Amphibia	Anura	**Frogs**	137	102*	Du Preeze & Carruthers, 2015
Chordata	Aves	Cuculiformes, Coraciiformes, Trogoniformes, Upupiformes, Bucerotiformes, Piciformes, Turniciformes, Anseriformes, Struthioniformes, Galliformes, Ciconiiformes, Falconiformes, Charadriiformes, Gruiformes, Strigiformes, Musophagiformes	**Birds**	846	175	Bronner 2015
Chordata	Mammalia	Primates, Rodentia, Sirenia, Proboscidea, Hyracoidea, Tubulidentata, Macroscelidea, Afrosoricida, Lagomorpha, Carnivora, Chiroptera, Eulipotyphla	**Mammals**	343	20	Bronner 2015
Chordata	Reptilia	***	**Reptiles**	407	15	Alexander 2015
Chordata	Actinopterygii, Cephalochordata, Elasmobranchii, Holocephali, Myxini, Sarcopterygii		**Ray-finned fishes**	2 200	174**	Skelton 2015
Gastrotricha			Gastrotrichs	3	Unknown	Day & De Moor 2002a
Cnidaria	Scyphozoa	Rhizostomeae, Coronatae, Semaeostomeae	Jelly fish	25	2	Day & De Moor 2002a
Cnidaria	Hydrozoa	Hydrida	Hydras	457	2	Day & De Moor 2002a
Mollusca	Bivalvia	Mytilida, Pectinida, Lucinida, Cardiida, Arcida	Bivalves	650	10	Appleton & Miranda 2015
Mollusca	Gastropoda	Eupulmonata, Sorbeoconcha, Neritopsina, Architaenioglossa	Gastropods	2262	23	Appleton& Miranda 2015
Myxozoa				6	Unknown	https://en.wikipedia.org/wiki/Myxozoa
Nematoda	Adenophorea, Secernentea	Tylenchida, Triplonchida, Dorylaimida, Aphelenchida	Round worms	1055	286	Day & De Moor 2002a
Nemertea	Nemertea	Anopla	Ribbon worms	17	2	Day & De Moor 2002a
Nematomorpha	Not assigned	Gordioidea	Horsehair worms	unknown	1	Day & De Moor 2002a

Platyhelminthes	Turbellaria	Lecithoepitheliata, Neorhabdocoela, Polycladida, Terricola, Tricladida	Flat worms	42	13	Day & De Moor 2002a
Porifera	Demospongia, Calcarea, Demospongia, Hexactinella	Astrophorida, Chondrosida, Clathrinida, Dendroceratida	Sponges	346	11	Day & De Moor 2002a
Rotifera			Rotifers / wheel animals	34	34	Day & De Moor 2002a
Tardigrada	Heterotardigrada, Eutardigrada	Echiniscoidea, Parachela	Water bears	38	37	Day & De Moor 2002a

** Amphibians include subspecies and newly described species in 2017*
*** Includes all freshwater species, not only primary freshwater species*
**** Anthoathecata, Trachymedusae, Actiniaria, Albuliformes, Alcyonacea, Anguilliformes, Anthoathecata, Arbacioida, Aspidodiadematoida, Ateleopodiformes, Atheriniformes, Aulopiformes, Batrachoidiformes, Beloniformes, Brisingida, Camarodonta, Carcharhiniformes, Cassiduloida, Cetomimiformes, Cidaroida, Clupeiformes, Clypeasteroida, Coelacanthiformes, Comatulida, Coronatae, Diadematoida, Echinolampadoida, Echinoneoida, Eurylida, Forcipulatida, Gadiformes, Gobiesociformes, Hexanchiformes, Holasteroida, Lamniformes, Leptothecata, Limnomedusae, Lophiiformes, Mugiliformes, Myctophiformes, Myxiniformes, Nacromeduae, Notacanthiformes, Notomyotida, Ophidiiformes, Ophiurida, Orectolobiformes, Osmeriformes, Paxillosida, Pedinoida, Pennatulacea, Perciformes, Pleuronectiformes, Polymixiiformes, Pristiformes, Rajiformes, Rhizostomeae, Saccopharyngiformes, Salenioida, Scleractinia, Scorpaeniformes, Semaeostomeae, Siluriformes, Siphonophorae, Spatangoida, Spinulosida, Squaliformes, Stephanoberyciformes,*

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APPENDIX C: PEAT PRESSURES

Grundling, P-L. & Grundling, A. 2019. **Appendix C: Peat Pressures**. In: Van Deventer *et al.* South African National Biodiversity Assessment 2018: Technical Report. Volume 2b: Inland Aquatic (Freshwater) Realm. CSIR report number CSIR/NRE/ECOS/IR/2019/0004/A. South African National Biodiversity Institute, Pretoria. http://hdl.handle.net/20.500.12143/6230.

C.1. Introduction

Globally peatlands are under pressure with peat fires ranging from the tropics in Indonesia since the 1990's to the latest peat fires reported for the Arctic in the Economist of 3 August 2019 (Economist 2019). The Economist states that peat fires are as the latest result of climate changes and also likely to accelerate the effects thereof (Economist, 2019). This is perplexing as peatlands are unique wetland systems that store large amounts of soil carbon, an important contributor of the global carbon cycle (Wu *et al.* 2017). A **peatland** is defined by Joosten and Clarke (2002:24) as '*an area with or without vegetation with a naturally accumulated peat layer at the surface'* whereas **peat** '*is sedentarily accumulated material consisting of at least 30% (dry mass) of dead organic material'*. Relative to terrestrial ecosystem types, wetlands occupy only a small extent of the land surface, estimated to be between 5 and 18% (Amthor *et al.* 1998) yet store a denser amount of carbon below ground (Joosten & Clarke) with peatlands specifically covering approximately 3% of the earth's land surface (Joosten & Clarke 2002). The global carbon stored in peat is estimated to be in the order of 500 billion tons, approximately 30% of the world's soil carbon (more than that of forests); as well as storing 10% of the world's freshwater (Joosten & Clarke 2002). Gorham (1991) estimated that peatlands worldwide hold up to 450 Gt of carbon (half of the global forest and soil carbon combined) (Dixon *et al.* 1994).

Peatlands occur across the earth ranging from mostly in moister temperate climates and the tropics to less common in semi-arid regions (Melton *et al.* 2013). Wu *et al.* (2017) estimated the total global peatland area at 4.42 million km^2, of which 4.0 million km^2 is located north of 30° N (Immirzi *et al.* 1992; Yu *et al.* 2010). However, for the southern region (south of 30°15 S), Wu *et al*. (2017) estimated 0.07 million km^2, which is higher than the value of 0.045 million km^2 identified by Yu et al. (2010). Peatlands are therefore truly unique and rare features in our arid landscape given that only 1–2% of the world's peatlands occurs in the southern latitudes and that less than 5% of the world's peatlands occur in Africa (Lappalainen 1996).

Peat forms under permanent water saturation conditions, capturing and storing atmospheric carbon through wetland vegetation, resulting in a positive carbon balance. This is the same for peatlands on coastal plains and those found in the interior. SANBI (2009:44) define **permanent inundation** *as 'surface water present throughout the year'*. Peatlands in semi-arid regions are dependent on sustained groundwater and/or hillslope intermediate flows to buffer seasonal and drier period fluctuations. Furthermore, water abstraction, draining and erosion in peatlands result in unstable water levels, desiccation of peat and the inability to sequester or store carbon resulting in these degraded wetlands becoming nett releasers of carbon. In semi-arid regions such as southern Africa peatland degradation is mostly caused by the interruption of groundwater and / or interflows from hill slopes, by water abstraction, forestry and alien species invasion. Forestry in the catchments of peatlands in semi-arid landscapes is of special concern as it negatively affects peatland hydrology Furthermore, erosion due to altered runoff from catchments as a result of land use change or related to infrastructure development across wetlands often results in gully formation therefore draining peatlands.

C.2. Peatlands of South Africa

In South Africa approximately 400 km², or less than 10% of the extent of South Africa's wetlands, is known to be peatlands (Grundling *et al.* 2017), yet the exact extent and depth are uncertain as detailed inventory work for the country as a whole is lacking. Only parts of karst landscapes (North West and Gauteng provinces), the moister Highveld and escarpment (Mpumalanga and Free State provinces), KZN coastal plain (Maputaland) and parts of the Cape Fold mountains (Eastern and Western Cape) were investigated infield through mostly point sampling with limited mapping of the peat extent or volume (Grundling *et al.* 1998, 2000; Grundling & Marneweck 1999; Sliva & Grundling 2002; Grundling & Grobler 2005). The true extent of inland wetlands with peat substrates are deficient and requires funding for improved mapping. The extent of only 169 (27%) of the 635 known peatland points of the National Peatland Database, is represented in the National Wetlands Map 5 (NWM5). This gap can be addressed on the one hand by desktop mapping through expert input, yet more importantly, infield verifications are required to determine not only the presence of peat but also peat thickness, extent and the quality thereof including the present ecological state of these wetlands. However, given the lack of resources to do extensive fieldwork, peatland ecoregions have therefore been modelled (Figure C.1) to predict the possible occurrence of peatlands (Grundling *et al.* 2017).

In South Africa, peatlands occur in a range of peatland ecoregions (e.g. Bushveld, Highveld, Lowveld, Coastal belt or plain and Cape Fold and Escarpment Mountain areas) all dependent on groundwater to maintain hydrological peat forming processes (Grundling *et al.* 2017; Grundling 2014). This is important in a semi-arid environment dominated by seasonal water deficits and surpluses (McCarthy & Venter 2006). Wetlands are not isolated features in the landscape and are often part of wetland complexes linked by streams and or groundwater flow systems (Winter 1999). In semi-arid climates, wetlands (and peatlands especially) are usually dependant on groundwater discharge from intermediate hillslope seepage or regional or perched aquifers as evaporation rates are considerably higher than seasonal rainfall (Jolly *et al*. 2008; Sanderson & Cooper 2008). Large evapotranspiration losses are stimulated by high water availability (Penman 1948) especially in subtropical peatlands. However, cooler winter periods and senescent vegetation as well as some wetland plants (including trees) can restrict water losses (Clulow *et al.* 2012). Infiltrating groundwater into wetlands reflect the input in terms of sustained saturation and transform these into outputs such as organic (peat) accumulation that may directly affect downstream systems by augmenting flow in drier periods (Smaktin & Bachelor 2005). Furthermore, groundwater recharge wetlands can augment local water resources (Roulet 1990; Branfireun & Roulet 1998; Bullock & Acreman 2003), although the implications such as maintaining groundwater level or water quality improvement are often difficult to define. Peatlands are therefore extremely sensitive to groundwater flow disruption or changes to the hydrological regime. For example the peatlands that occur in the more arid regions of South Africa, such as the karst regions of the North West Province (Highveld Peat Ecoregion) and the Southern Coastal Belt Peat Ecoregion on the West Coast.

The extent of the 635 peatland points in the National Peatland Database is approximately 2 157 km^2, totalling about 1/10 000th of the world's global peatland extent. The distribution of peatlands is mostly located in the well-watered eastern and southern regions of the country with a high mean annual recharge of primary aquifers. According to South Africa's National Peatland Database, 50% of South Africa's peatlands are located in the Natal Coastal Plain Peat Ecoregion in the KwaZulu-Natal Province (Figure C.1).

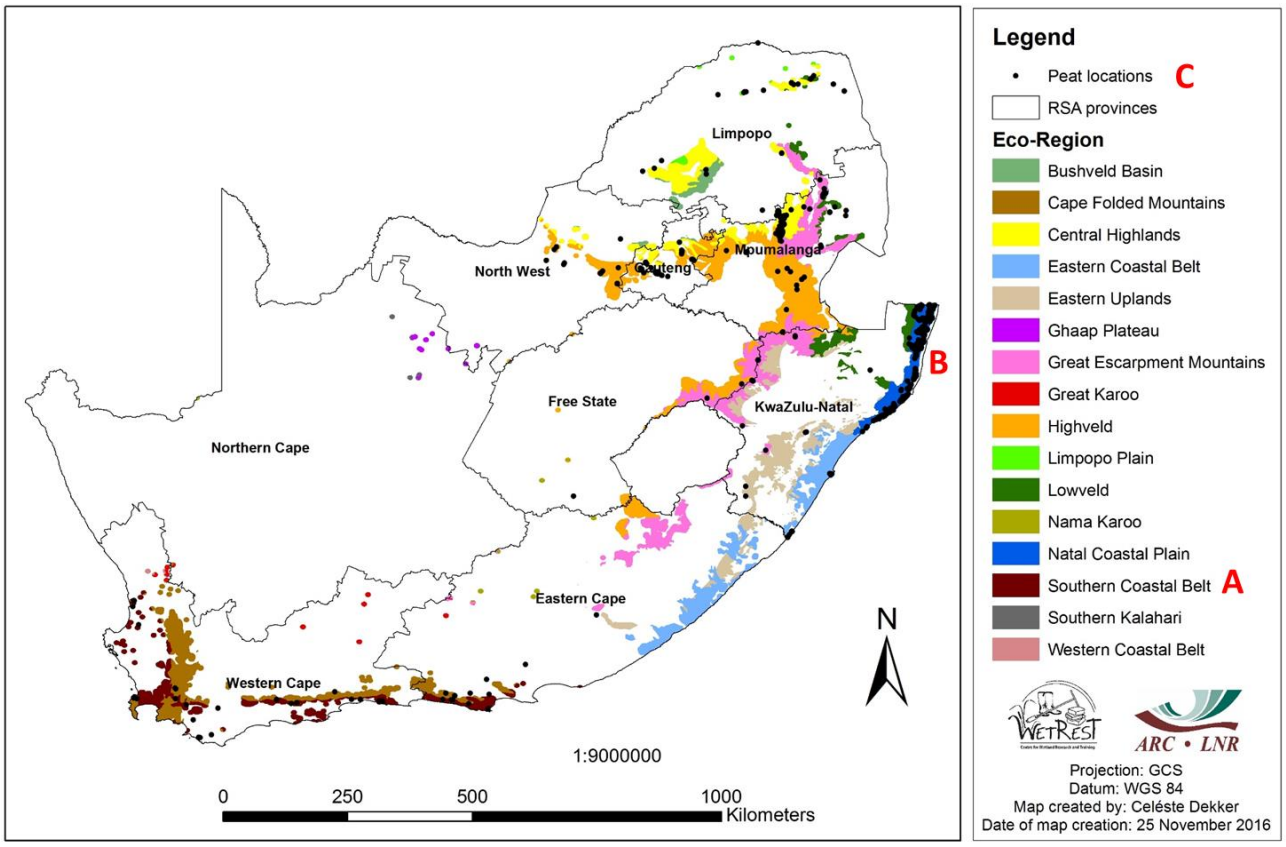


Figure C.1. Peat ecoregions with peat sites. Palmiet systems occur along the Southern Coastal Belt (A), Mfabeni Mire (B) occurs in the Natal Coastal Plain. Peatland carbon storage was estimated using the known peat sites (C) (Grundling *et al.* 2017).

Although peatlands are not common in South Africa, a number of systems are unique, such as the endemic Palmiet systems (point A on Figure C.1; Figure C.2), and the world's oldest known peatland, the Mfabeni Mire (point B on Figure C.1), which is 45 000 years old (based on carbon dating) and still accumulating peat (Grundling *et al.* 2017). Studies indicate that peat accumulation in South Africa took place during the past 50 000 years (Late Pleistocene and Holocene periods) (Thamm *et al.* 1996; Grundling *et al.* 2000; Elshehawi 2015) with the Middle Holocene as the most favourable period for peat accumulation. The gap (35 000 to 15 000 years before present or YBP) with no peat formation is most likely linked to the colder and drier conditions of the last glacial maximum. Grundling *et al*. (2017) documented accumulation rates to vary between 0.3 mm/yr and 2 mm/yr with exceptions such as the inland Matlabas mire in the Marakele National Park, of which the accumulation rate is estimated at 4 mm/yr due to high load of clastic sediment into the peatland.

Figure C.2. Palmiet (*Prionium serratum*) (Grundling 2004).

In terms of South African peatland carbon storage ability, the stock was estimated to range between 4.2 million tonnes and 431.5 million tonnes representing only 0.006% of global carbon stored in peat. Estimates of the accumulation rates ranged between approximately 2 500 and 45 000 tonnes of carbon per year (Point C on Figure C.1 Grundling *et al.* 2017).

C.3. Peatlands of the Maputaland Coastal Plain and iSimangaliso Wetland Park

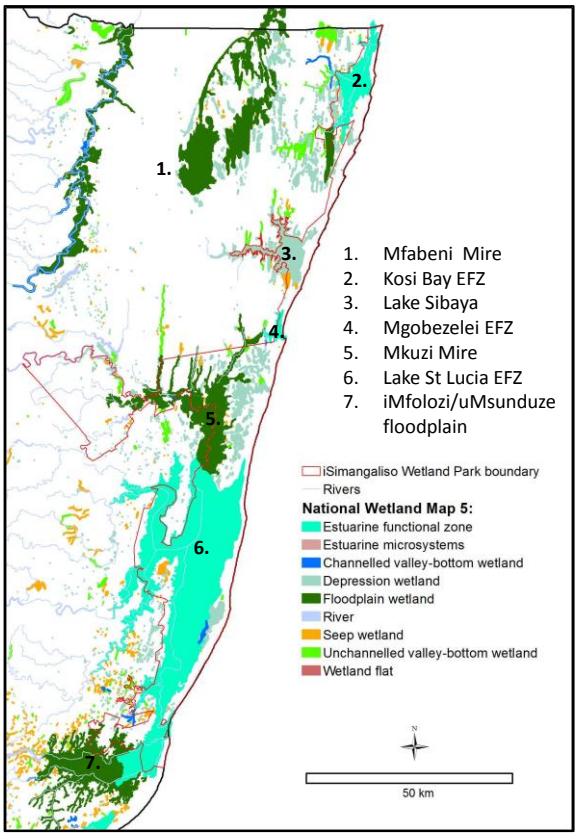
The Maputaland Coastal Plain on the north-eastern seaboard of South Africa contains about 60% of country's peatlands (20 000 ha), half of which fall within the boundaries of the iSimangaliso Wetland Park. This extraordinary concentration of peatlands, freshwater lakes, marine and estuarine wetlands contributed to the Park being awarded World Heritage Site (WHS) status. The carbon stored in wetlands in the park differs for different wetland types. Swamp forests have values ranging from 0,046 - 0,060 t C/m^3 and reed/sedge mires were found to be lower, ranging from 0,032 - 0,040 t C/m^3. Organic rich mineral soils associated with permanent (non-peatlands) had typical values around 0,032 t C/m^3. The average for all the peatlands in the park is 0,041 t C/m^3. The estimated figure of 7 160 000 t of carbon for the organic rich mineral soils of the wetlands devoid of peat is virtually equal to the Park's total peatland carbon resource. Carbon locked up in the lakes, salt marshes, tidal flats, estuaries and coral reefs were not included in this study.

Sixty percent of SA's peatlands are located on the Maputaland Coastal Plain. The iSimangaliso Wetland Park hosts 30% of SA's peat wetlands.

The Mkuze Mire, the largest peatland in South Africa, contains 4 279 400 t carbon. The wetland covers more than 8 800 ha (of which 7 265 ha is peatland) (Point C on Figure C.1; Grundling *et al.* 1998). The carbon in this peatland represents about 60% of the carbon pool in the iSimangaliso Wetland Park's peatlands and is estimated to contain 25% of the carbon deposited in South Africa's peatlands. The Mkhuzi Mire has a carbon store capacity of 589 t C/ha compared to the Mfabeni Mire, which has a storage capacity of 1 768 t C/ha; a substantial peat thickness of 11 m and covers an area of 1 250 ha (Grundling *et al.* 1998).

In South Africa, peatlands are assumed to be less effective in carbon sequestration when compared to exotic *Eucalyptus* and *Pinus* spp. plantations adjacent to the park in terms of capacity to lock up carbon per area per unit time (t C/ha/year). For instance, a hectare of pine forest is able to accumulate about an order of magnitude more carbon per year (6.4 t C/ha/year) than an average peatland in Maputaland (0.46 t/ha/year). However, a large amount of the accumulated carbon in wood products is released to the atmosphere again within a relatively short time after harvesting due to consumer patterns, compared to the effective permanent or long term storage capacity of peatlands.

The Mkuze Mire, the largest peatland in South Africa, contains 4 279 400 t carbon. The wetland covers more than 8 800 ha (of which 7 265 ha is peatland). The carbon in this peatland represents about 60% of the carbon pool in the iSimangaliso Wetland Park's peatlands and is estimated to contain 25% of the carbon deposited in South Africa's peatlands.



Case Study: Vasi North Peatland, KwaZulu-Natal, South Africa

Based on a Water Research Commission Project K5/2346: Investigation of peatland characteristics and processes as well as understanding of their contribution to the South African wetland ecological infrastructure, the Vasi North Peatland case study is a site with the most information in terms of its hydrological networks for water level monitoring, vegetation analysis, isotopic and dating results (Grundling *et al.* 2017). Peat fires at Vasi peatland complex flamed up again 5 September 2017 due to decreasing water table levels as a result of a regional drought and plantation expansion at the time, resulting in the peat drying out, desiccation cracks forming and the spreading of subsurface fires releasing carbon dioxide instead of storing it. New *et al.* (2016) reported that peatland fires have the potential to release substantial amounts of the carbon, which are currently sequestered in these vulnerable ecosystems.

Figure C.3. Aerial photo by Carl Myhill (from the iSimangaliso Wetland Park Authority) of the burning Vasi North Peatland. Photo was taken on 6 September 2017 from west to east.

Study area

Vasi North Peatland is located (27°10'36.50" S; 32°43'4.05" E) within the Manzengwenya State Plantation, near the towns of Manguzi and Mseleni, north-eastern KwaZulu-Natal Province on the Maputaland Coastal Plain. Primary land use is forestry (Pinus and Eucalyptus plantation) followed by communal land use. A thick peat layer (8 m) is one if it's exceptional features.

The peat extent, carbon volume, age and accumulation rate for Vasi North Peatland are:

- Peat volume estimation of 355 182 m^3;
- Total carbon is estimated to be 20 182 tonnes;
- Average peat-accumulation rate was determined to be 1.15 mm/yr;
- Age dates at 8490 years before present (YBP) at a depth of 7.58 m. The top 0.47 m has already been dated at 1665 YBP. It can therefore be assumed that an estimated 1200 years' worth of carbon has already been lost through degradation since 1967 when the Manzengwenya plantation was established.

Carbon storage values

The value of the timber to be removed around the Vasi North Peatland was based on a price of R500/m3 and 400 m3 per ha (Sabi 2017) with limited buffer zones ranging from 20 to 100 m (Table C.1). The industry standard is in general 20 m but the nature of the Maputaland Coastal aquifer requires are larger buffer. Historically a buffer of about 100 m worked well with Pine trees in this plantation (Grundling & Blackmore 1998). The timber values range from R3 600 000.00 in the 100 m buffer to R720 000.00 in the 20 m buffer (Table C.1). The carbon value within the Vasi North Peatland (Table 2) was calculated based on an USA

average price of $ 8.5/ton (range: $2–15) and an exchange rate of $1 = R13. The difference in the carbon value of the peat (R2 230 111.00) and the value of the timber in the different buffer zones are reflected in Table C.2.

Table C.1. Timber value around in Vasi North.

BUFFER (M)	AREA(HA)	VOLUME (m^3) IN SITU/HA	TOTAL WOOD (m^3)	VALUE
100	18	400	7200	R 3 600 000.00
60	10.8	400	4320	R 2 160 000.00
50	9	400	3600	R 1 800 000.00
30	5.4	400	2160	R 1 080 000.00
20	3.6	400	1440	R 720 000.00

Table C.2. Estimated carbon value of the Vasi North Peatland.

AREA	TONS IN SITU/HA	RAND PER TON	VALUE	DIFFERENCE PEAT VS TREE	BUFFER (M)
6	20182	110.5	R 2 230 111.00	R -1 369 889.00	100
				R 70 111.00	60
				R 430 111.00	50
				R 1 150 111.00	30
				R 1 510 111.00	20

C.4. Pressures on peatlands

Wetlands are catchment dependant as catchment characteristics contribute significantly to the nature of flows into the wetland (e.g. steeper catchments will result in higher storm flow into a wetland compared to a gentler sloped catchment). Land cover and land use in catchments will likewise regulate flows to wetlands and will have a direct impact on wetland condition (e.g. degraded erosion prone catchments will result in high sediment loads entering a wetland). Consequently the hydrology and sediment dynamics of wetlands are catchment dependant, and their impact on aquatic ecosystems such as peatlands can be critical (Smaktin & Bachelor 2005) having a huge impact on their intactness. Increased water abstraction reduces the availability of groundwater to these systems and can result in complete dry out and burning of the systems to a point of total collapse. Changes in the hydrological regime have several drivers and impacts:

- **Abstraction and diversion for domestic and agricultural use**: Excessive water abstraction of the groundwater aquifer resulted in the lowering of the water table to the extent that no discharge of water to the peatland is taking place. Examples include the Rietvlei and Molopo peatlands (North West Province) and the Langvlei system (Western Cape Province).
- **Increased water demand from land uses such as forestry:** Resulting in increased groundwater use, as in the case of the KwaMbonambi and Manzengwenya Plantations in the KwaZulu-Natal Province and Lakenvlei in the Mpumalanga Province. These exotic trees do not only tap into the groundwater table but also retards rainwater infiltration to the groundwater, as the land cover on recharge areas is extensively altered. The combined impacts are that peatlands in and adjacent to these plantations are desilicated and eventually the dried peat burns. Furthermore, not only are peatland impacted but also adjacent aquatic ecosystems as is illustrated in the Vasi Pan peatland in the Manzengwenya plantation (Figure C.4). This peatland is located within the plantation and as experienced two severe peat fires after it was originally saved from the 1st

fire in 1998 when the former National Department of Water Affairs and Forestry (DWAF) ordered the withdrawing of trees to about 100 m from the edges of the wetland. Regardless of this directive, the Pan continued to dry out. The plantation was later changed from pine to bluegum and in 2011 extended into the peatland, exacerbating the desiccation of the peatland. Of greater significance however, is that peatlands bordering the plantation also started to desiccate following the change to blue gum and the most severe impact are expressed in the lowering of Lake Sibiya which is bordered by the Manzengwenya planation in the north and the Mbazwana planation in the south. The impact of indiscriminate small-scale subsistence growers and illegal plantations across this area, supported by both commercial and state forestry during the past two decades is of concern as the combined impact of all these area under plantation resulted in not only to lower groundwater levels, desiccated and burning peat but also a negative impact on the biodiversity of Maputaland.

- **Increased water attribution to low energy ecosystems**: The addition of water to systems, resulting from either Waste Water Treatment Works (WWTW) or irrigation, as well as increased run-off from urban areas, overgrazed areas and afforestation, result in and increase flow of water in peatlands. Particularly in the dry season, the peatland is changed from low energy to higher energy regimes causing severe erosion and degradation of the peatlands. The Colbyn wetland in Pretoria, Klip River south of Johannesburg (both in the Gauteng Province) and several Palmiet peatlands in the Cape Fold Mountains (Western Cape Province) are some examples of peatlands that suffer from additional water input. Furthermore, these additional flows are often polluted and nutrients such as phosphates can accelerate peat degradation as is evident in the Rietvlei peatlands where erosion resulted in peat desiccation with polluted return flows from upstream waste water treatment plants further exacerbating the degradation of peat.
- **Clearing vegetation cover: i**s particularly problematic in the swamp forest peatlands across the northern and eastern parts of the country. Degradation due to hydrological flow alteration occurs where trees are cleared and the peatland drained for cultivation of subsistence and commercial crops, as in the cases of the Siyaya and Swamanzi systems flowing into Kosi Bay (KwaZulu-Natal Province), as well as Lakenvlei near Dullstroom (Mpumalanga Province) and Palmiet systems such as in the Kromme in the Langkloof and Riviersonderend downstream of the Theewaterskloof Dam (Western Cape Province).
- **Peat extraction**: Peat mining occurred extensively in the interior of South Africa from the 1980's to 2011, especially in the karst related peatlands in North West and Gauteng with some peat mining also reported in the Soutpansberg in Limpopo and the George area in the Western Cape. The peat mining was eventually stopped due to public outcry and concerted efforts of officials in several national departments, including former DWAF, the former Department of Environmental Affairs (DEA) and the former Department of Agriculture, Forestry and Fisheries (DAFF) with support from provincial conservation bodies such as the Gauteng Department of Agriculture and Rural Development (GDARD). The last operation in the Gerhardminnebron peatland eventually ceased in 2011 by the personal intervention of the late minister of DEA, Minister Edna Molewa. However, the impact of these extraction operations continues to linger with erosion evident in drainage channels (e.g. Kliprivier, Rietspruit and Rietvlei wetlands in the Gauteng Province), open water bodies unable to support revegetation and peat accumulation (Kliprivier and Gerhard Minnebron), all related in diminished functioning of these systems in terms of water storage, base flow maintenance, carbon storage, filtration and biodiversity.

- **Invasive small mammal damage:** The impact of Ice Rats (*Otomys sloggetti robertsi*) in the head water peatlands of the Maluti Mountains (Lesotho) catchments of these have been well documented (Du Preez & Brown 2011; Grundling *et al.* 2015). These are mainly due to the erosion of the peatlands and subsequent desiccation as a result of a variety of factors such as infrastructure development and overgrazing, of which most are directly related to the Lesotho Highlands reservoir development, which is an ongoing water supply project for the provision of water to Gauteng residents. Lately the impact of Gerbil (*Tatera leucogaster*) on wetlands in the Mpumalanga Highveld has also become evident where the hydrology of these wetlands was impacted upon by coal mining activities. Of interest is the current impact of Mice (*Mus musculus*) on the bird populations of Marion Island. Many of the bird species nest on the extensive mires occurring on the island and it is postulated the burrows and related activities of the mice could impact on the Marion Island mires with burrowing tunnels causing peat surface desiccation.

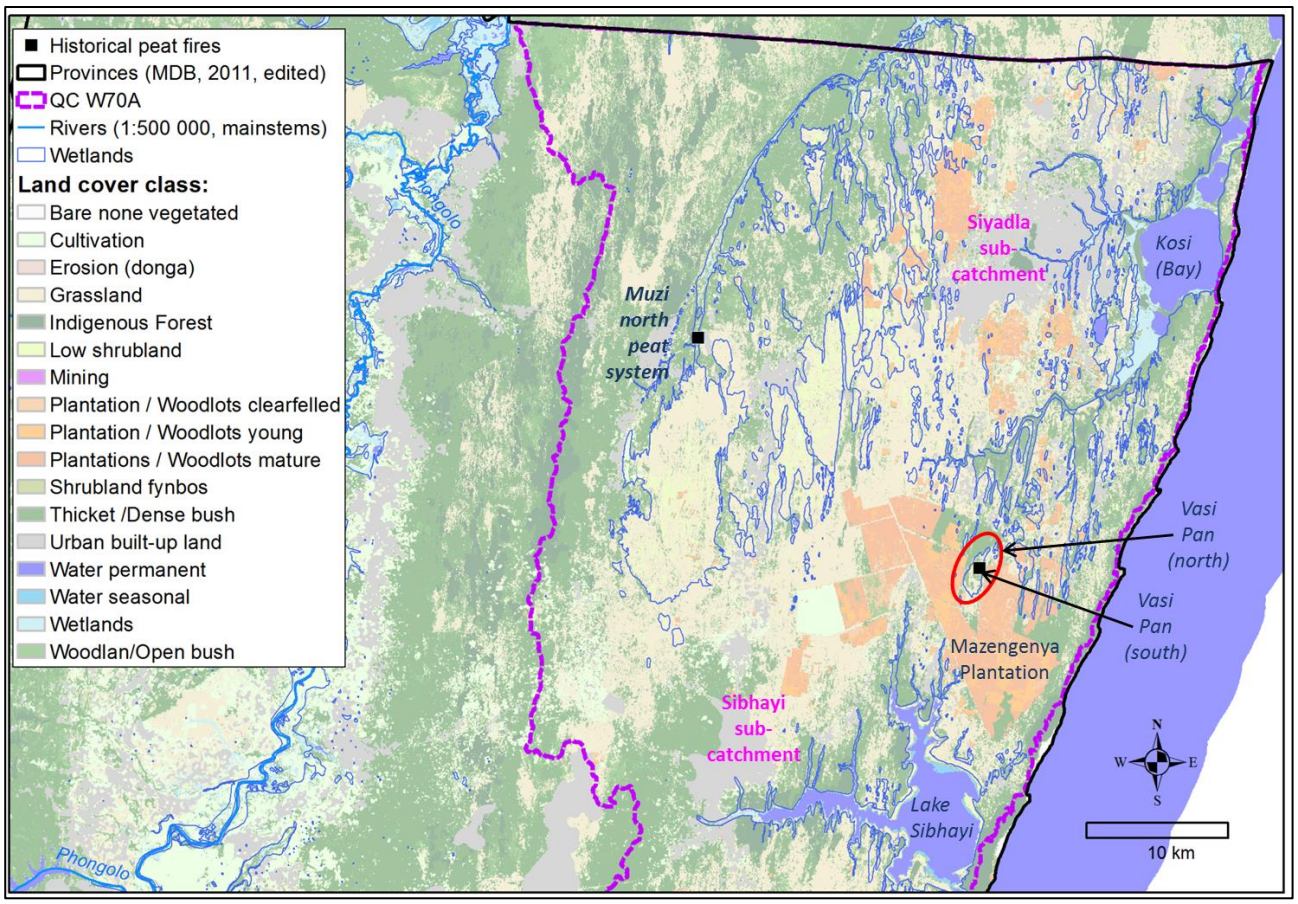


Figure C.4. Location of the Vasi Pan complex relative to the quaternary catchment W70A and surrounding land covers.

Peatlands in poor condition can turn from carbon sinks to sources, with levels of greenhouse gasses (GHGs) emitted into the atmosphere (Ramsar Convention of Wetlands 2018). Peat degradation due to drainage erosion or water abstraction all result in the draining of peat pores, oxidation of the peat, compaction, hydrophobicity and eventual collapse of the peat body or deposit (Illnicki & Zeitz 2003; Szajdak & Szatyłowics 2010). To restore degraded peatlands are expensive (Kotze *et al.* 2018) and success is not always guaranteed as the intactness of a peatland is intricate and depend not only on sustained groundwater levels and revegetation, but also requires a suite of microbial guilds and bio-chemical processes to be in place (Kanokratana *et al.* 2011). Water quality as well as invasive species impacts can

further disturb the intricate process and balances resulting in an intact peat forming system into a source of GHGs (Ramsar Convention of Wetlands 2018; Urbina & Benavides 2015). Therefore, prevention is better and more cost effective than cure.

A number of peatland systems have potentially completely collapsed, where the system has been degraded to such a degree that the vegetation cover, hydrological regime and substrate have been destroyed. Extreme water abstraction had led to at least 17 known systems to have burnt to date or become desiccated, totalling an estimated 616 ha in extent (Figure C.5; Table C.3). Emissions from these are estimated at 64 125 t C In the case of Vasi Pan, the plantation management teams were not geared for emergency response. National DEA therefore called upon the Working for Fire team to assist in extinguishing the subsurface fire. Risks involved includes desiccation cracks creating an unsafe work environment (falling into dessication cracks can result in falls and injury when traversed), and undetected subsurface fire under a thin crust of hardened peat ash can result in severe burns. However, recently a revolutionary effective but simple technique was applied by Working on Fire (WoF) to extinguish a peat fire in the Onrus wetland (Grundling *et al.* 2019). Emergency response plans are critical for municipalities with systems that have historically collapsed and where collapse is imminent. Further assessments are required to determine if these systems have recovery potential or qualify as permanently collapsed systems (Bland *et al.* 2017).

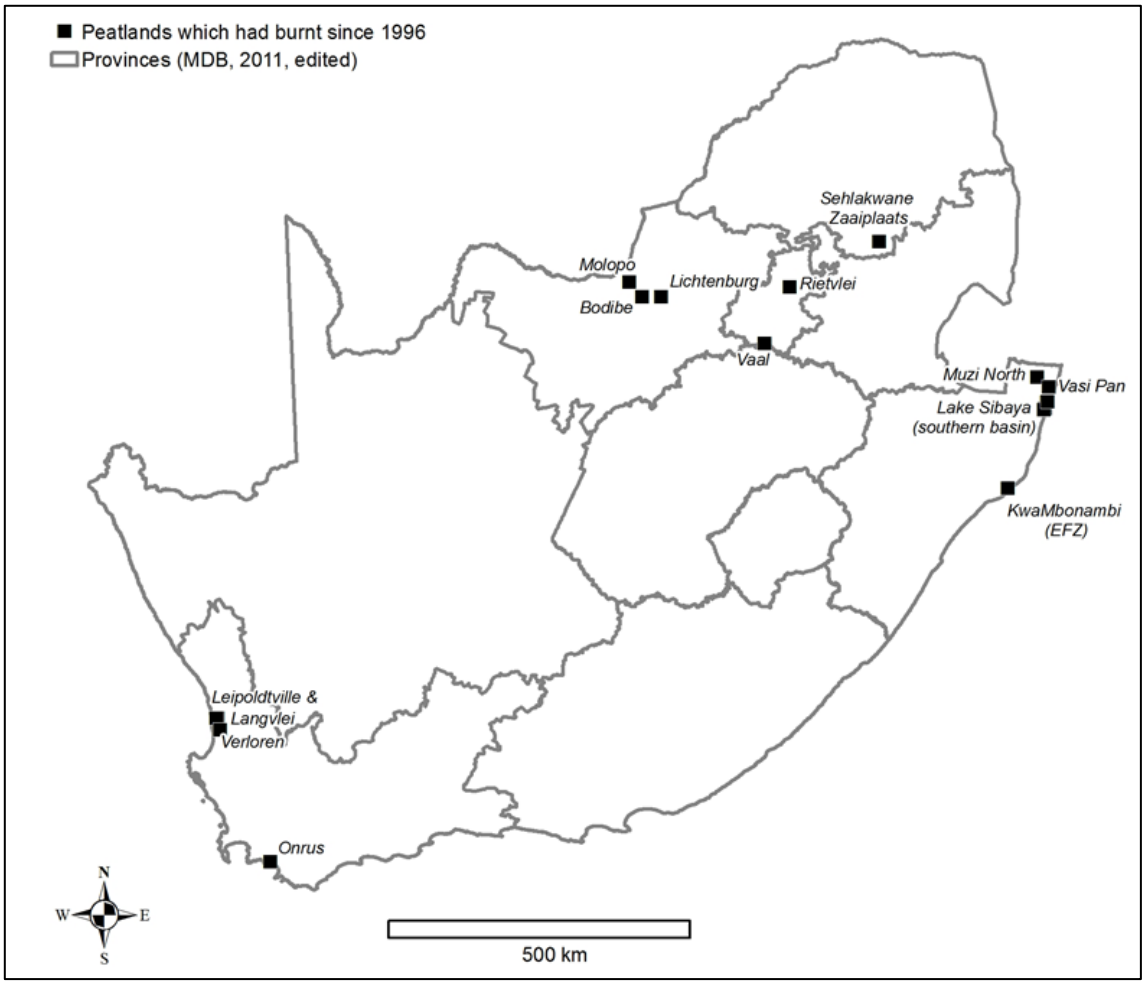


Figure C.5. Locations of peat fires and desiccated peatlands reported across South Africa since 1996.

Table C.3. Extent of peat fires and desiccated peat lands reported across South Africa since 1996.

Peatland name	Dates	Maximum extent burnt (ha)	Maximum extent desiccated (ha)	Province	Total peatland extent (ha) affected in province
Vaal Racecoures	4 September 2018	3		FS	3
Rietvlei	1991 (for ± 6 months)	16		GT	16
KwaMbonambi	Various	40		KZN	121
Lake Sibaya four peatlands	2018 and 2019	2.6	9.4		
Muzi North	Various	43			
Vasi Pan	1996, 2014, and 30 October 2018	26			
Sehlakwane Zaalplaats	25 August 2016	1		LP	5
Bodibe	2000, 2010, and 16 May 2019	10		NW	69
Lichtenburg Game Breeding Centre	28 May 2016	13			
Molopo	8 May 2016 and 9 January 2018	46			
Leipoldtville-Langvlei wetlands	2010	1.4		WC	402
Onrus	Before 22 January 2019	8.6	33		
Verloren	April 2019		359		

Other peatland systems which may be under pressure of imminent collapse, particularly those in dolomitic areas, (Table C.4) and that can only be addressed with a holistic approach including political will to address the causes, drivers and pressures impacting on these peatlands. It is evident from the main pressures that current legislation and related regulations are poorly enforced in granting authorisations or by government taking decisions. The Karst systems are a case in point:

1. Water abstraction by the Department of Water and Sanitation (DWS) in the Molopo system is done without a reserve determination been available for the system. Furthermore, the release of sewage and dumping in and downstream of the town of Mahikeng is not at all controlled; nor is any attempt made to recycle water that is released into two downstream dams.
2. Illegal peat extraction (no authorisations were issued in terms of the National Environmental Management Act and the National Water Act) in the Gerhardminnebron peatland was condoned by officials of DAFF on the basis of an expired licence in terms of CARA.

This unacceptable and corrupt practice of applying good legislation and policy poorly is also evident in the forestry sector as was demonstrated in Maputaland, situated within the northern KwaZulu-Natal Province where various peat fires are directly related to poor forestry practices that were not controlled or established without water use licences.

Therefore, a turn-around strategy for these systems must start with proper legal compliance and enforcement. Parallel to this the environmental degradation needs to be addresses including amongst others:

- Karst systems: determine the water reserve and allocate and control water accordingly.
- Primary stems: determine recharge areas, delineate peatlands and remove plantations accordingly. Furthermore determine groundwater reserves and allocate and control abstraction accordingly.
- Palmiet: map and determine the extent of peatlands, determine status and allocate restoration resources accordingly. Parallel to this enforce sound soil conservation practices in peatlands and catchment alike with special reference to over grazing in catchments, cultivation in Palmiet wetlands and alien invasive species control.
- Peat Swamp forests: map and determine the extent of swamp forests, determine status and allocate restoration resources accordingly. Parallel to this determine house hold dependency, determine alternative income streams and enforce wise use and sound soil conservation practices in swamp forests including mulching, rewetting and revegetation.

Table C.4. The following peatland hotspot areas are under pressure with collapse imminent.

System	Pressure 1	Pressure 2	Pressure 3	Collapsed
Karst	Water abstraction	Peat extraction	Pollution: Acid Mine Drainage (AMD) and Sewage	Bodibe; Lichtenburg; Molopo; Rietvlei (peat fires also erosion)
Primary Aquifer: Maputaland	Afforestation: Infiltration	Afforestation: Water abstraction	Drainage and Cultivation	Vasi (Manzengwenya-Mbazwana: various); Lake Sibaya and Mbazwana; KwaMbonambi: various (peat fires)
Primary Aquifer: Sandveld	Water abstraction	Water abstraction:catchment	Land use change	Langvlei (peat fires); Verloren
Palmiet (Cape Fold mountains)	Infrastructure: Roads, Dams	Drainage and Cultivation	Alien invasive species	Sections of Kromme, Duiwenhoks, Riversdale, Pietsersieliekloof, Onrus *etc.* (Erosion and desiccation).
Peat Swamp Forest: Drakensberg Escarp and Maputaland	Clearing	Drainage and Cultivation		Bushbuckridge; Mutale (Erosion and desiccation) Swamazi and Siyaya (desiccation)

Climate change:

It is expected that peatlands in the western and drier, groundwater-dependant regions will be adversely affected by climate change. According to DEA (2008):

- Sub-continental warming is predicted to be greatest in the northern regions;
- Temperature increases in the range of between 1°C and 3°C can be expected by the mid-21st century, with the highest rises in the most arid;
- A broad reduction of rainfall in the range 5% to 10% can be expected in the summer rainfall region;
- This will be accompanied by an increasing incidence of both droughts and floods, with prolonged dry spells being followed by intense storms; and
- A marginal increase in early winter rainfall is predicted for the winter rainfall region.

Wetlands in South Africa are heavily dependent on hydrological process related to the catchment and catchment changes impacting on hydrological and geomorphological process and water quality. Intense storms in degraded catchments will result in adverse stormflow into peatlands resulting in erosion and

desiccation and high clastic sediment flows could disrupt peat accumulation. Furthermore, wetlands in these regions will compete with humankind for water resources (especially groundwater) and are thus likely to suffer desiccation.

C.5. Protecting peatlands

Peatlands are poorly protected in South Africa. It is estimated that between 30 and 50% of the extent of peatlands are located within the iSimangaliso Wetland Park on the east coast of the KwaZulu-Natal Province. This protected area includes three Ramsar sites, namely, Kosi (estuarine, lakes and swamp forests), Lake Sibaya (limnetic depression) and the Lake St Lucia System (lakes, estuary, wetlands, mires and swamp forests). The Kruger National Park hosts the Mahlapanga and Mfayeni Hot Spring Mires, whereas the Marakele National Park (Limpopo Province) also includes peatlands. Some peatlands also fall in another four of South Africa's Ramsar sites, including Verlorenvlei, Drakensberg, Ntsikeni, and the Marion and Prince Edward islands). The efficacy of protection is however constraint by a lack of knowledge, the extent of wetlands in SA, which of these are peatlands, ecological status to determine management and conservation requirements, poor enforcement of relevant environmental legislation and policies, lack of response to disaster events such as peat fires and erosion events. Furthermore, most of the peatlands in semi-arid regions are dependent on sustained groundwater and/or hillslope intermediate flows and therefore their designation should consider catchments and related landscapes as part of the strategy to conserve these peatlands. Not only should land use practices in and adjacent peatlands be managed, but also in related catchments; and especially those that could impact on the water and sediment balance of a peatland. Lastly, since most peatlands occur outside formal areas the precautionary rule should be apply to any activities that could jeopardize the integrity of peatlands and stipulations of authorizations in terms of the relevant legislation must be adhered to as well as being monitored and enforced by the relevant authorities.

However, in the past three decades the application of wetland management through the Conservation of Agriculture Resources Act 43 of 1983 (CARA) and the National Environmental Management Act 28 of 2008 (NEMA), Environmental Impact Assessment policy and Water Use Licence Authorisations (WULA) ito regulations 21 c and I of the National Water Act no 36 of 1998 have resulted in:

- Limited granting of commercial wetland cultivation authorisations;
- Environmental Impact Assessments (EIAs) and WULA regulations enforced on any peatland related impacts resulting in a decrease development and dams been built in peatlands, or upstream;
- No granting of peat extraction authorisation; and
- A decrease in afforestation and mining authorisations in peatland areas.

This illustrates that the intervention effort through legislation, policy and enforcement is critical, as peatlands and wetlands do not occur in isolation and are components of broader landscapes. Change in catchments impacts on wetlands. The cumulative effect of poor protection and compliance, climate change and increasing demand for surface and ground water will ultimately determine the fate of our peatlands.
Conservation management should take note of modern advances in sustainable utilisation of carbon stores including rewetting of peatlands, wise use practices, paludiculture and carbon trading in order to secure the long-term storage capacity of wetlands. The dearth in knowledge in the distribution of peatlands in South Africa, their ecological and conservation status as well as their functioning result in poor

management, a lack of a coherent national conservation strategy and response to pressures. Consequently, peatland management actions in South Africa should focus on:

i) Locating peatlands: map them and determine peat extend;
ii) Determining their ecological condition;
iii) Take pro-active steps to conserve the most pristine or natural ones;
iv) Control the use or exploitation (enforce EIA and WULA regulations), especially in the forest industry and water supply to municipalities and agriculture;
v) Prevent and control peat fires as well as rewet degraded sites;
vi) Maintain intervention on existing restoration projects;
vii) Identify new restoration sites and prioritise the peatlands which have burnt to date or are desiccated; and
viii) Research and promote sustainable/wise use practices such as paludiculture (where appropriate).

In conclusion, we recommend the following three key steps for South African peatlands:

I. Peatland inventory and status assessment (determining their present ecological state);
II. Legal compliance, extension and control the use or exploitation (enforce EIS and WULA regulations), especially in the forest industry and water supply to municipalities and agriculture; and
III. Create a disaster response protocol for peatlands in peril: prevent and control peat fires as well as rewet degraded sites and arrest erosion.

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APPENDIX D: PRESSURES ON THE MAPUTALAND COASTAL PLAIN

Janse van Rensburg, S. 2019. **Appendix D: Pressures on the Maputaland coastal plain**. In: Van Deventer *et al*. South African National Biodiversity Assessment 2018: Technical Report. Volume 2b: Inland Aquatic (Freshwater) Realm. CSIR report number CSIR/NRE/ECOS/IR/2019/0004/A. South African National Biodiversity Institute, Pretoria. http://hdl.handle.net/20.500.12143/6230.

D1. Mystical Maputaland

D1.1 Regional context

'Mapoota' (Maputaland) was described by Owen (1833) as extending southward from the 'great bay of Delagoa' (current day Maputo Bay). Historically, it was said to terminate at the southern edge of St Lucia in the south. This 'extent' of Maputaland is partly socio political in nature with a complex and convoluted history (see Sousa, 1695; Owen 1833; Carruthers 1988; Kloppers 2003; Mthethwa 2002; Mathebula 2017). These historical dynamics still influence contemporary relationships within the region (Mthethwa 2002) and of relevance to addressing current pressures and opportunities. However, as a geological unit, the dune stratigraphy extends southwards as far as Port Dunford, near Mtunzini forming the contemporary southern extent of Maputaland (Porat & Botha 2008). It is bounded by the Lubombo Mountains and the Pongolo and Mkhuze River valleys in the west (Botha & Porat 2008; Smith *et al.* 2008) (see Figure D.1 interpretation from historical records and Figure D.2 for contemporary representation).

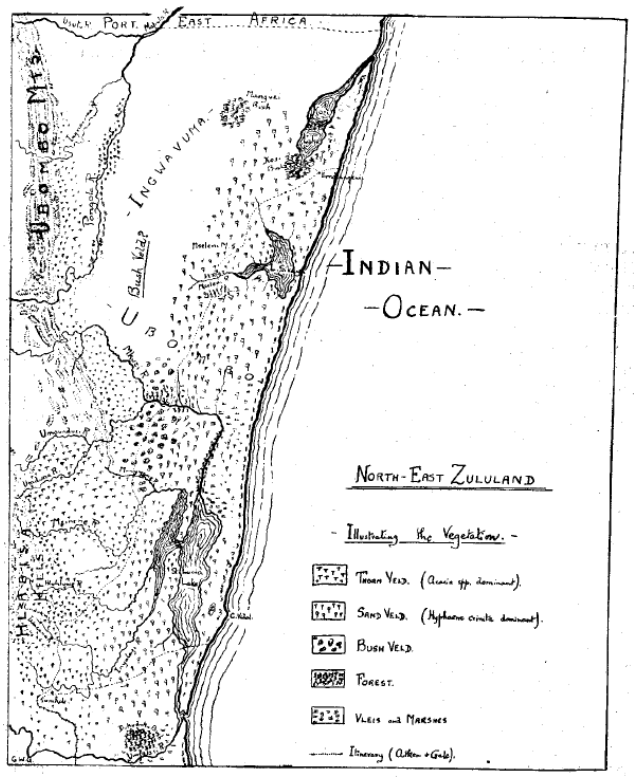


Figure D.1. First Vegetation Map of North-East Zululand (Scale: 20 miles to 1 inch) indicating the extent of the historic description of the southern Maputaland region within South Africa (Aitiken & Gale 1921:6).

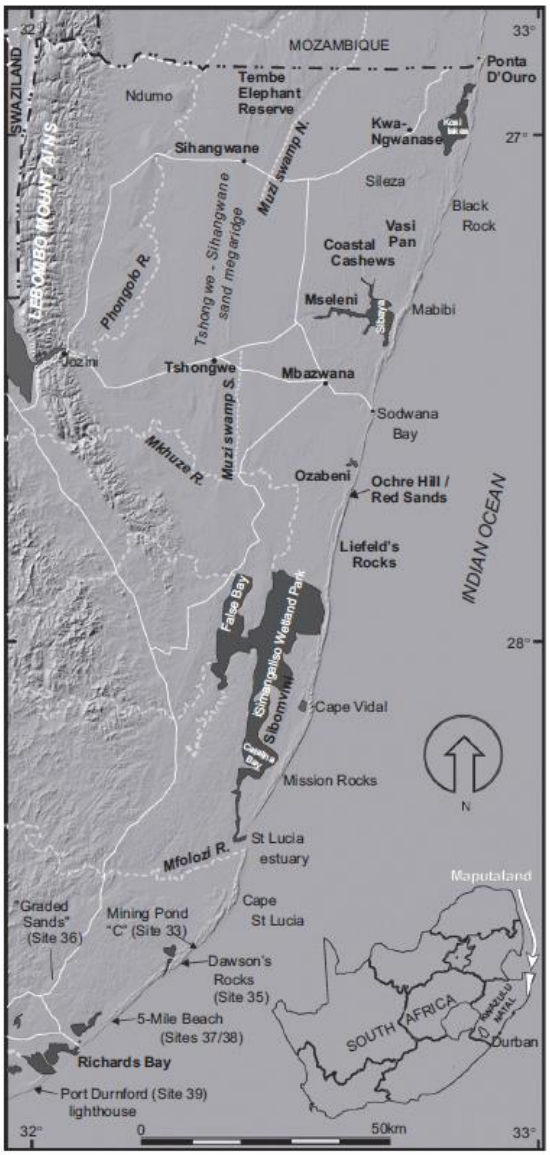


Figure D.2. From Porat & Botha (2008), locality map showing the contemporary extent of the southern Maputaland coastal plain region as a stratigraphic unit. Major roads are shown in white lines and major rivers in dashed white lines. Maputaland is the region to east of the Lebombo Mountains extending southwards to Port Durnford east of the N2.

D1.2. Regional biodiversity

The Maputaland Coastal Plain (MCP) region is commonly described as the mixing point between biota from the subtropical and temperate south and west and the tropical north (Aitiken & Gale 1921; Lawrence 1947; Bruton & Cooper 1980; Perera *et al.* 2018). Maputaland, part of the Maputaland-Ponda-Albany biodiversity hotspot, is a recognised centre of endemism (Smith *et al.* 2008) in faunal (Perera *et al.* 2018) and floral (Matthews *et al.* 1999) taxa with high diversity across the taxonomic spectrum (Steenkamp *et al.* 2004). For example, Perera *et al*. (2018) assessing the entire Maputaland-Ponda-Albany hotspot, revealed high peaks of vertebrate diversity endemism within the Maputaland region, corresponding to floristic endemism in the area. There are over 2 500 vascular plant species (Van Wyk 1996) and a diversity of plant communities including forests, savanna, hygrophilous grasslands and dry grasslands with palm veld, wetlands and swamps (Van Wyk 1996), including rare and unique communities such as geoxylic suffrutic rich grasslands (Matthews *et al.* 1999).

The 'recent' history of Maputaland is rich with the allure of heroic shipwreck survivors accounts, 19th century hunting 'adventures', which saw the wholesale destruction of big game (Ellis 1994) and a long history of ivory trade, at least since the 1500's (*sensu* Sousa 1695) through Maputo Bay and later current day Durban. A very special and revealing archaeological site also exists in Border cave in the Lubombo Mountains providing insights into of about 200 000 years of different periods of human occupation in the region (Villa *et al.* 2012).

Maputaland is by all accounts a veritable historical, cultural and ecotourism paradise, with five Ramsar sites, the iSimangaliso Wetland Park World Heritage Site (WHS), ten Important Bird Areas (Steenkamp *et al.* 2004; Smith & Leader-Williams 2006) as well as special provincial protected areas, such as Tembe and Ndumu Game Parks. There are also successful private (e.g. Phinda) and communally-owned game farms in the area (Hearne & McKenzie 2000; Smith *et al.* 2006). The marine area is as spectacular as the terrestrial systems. It boasts the southern distribution of coral reefs with some of the best diving spots in the world and home to the recently discovered 'living fossil four legs' (coelacanth) who hang out in caves over 100 m deep in underwater canyons carved out by rivers when the sea was much lower than it is now. The beaches are important turtle nesting grounds, which also form part of the tourist attraction in the region. The Lubombo Transfrontier Conservation Area (TFCA) initiative was launched in 2000 in response to agreement by the Swaziland, South African and Mozambique governments that ecotourism, tapping into the already existing burgeoning tourism industry in the region, should be used strategically to develop the region to support economic development and job creation for what is recognise as a generally poor area (Smith & Leader-Williams 2006).

D1.3. Geological setting

'Sea-level fluctuations have influenced the full width of the coastal plain within the past four Mega annums (Ma) , and the coastline bears witness to shorter term cyclic climate change and sea-level fluctuations. This region has been granted international conservation significance in the light of globally significant endemism, biodiversity and scenic beauty. Management practices for conservation must adapt to the varied geology, landforms and geomorphic processes of this ancient landscape. The geological history bears witness to the dramatic environmental changes that occur rapidly in response to global climatic cycles, and our strategy to cope with these influences should consider lessons from the past.' (Botha 2015:128).

The geological history and formation of the area is described in detail in (Botha & Porat 2008; Porat & Botha 2008; Botha 2015). In simple terms: over geological time the area was subject to fluctuations in sea level, resulting in marine, alluvium and Aeolian deposits over the underlying cretaceous layer. Porat & Botha (2008) provide a temporal framework, as well as postulating underlying processes, associated with the series deposits and dune formations, from the late Middle Pleistocene to Holocene. These dune formations are associated with global glacial or interglacial climatic cycles and sea level influences and as a geological unit with respect to dune stratigraphy, extend to as far south as Richards Bay and up into Mozambique (Porat & Botha 2008). At a very basic level, the coastal plain is comprised of young porous sandy material, over older less permeable sometimes 'reworked' paleo dune formations (general running in a north south direction) underlain by a relatively impermeable cretaceous layer. This results in a perched water table (deep aquifer) overlain with a shallow aquifer which are variably inter-connected (Grundling 2014). The inter-dune depressions are thus rich in wetlands and peatlands where the topography intersects with the water table. The close association between the geological history and resulting water table is a key determinant on of vegetation communities in the area (Watkeys *et al.* 1993; Matthews *et al.* 1999;

Grundling *et al.* 2013; Botha 2015). It can be considered as a big sand pit with a bit of underlying complexity and variability in porosity with 'deep' and 'shallow' aquifers interacting with each other to varying degrees across the system, which is essentially connected at a fundamental level. For a more detailed description of the different aquifer types see (Miller 1998; Grundling 2014; Weitz & Demlie 2015).

D2. The place that is flat

'Gently undulating country, never more than 500 feet [152,4 m] in altitude, is succeeded to the east again by a belt of flat sandy county, some 10 miles [16,1 km] wide, in which veils and bogs are common' (Aitkin & Gale 1921:7).

D2.1. The curious case of quaternary catchment W70A

This 'belt of flat sandy country' describes the current day local municipality of Umhlabuyalingana (ULM), meaning, unsurprisingly, 'the place that is flat'. It falls within the coastal plain of Maputaland and is home to the rather unique quaternary catchment W70A (Figure D.3) where frustratingly 'nothing really fits' or 'obeys the rules' of otherwise well-behaved classifications and legislative imperatives.

Early accounts from shipwreck survivors moving through the area in the 1500's attempting to get to Delagoa Bay give an indication that the area was wet with extensive marsh and swamp forest areas (Pebestbello 1564; 1576). The first botanical survey of the coastal plain within quaternary catchment W70A took place in the winter of June or July of 1920 by Aitkin & Gale (1921). Their observations indicated that the groundwater table was close the surface, with only slight drops in elevation resulting in seeps and swamps. Water could be easily obtained by digging a shallow amount into the sand. They indicated large extents of hygrophilous vegetation as well as an abundance of wetland and swamp vegetation in the region, providing evidence that the region was historically generally wet and rich in aquatic ecosystems.

On the surface, significant features within the catchment include Lake Sibaya freshwater and the Kozi Bay estuarine system. Lake Sibaya is notability the largest natural freshwater lake in South Africa. The lake level of Sibaya is interpreted as an 'exposed portion of the groundwater table' (Hill 1979). 'Streams' or rivers are essentially groundwater discharge zones. The numerous wetlands and ephemeral hygrophilous grasslands areas are associated with the inter-dune depressions within this relatively flat and low-lying landscape (Porat & Botha 2008; Pretorius *et al.* 2016).

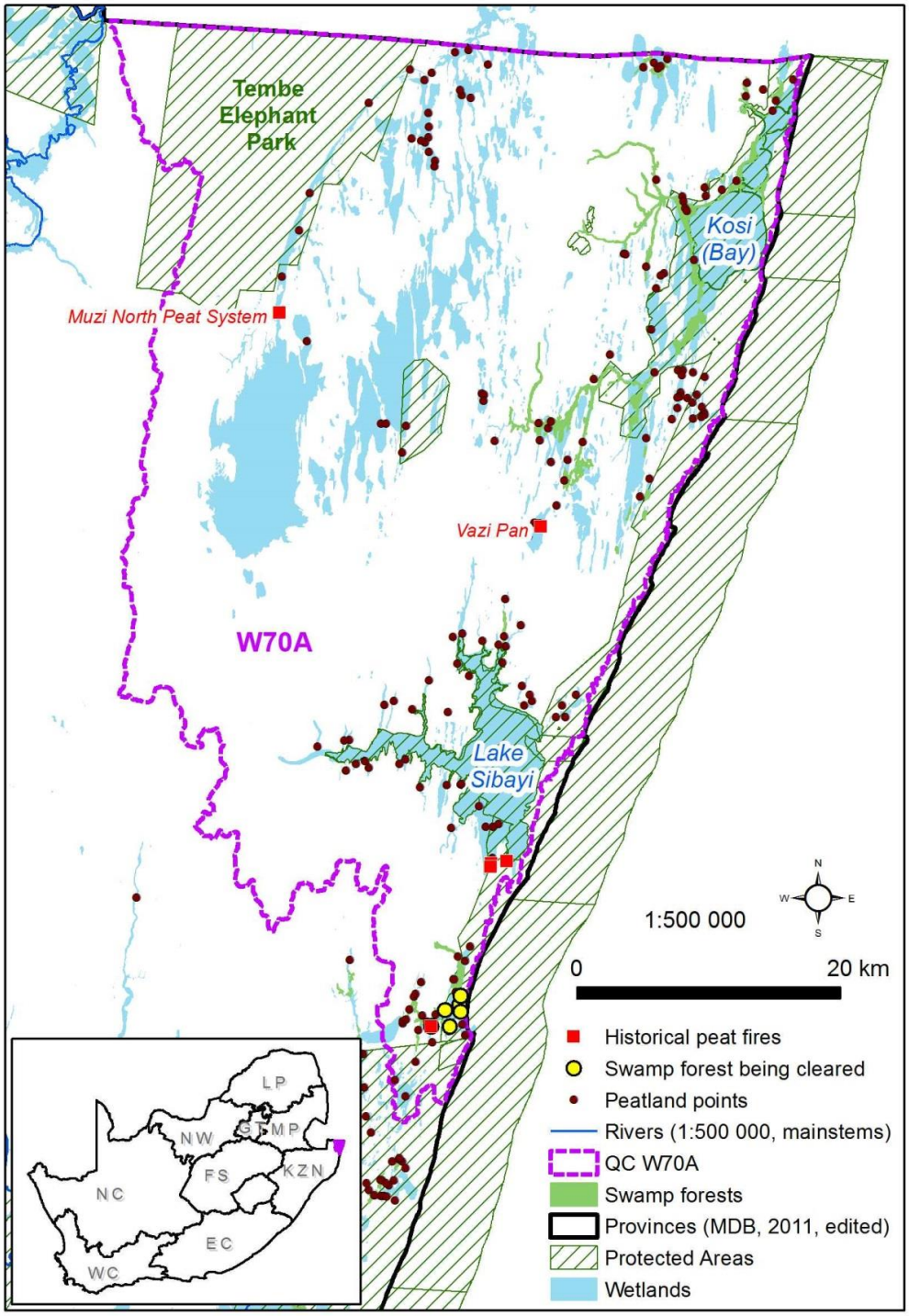


Figure D.3. The location of quaternary catchment W70A on the Maputaland Coastal Plain.

Bruton *et al.* (1980) give a detailed summary of the human history of the region. Known as '*Terra de fumos*' or '[The land of fire]' by the Portuguese in the 1500's, and soon a reputation developed that the areas on low land near the coast were not suited to livestock production, has poor soils unsuited to agriculture, were swampy and considered 'unhealthy'. This was due to the prevalence of various diseases, such as sleeping sickness, African Trypanosomiasis (*Trypanosoma brucei*), transferred from the tsetse flies, affecting livestock and humans. Malaria (*Plasmodium falciparum*) was particularly rife as noted from accounts by Owen (1833). "The fever now began to make its ravages amongst our officers and seamen: in three days I was the only white person on board able to do anything; and it is most astonishing to me how I bore up so

long, surrounded as I was by the dying and the dead … . There now remained only seven officers and men out of the twenty who composed our original crew … . Such was the fatal result of the Cockburn expedition up the Mapoota, a tragedy not the less to be deplored, because hitherto it had been almost the certain consequence of exploring African rivers … ." (Owen 1833:142). Malaria and sleep sickness were only contained with the large scale with the spraying of Dichloro Diphenyl Trichloroethane (DDT) pesticide, which has left its mark on Lake Sibaya as reported by Humphries (2013) who demonstrated total DDT levels are in Lake Sibaya are some of the highest in South Africa, and exceed safety guidelines. This pollutant and derivatives from DDT have also made their way into the ocean where they have been found to be accumulating in corals, postulated to be coming from subterranean outflows of contaminated groundwater into the ocean (Porter *et al.* 2018).

The area around Lake Sibaya was proclaimed for rural development in 1936 and by the 1970's was still considered 'largely unspoilt' (Bruton 1979) within 5 km's of the Lake Sibaya (Figure D.4), with only 631 huts and 1 451 people (Appelton & Bruton 1979).

Figure D.4. Lake Sibaya (Photo: Susan Janse van Rensburg, August 2018).

D2.2. The recent history of the formation of Lake Sibaya and the coastal wetlands

According to Miller (1998) the wetlands and coastal lakes developed about 43 000 years before present (YBP) within the Maputaland region, including the 'Proto-Lake Sibaya'. Sea levels then started to drop, initially gradually and then rapidly to 150 m below present levels, ultimately resulting in a breach of the lake into the sea between 24 000–18 000 YBP, draining the lake and incising the coast plain topography to 40 m below current sea level. Thereafter sea level recovered to approximate current levels around 8 000 YBP. Processes from then are best described in Miller's (1998) own words:

'*Coastal wetland conditions developed inland of the lagoon ± 7 060 YBP and the Holocene dune topography was flooded to form small interdune lakes. These small water bodies had high levels of productivity and were the accumulation sites of thin lenses of calcareous freshwater diatomite. At ± 5 610 YBP to ± 5 030 YBP the coastal barrier was established allowing beach/aeolian processes to begin infilling the breach in the coastal dunes and for the lagoon to begin evolving towards freshwater conditions. The dune topography rises up to elevations of 166 m in the area that was only 5 000 years ago a shallow sand bar that separated a saline lagoon from the open sea ... .'* (Miller 1998:113).

D2.3. Vegetation communities and wetland types

Quaternary catchment W70A falls within the Indian Ocean Coastal Belt biome where vegetation units as per Mucina & Rutherford (2006), include Maputaland wooded grasslands, northern coastal forest, azonal swamp forest, a large extent of sub-tropical azonal freshwater wetlands, azonal mangrove forest, azonal sub-tropical salt pans, subtropical dune thicket and sub-tropical seashore vegetation units. More detailed work in the area reveals a rich diversity of wetland types including some of the deepest (as well as diverse) peatlands in South Africa (Kramer 2003; Grundling *et al.* 2013; 2016; Grundling 2014; Pretorius *et al.* 2016; Gabriel *et al.* 2017; 2018). Grundling (2014) identified the following wetlands types in a study area focused on the northern section of quaternary catchment W70A north of Lake Sibaya '*permanent wetlands such as peat swamp forests, peat reed and sedge fens; temporary wetland systems such as perched depressions, and sedge/moist grasslands'.*

Importantly, the Maputaland coastal plain holds a high proportion of South Africa's peatlands (see Appendix C3. *Peatlands of the Maputaland Coastal Plain and iSimangaliso Wetland Park*). For peat to form it needs a near constant supply of water so it is safe to say where peatlands exist those areas have traditionally been continually or near continually wet. Peatlands play an important role in local hydrological dynamics, particularly in the sandy coastal plain, in that they act as sponges, retaining water from high rainfall events, impeding rapid discharge (Gabriel *et al.* 2018). The peatlands within the northern section of the Maputaland are estimated to be approximately 6–7 000 years old (Miller 1998; Gabriel *et al.* 2017). The high conservation priority, the diversity of natural ecosystems and tourism rich opportunities, coupled with the fact that the soils are generally poor with little option for agriculture or industrial development in the region, has led to numerous calls careful systematic conservation planning and the development of the region as an ecotourism hub (Watkeys *et al.* 1993; Matthews *et al.* 1999; Botha 2015; Perera *et al.* 2018).

The high conservation priority, the diversity of natural ecosystems and tourism rich opportunities, coupled with the fact that the soils are generally poor with little option for agriculture or industrial development in the region, has led to numerous calls for careful systematic conservation planning and the development of the region as an ecotourism hub (Watkeys *et al.* 1993; Matthews *et al.* 1999; Botha 2015; Perera *et al.* 2018).

D2.4. A messy misfit: conventional water resources management and classification systems just don't work well here

'*Accurate wetland mapping and delineation in this environment is problematic due to the ephemeral nature of wetlands and extensive land use change. Furthermore, the deep Aeolian derived sandy soils often lacks soil wetness indicators in the soil profile'* (Grundling 2014:vi).

This area presents a number of challenges with respect 'how to deal with it' from conservation management, wetlands classifications, water resources management and compliance perspectives. In addition, poverty, politics, power relations and land use planning challenges are complex. Simply put, it's not as well 'behaved' and easy to classify compared to other landscapes in South Africa and the socio-economic and political dynamics seem insurmountable. In combination this makes the area highly vulnerable to mismanagement that, coupled with climate change, will increase water scarcity.

Other than being very flat, the catchment is distinct from other catchments along the coastal plain in that ***there are no upper catchment surface rivers importing water into the area***. Local rainfall is therefore the only source of water for maintaining and recharging the water table. Groundwater is vital source of water

for of 'offsetting' evapotranspiration in the lakes and wetlands (Botha 2015). While the Maputaland coastal plain in general is described as a groundwater-driven system or aquifer dependent ecosystem (ADE) (Colvin *et al.* 2007; Vaeret *et al.* 2009), this is particularly true for the quaternary catchment W70A, where Lake Sibaya is a truly ADE as per Colvin *et al*.'s (2007) definition. Terrestrial and aquatic resources over the entire catchment could or should be considered as one large ADE since biodiversity and ecological processes are directly linked to groundwater dynamics which occur at the catchment scale and are fundamentally interlinked. While a number of the wetlands in the systems are possibly perch and thus not true ADE's, their embedded interactions at a regional context are likely linked to the dynamics of the aquifer.

Grundling *et al.* (2013) provides an indication of the difference in observable extent of wetlands for the northern portion of quaternary catchment W70A, demonstrating significant differences in wet years compared to dry years. Grundling's work, together with challenges highlighted with delineation techniques on the sandy plain (Grundling 2014; Pretorius *et al.* 2016) emphasise the importance of ensuring wet period extent mapping is critically important in any delineation and land use management work.

The National Water Act (RSA 1998) as well as other forms of legislation refers to potential use of 'buffer zones' to mitigate negative impacts of land use or streamflow reduction activities on water resources. How these are applied is still some source of debate in general for the country. The application of wetland delineation concepts to create buffer Zones to protect wetlands in the sandy Maputaland Coast Plain may be somewhat nonsensical in this geohydological setting. Here the 'riparian or buffer zone' is essentially the entire groundwater catchments' water table. Using polygons to define wetlands with buffers to define what should be protected is somewhat meaningless in this system unless you concurrently protect the ground water catchment that feed these wetlands. In order to ensure the integrity of the hydrological regime, a novel approach is likely to be required that takes the connectivity of the system into account. Applications of the prescripts of stream flow reduction principles in this area are problematic and difficult to apply. The National Water Act (RSA 1998) specifically details streamflow reduction activities in Part 4, section 36, ensuring that activities such as forestry are controlled in relation to their impact on streamflow. This however does not adequately cater for impacts on groundwater driven systems such quaternary catchment W70A where rivers are largely absent, but the impact of forestry on the groundwater resources is potentially significant. Ideally these policies, the Resource Quality Objectives and Reserve Determination studies of the Department of Water and Sanitation (DWS) and the application of river and wetland buffer zones for mitigation should be revised and adapted to take the unique hydro-ecological nature of unique coastal systems into account. In this respect is important to note that while Lake Sibaya itself is within the iSimangaliso WHS, the fringe areas, parts of its high-water floodplain and the greater groundwater catchment sustaining the system are external to the designated 'protected' WHS boundaries. It was already understood in the 1970's that the Lake Sibaya area system is sensitive to fluctuations in rainfall and should be managed as a catchment in an integrated way (Bruton 1979). Here it should be noted that the surface water catchment and the groundwater catchment are not the same thing (see Box D.1).

Box D.1. Concepts in Geo-Hydrological modelling of Groundwaer dominated environments: The Maputaland Coastal Primary Aquifer.

Contribution from Prof. Bruce Kelbe: HRU-University of Zululand, 24 October 2018.

Introduction

The Zululand Coastal plain is a region where there are strong linkages between the terrestrial, the aquatic, the ecological and the marine environments. Nearly the entire coastal margin from the Mfolozi Estuary to the Mozambique border is a proclaimed nature reserve due to its national and international importance linked to groundwater

Modelling the Hydrology

A common approach to hydrological modelling is based on the perception that rainfall impinging on the land surface will flow downhill to the rivers and streams (drainage lines) where it is more rapidly transported to the catchment outlet. In these situations, the steep topography and shallow soils will support surface (Hortonian flow), subsurface (Inter-flow) and saturated overland (Dunnian flow) runoff that is controlled to a very large extent by the topographical gradients (Figure 1). Discharge from the rivers is provided by rainfall contained within the topographical catchment (Beven 2001). This simple conceptual, vertically driven flow model that is used in most surface water modelling system ignores the 3D groundwater flow dynamics that can play a fundamental role in the distribution of rainfall (recharge) to distant boundaries such a stream, lakes and the Ocean.

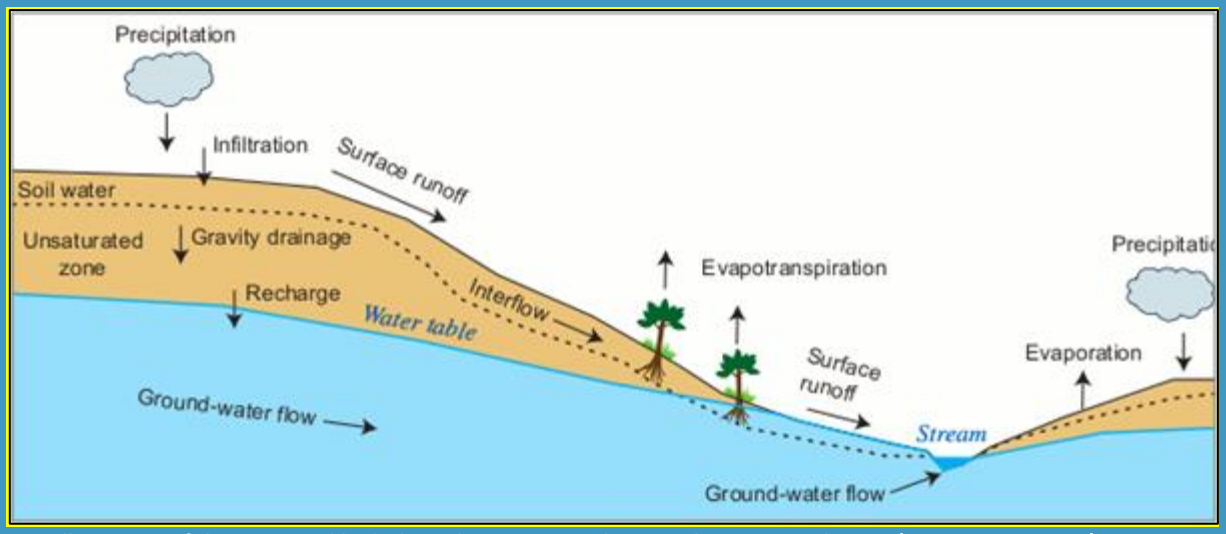


Figure.1 Illustration of the conceived hydrological processes under consideration in selection (USDI & USGS 2008).

The primary aquifer in the Maputaland Coast Plain is characterised by an extensive, veneer of unconsolidated deep sandy deposits overlying an impermeable layer of mudstone (silt and clay) formed during the Cretaceous Period. These deep soils are highly permeable and exhibit little signs of surface runoff. Nearly all effective rainfall, after accounting for interception losses, is perceived to infiltrate the deep soils or pond in shallow depressions and wetlands. The infiltrate will percolate vertically downward under gravity drainage to the saturated zone (water table). This vertical flow will form the groundwater recharge that will then be transported down the groundwater gradient toward discharge boundaries such as rivers, lakes and wetlands where they intercept the water table. Under these conditions the discharge in the drainage lines is derived from the recharge contained within the groundwater catchment rather than the topographical catchment.

The groundwater catchment may be significantly different from the topographical catchment in the coastal plain. For example, Bate *et al*. (2016) showed that the topographical catchment for the Mgobezeleni estuary incorporating two lake systems (Mgobezeleni and Shazibe) was significantly different to the groundwater catchment (Figure 2).

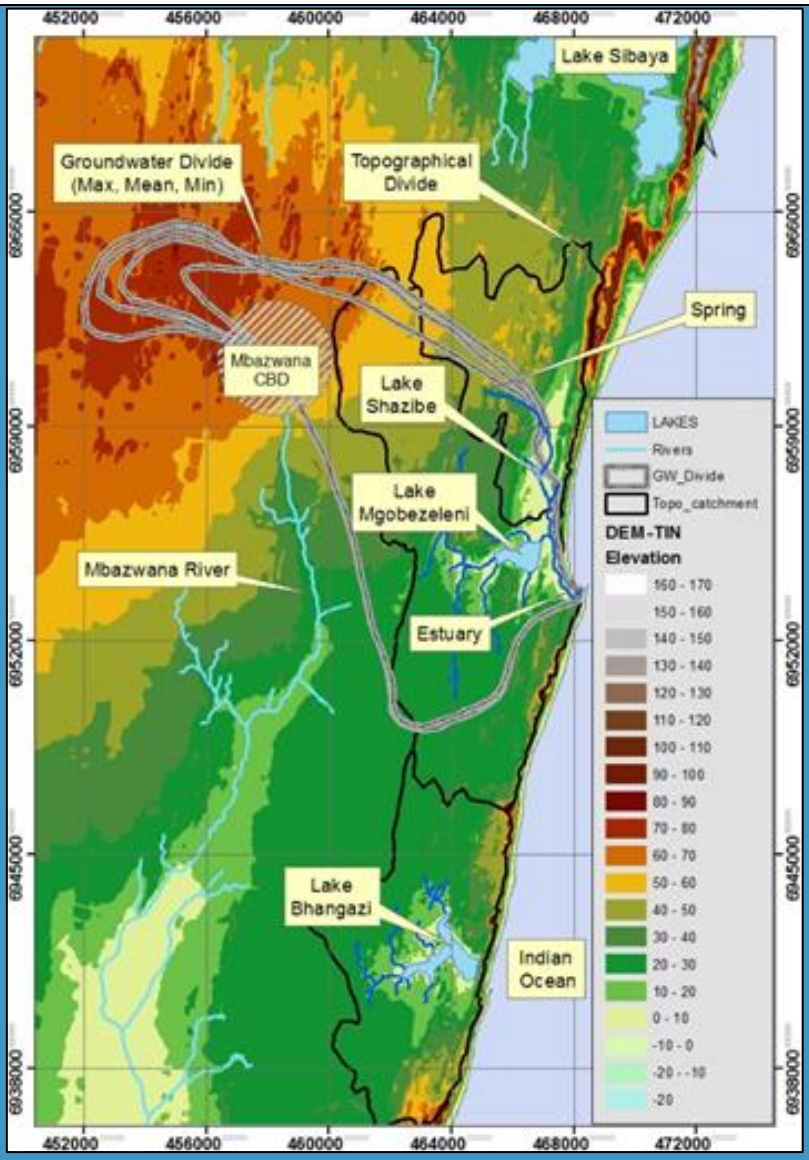


Figure 2. The hydrological catchments for the Sodwana Estuary, including the Mgobezeleni and Shazibe Lakes from Bates *et al.* (2016). The topographical catchments derived from Survey & Mapping data is shown by the black-outline polygon for the lakes. The white polygons show the transient outline of the groundwater catchment zones during wet and dry periods (2002–2016). The groundwater catchment was 101 Mm^2 on average and varied by 15 Mm^3 between wet and dry periods.

A surface-groundwater interaction study (Everson *et al.* in prep) for the Vasi Pan area between Lake Sibaya and the Kosi Bay Lake system shows similar differences between the topographic and groundwater catchments. In addition, the same pattern is evident for Lake Sibaya in an ongoing study by Kelbe (unpublished).

These highly significant differences between the topographical and groundwater catchment are a crucial issue in land use impact studies if the anthropogenic activities are located inside the groundwater catchment but are external to the topographical catchment.

Conclusions

With respect to the perceived difference in the dominant hydrological processes that are likely to control the movement of water from source (rainfall or recharge) to sink (rivers, lakes and the Indian Ocean), it is proposed that the groundwater dynamics are an essential component of the hydrological modelling of the downstream impacts from anthropogenic activities such as changes in land use practice. Consequently, hydrological models with limited or no groundwater storage and transport capability are generally not suitable for hydrological impact studies on the Maputaland Coastal Plain.

Wetlands in the area are also notoriously difficult to map in terms of spatial extent and to classify using standard or traditional methods (soil form, topographic, vegetation and soil wetness) which tend to fall apart as highlighted by the former Department of Water and Forestry (DWAF) guidelines (DWAF 2005), as well as according to Grundling (2014) and Pretorius *et al*. (2016), due to the nature of the Aeolian derived sandy flats and the consequent lack of wetness indicators. Traditional methods are not adequate to identify and delineate wetlands sufficiently to reflect their true extent. As a result, some wetland delineators employed by wealthy corporates (forestry companies) will 'follow the rule book to the 'T' to the advantage of the paying client, which will result in a number of true wetlands and/or their full extent that are seasonally dry when mapped, being conveniently ignored and not 'identified' as wetlands' according to personal observed accounts. Another constraint is, because the area is very flat, doing remote mapping where slight changes in the topography are ecologically meaningful, the absence of high-resolution digital elevation model (DEM) data results in outputs being too coarse and missing wetlands units and 'edges' more easily. The ephemeral nature of this system has been clearly demonstrated by Grundling *et al*. (2013), which emphasises the need to capture the extent and nature of high water table periods in wetland delineations.

D2.5. Lake Sibaya: South Africa's largest freshwater lake in peril

Lake Sibaya — as per 1:50 000 map sheets (also known as Sibhayi, or Sibaya) — when 'full', its approximately 41 m deep at its deepest section (Miller 1998), and sits about 20 m above mean sea level (Hill 1979; Miller 1998; Weitz & Demlie 2015; Smithers *et al.* 2017). Its surface area ranges from approximately 69 km² (Smithers *et al.* 2017) to 77 km^2 (Hill 1979) and it holds over 900 $x10^6$ m^3 of water when full (Hill 1979; Weits & Demlie 2015; Smithers *et al.* 2017). This is quite substantial, equating to be in excess of Midmar Dam, Albert Falls Dam and Indunda combined (Smithers *et al.* 2017). This would have been the situation in the year 2000 (see Figure D.3.). The water level of Lake Sibaya has, however been declining since 2001 and dramatically since 2010 (DWS 2015; Weitz & Demlie 2015; Smithers *et al.* 2017).

The lake level is known to fluctuate between high and lower water levels in relation to rainfall wet dry cycles, typically by about 3 m (Hill 1979; Weitz & Demlie 2015). Smithers *et al.* (2017:485) demonstrated that there is consequently a close relationship between the lake level and 'cumulative deviation of annual rainfall from the Mean Annual Precipitation (MAP), confirming previously reports (Hill 1979) and indicating the sensitivity of the system to long term fluctuations in rainfall.

Lake Sibaya high water level(s)

Lake water levels have been recorded since 1967 and modelled as far back as 1914. The highest ever reported water level since 1914 to date was in 1977 (Hill 1979; DWS 2015; Smithers *et al.* 2017) see Figure D.5. Hill (1979) indicates this was at approximately 23,25 m amsl (metres above mean sea level), whereas Smithers *et al*. (2017) with the use of updated input data, indicated approximately as 20.4 m amsl. Anecdotal information regarding the 1977 high water period of Lake Sibaya exists due to a research station started in 1965, which initially started as a tented camp and was subsequently upgraded to have more permanent features in 1967 and permanently staffed as of 1968 (Bruton 1979). The research station was situated within a *Vachillia karoo* fringe in between the lake and the dune forest (Breen 1979). Following heavy rainfalls in February and March of 1975, the lake began to rise rapidly. Barriers were put in place to try and save the research station from flooding, but above average rainfall through the winter months of 1976 followed. Fearing continued high rainfall in early 1977, evacuation started as it seemed road access

was in threat of being flooded (Bruton 1979). It was then deduced that the *V. karoo* fringe is pioneer vegetation from a previous high-level mark and postulated 'It is not unreasonable to suggests that the development of such a community may take between 17–20 years keeping pace with the hydrological cycles' (Breen 1979:33). It was concluded thus: 'The moral of the story is clear: do not build a field research station in *V. karoo* communities on the shores of the lakes!' (Breen 1979:33).

Subsequent peaks in high water levels have been in 1983/84, coinciding with Tropical Storm Domoina January (1984; 1991/92). The severe Tropical Storm Debra between 22 February and 4 March 1991 may have brought goods rains, with the last peak being in 2000, coinciding with Cyclone Leone-Eline (February 2000) see Figure D.6. The 1977 flood event was not said to coincide with a cyclone in that year, however, in 1976, Cyclone Danae hit the east coast of Mozambique and South Africa. Maud (1980) reported that 700 mm associated with cyclonic rainfall fell at Lake Sibaya in three days in early 1976, most likely from Tropical Cyclone Danae (between 10 and 29 January 1976). While rare, it does seem clear, as Maud (1980) indicated that the region is at least occasionally subject to significant rainfall from tropical systems. These may play an important role in the long term dynamics of the system. Grundling (2014) reported wet periods within the catchment as having occurred in the years 1909–1922; 1954–1967; 1971–1984 and 1989–2000, with an alternating of wet dry cycle of 9 to 13 years. Such a decadal time scale is close to that previously identified to exist in summer rainfall over South Africa (Tyson *et al.* 1975).

Figure D.5. Landsat view of Lake Sibaya at high level in around the time of 1977 from a 1976/1978 composite, note wetland areas to the north of the lake indicated in the orange circle within the forestry area known as Vazi Pan (Source: https://landsatlook.usgs.gov/viewer.html).

Figure D.6. Last high water event in 2000 after cyclone Eline, not large sections of surface water to the north of the lake, including Vazi pans (Source: https://landsatlook.usgs.gov/viewer.html).

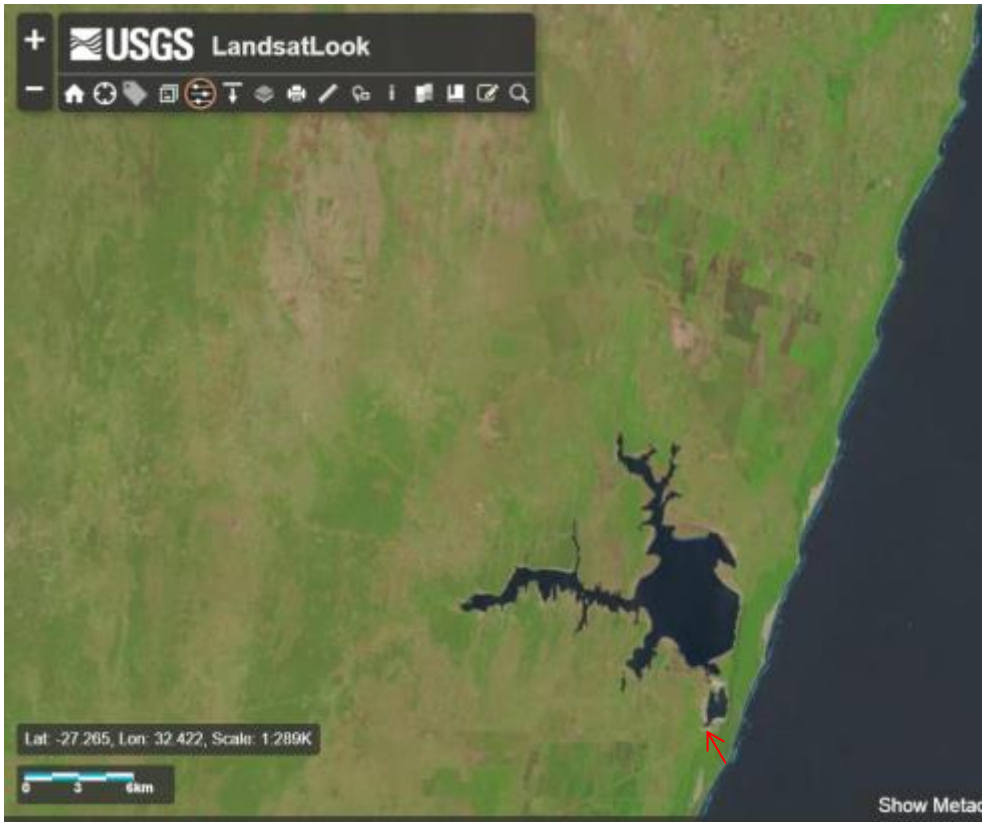


Figure D.7. Low water event composite from August to November 2017, at the start of the 'rainy season'. No water in any wetlands areas evident (Source: https://landsatlook.usgs.gov/viewer.html). Red arrow indicates the Department of Water and Sanitation (DWS) gauge plate well out of the current extent of the water.

Lake Sibaya lows: 2018 lowest water level in recorded history

Prior to 2010, the lowest **recorded** water level at Lake SIbaya was in 1970 (Hill 1979; DWS 2015; Smithers *et al.* 2017). In 2010, this low water mark was exceeded with levels dropping below the 17 m amsl mark (DWS 2015; Smithers *et al.* 2017). The only other major dip was in 1997 or 1998 when the level dropped to about 18.3 m amsl (Smithers *et al.* 2017).

Modelling and analyses completed before or ceasing in the early stages of the 2015 drought showed the lake had reach an all-time low of just over 16 m amsl. By May 2015 the level was 15.5 m amsl in (DWS 2015). Sometime between 25 December 2014 (Google Earth images of the date) and July 2015 (DWS 2015) the southern basin and main lakes became separated. Around the same time, the water level in the southern bay dropped to the extent that the DWS recording station was above the water level, therefore lake level readings stopped at this point (See Figures D.5 and D.7). By July 2015 the surveyed difference between the southern basin and the main lake was already 1.3 m amsl (DWS 2015). In November 2017, The South African Environmental Observation Network (SAEON) in collaboration with DWS, surveyed the edge of the lake(s) and boreholes in the close proximity as part of their effort to revitalized long term monitoring of the system in order to understand relative impacts on land us and climate in the region, which is impossible in the absence of lake level data which is currently not being officially recorded. At this point the difference between the main lake and southern basin was 6.4 m (SAEON, unpublished data). In January 2018 the large main basin was only **14.8 m** amsl, a new record low, and the southern basin was at **8.3 m amsl** (see Figures D.8 and Figure D.9, with particular focus on D.9(C)).

Figure D.8. The Department of Water and Sanitation's (DWSs) gauge plates (green arrow) have been above the low water mark since 2015. Looking north east, the large red arrow indicates land bridge between southern basin and the main basin. The yellow arrow shows location of Banda Banda Bay from where repeat photos below were taken (Photo: Susan Janse van Rensburg, 20 July 2018).

Water licences with the abstraction point in the southern basin (which serves Mbazwana and surrounding areas) have been determined relative to the entire lake. The fact that these two sections are now separated violates the assumptions that would have been in place to determine the licence. Abstraction is still taking place from what is now essentially a much reduced water source in the southern basin which does not appear to be well enough connected to the main basin in order to replenish levels as indicated by the increasing gap between the main basin levels and the southern basin levels. This at first glance highlights the question of the sustainability of abstractions from the southern basin, especially when lake levels are very low when the two basin areas are separate. Essentially this should necessitate a review of the water

licencing conditions. However, the question is whether this still be the case if the surrounding land use changed and what if the groundwater catchment was better protected from the impacts of forestry?

(A)

(B)

(C)

(D)

Figure D.9. Repeat photos taken at Banda Banda Bay, looking southwest, from the eastern edge of the lake demonstrating decline in water level in the southern basin of Lake Sibaya. Note the land bridge to the right of the photos is what is separating the southern basin with the main basin; (A) was taken in 2015, at this stage there was already significant concern regarding the decline in the lake level; (B) September 2016; (C) November 2017; (D) September 2018, showing Bunda Bunda Bay no separated from the rest of the southern basin (Photos: Susan Janse van Rensburg).

Day zero looming?

The relationship with bathymetry and lake volume has previously been calculated. However, reports differ in this relationship. A conservative approach to view the lake level of 14.8 m amsl with the assumption that the southern basin was at the same level (which it is not), the volume of the entire lake at 14.8 m amsl would equate to a volume of between 200 x10^6 m^3 to 500 x10^6 m^3 depending on which relationship is used. At worst, this is ¼ of the potential total lake volume left at best just over half. In other words, **the lake has lost 50–75% of its total volume since 2001.** Which urges us to ask, when is Day Zero for Lake Sibaya?

As stated before, Lake Sibaya levels are a reflection of the groundwater dynamics over the whole system. As lake levels starting dropping in 2001, with time wetlands in the system started drying out (see Figure D.10 A–D). The degree to which this has been taking place seems unprecedented. Indeed, concern has been raised in particularly around the Vazi Pan peatland just north of Lake Sibaya (see Section D.3), as well as the extensive wetlands network towards the Kosi Bay. Several studies have been highlighting the significant decline water table in the region since 2001 (Grundling *et al.* 2013; Grundling 2014; Von Roeder 2015; Pretorius *et al.* 2016). Local experience in drilling boreholes for water for human consumption indicates this decline is more significant that anything previously encountered (Anon 2018).

(A)

(B)

(C)

(D)

Figure D.10. A–D: Dry wetlands and around Lake Sibaya. Photos: Susan Janse van Rensburg July 2018.

D3. Causes of water table declines in quaternary catchment W70A

Water leaves the groundwater aquifer or lake through several pathways, such as seepage into the sea through the dune cordon, evaporation from the lake, evapotranspiration from plants tapping into the saturated soils or groundwater table, abstractions from boreholes and pumping directly from the lake for potable water for Mbazwana and Mseleni. It enters the region only through local rainfall.

D3.1. Abstraction from the lake

The total population in the Umhlabuyalingana Local Municipality (ULM) local municipality for the 2011 population census totalled 156 736. In 2018 populations is currently estimated at over 170 000 individuals. There is no bulk water supply importing water into the area and minimual infrastructure within the catchment. Community boreholes, municipal borehole well fields, wetlands and Lake Sibaya are the primary sources of water, all of which draw from the groundwater aquifer.

By the 1970's people were already using piped water from Lake Sibaya abstracted from the western arm of the lake to supply the Mseleni Provincial Hospital however this was considered negligible in relation to the volume of the lake (Bruton 1979). Over time abstraction from the lake has increased. However, studies indicate the **volume abstracted for human use is still negligible** compared to losses such as drought and forestry (Weitz & Demlie 2015; Bate *et al.* 2016; Smithers *et al.* 2017).

D3.2. Impact of afforestation

Global reviews of catchment experiments (Bosch & Hewlett 1982; Zhang *et al.* 2017) demonstrate that forests impact on water yield by reducing runoff and groundwater storage. Within the Maputaland Coastal Plain, concern regarding the impact of commercial pine and eucalyptus plantations dates back to the 1960's when a commission was set up to investigate the risk they posed to the St Lucia system (Kelbe *et al.* 1995). Indeed, groundwater decline was demonstrated as more significant under plantations then in natural grasslands within the St Lucia system (Rawlins & Kelbe 1991).

An extensive afforestation program was started around Lake Sibaya in 1958 by the then Department of Forestry (Marwick 1973). Two forest stations were developed; one in Mbazwana, south of the lake and one at Manzengwenya. Manzengwenya drew water for its operations from a well near Vazi Pan (Bruton 1979). The catchment area for Lake Sibaya is estimated at 578 km^2 (Smithers *et al.* 2017) with 60–77 km^2 of the catchment being taken up by the lake depending on its level (Hill 1979). By the 1970's, 70 km^2 of the catchment was covered by plantations comprised of eucalyptus and pine (Bruton 1979). At this stage it was postulated that these trees may affect the hydrological balance of the shallow aquifer (Bruton 1979). Personal accounts from people living in the Vazi Pan area and around Lake Sibaya indicated that prior to forestry there was a lot of water, with many pans in the area. Crocodile, fish and hippos were common in these pans (*The Vazi storyboard* film by Mrs Siphesihle Bukhosini).

In recent years pines are being replaced by eucalyptus species in the commercial plantations and informal eucalyptus woodlots are expanding (see Figure D.11; Table D.1 based on data from Skowno 2018). Figure D.11 demonstrates the increase between 1990 and 2013/4 of 45.6 km^2. Forestry species, particularly eucalyptus, are known to have relatively high evapotranspiration compared to indigenous vegetation (Rawlins & Kelbe 1991; Vaeret *et al.* 2009; Von Roeder 2015; Weitz & Demlie 2015; Smithers *et al.* 2017). As a result, plantations can have a significant impact on drawing down the water table. The degree of

afforestation within the groundwater catchment boundary is thus likely to affect the water table. This is particularly so in this area due to the sandy nature of the soil and the unconsolidated nature of the sandy aquifer. Trees can only use water if it is available and if they have enough energy to take water up. For many tree species, as the water table drops, transpiration stops when roots can no longer get access to the water. However, eucalyptus trees are deep rooted and observations have been made of roots being found well below 30 m of the surface (Schapers, 2018, *pers. comm*.). It is speculated that as the water table drops the eucalyptus roots continue growing downwards, tracking the saturated zone or water table as it declines.

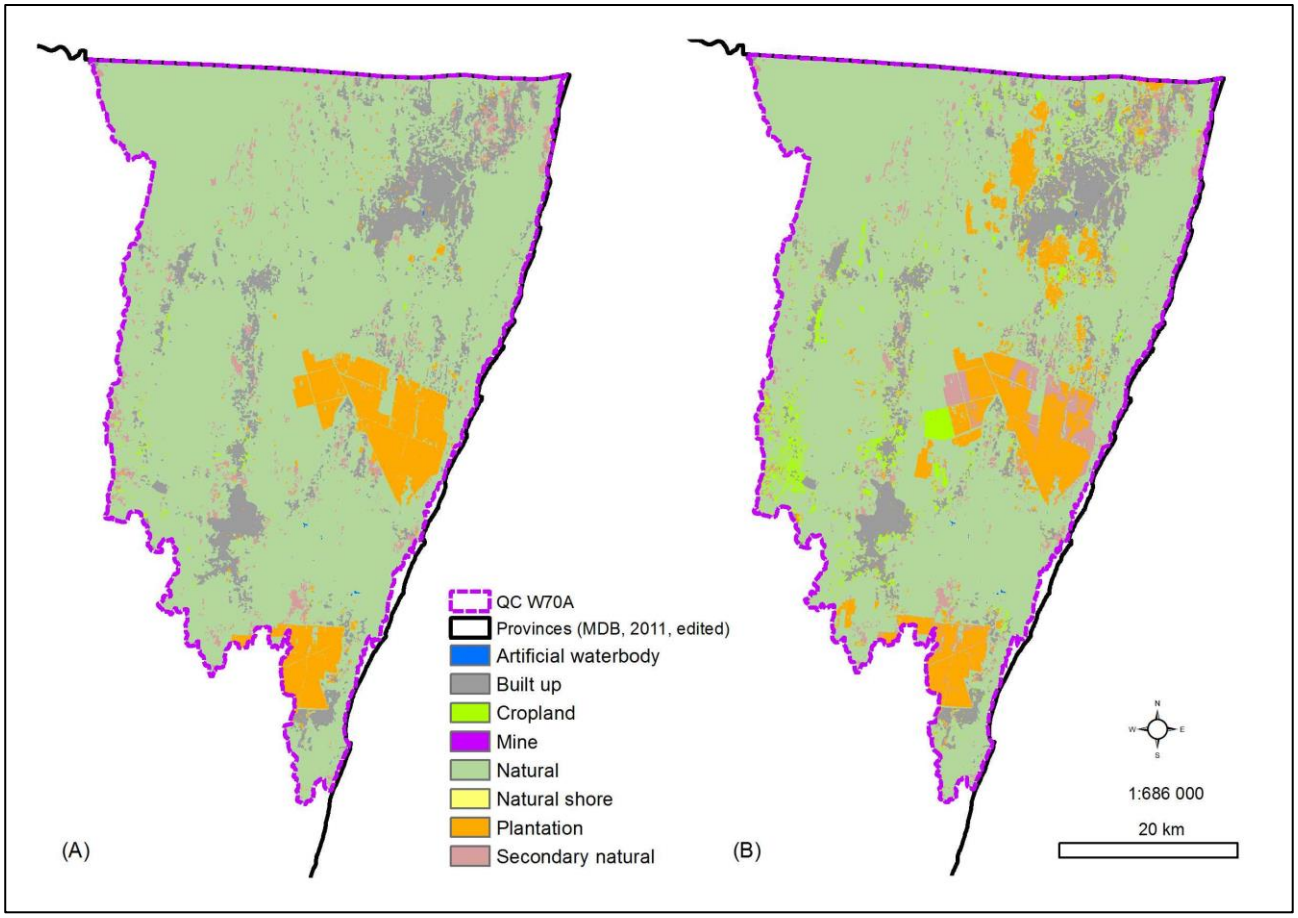


Figure D.11. Land cover changes between 1990 and 2013/4, demonstrating the increase in forestry by about 4 557.7 ha [45.6 km^2] shown in orange between 1990 (A) and 2013/14 (B). Further expansion of eucalyptus has taken place subsequent to this (S. Janse van Rensburg, personal observation).

Table D.1. Changes in land cover between 1990 and 2013/4 (A) in extent and (B) in percentage of study area W70A.

(A) Extent of change in hectares: LC1990 (down) / LC 2014 (across):	Artificial waterbody	Built up	Cropland	Mine	Natural	Natural shore	Plantation	Secondary natural	Grand Total
Artificial waterbody	43.1								**43.1**
Built up		22 478.7	499.0				183.8	2 294.5	**25 455.9**
Cropland		0.9	517.6				18.8	49.9	**587.2**
Mine				0.1				1.4	**1.5**
Natural		542.7	6 996.9	0.3	193 709		8 969.4		**210 218.3**
Natural shore						0.2			**0.2**
Plantation		90.4	32.2				14 545.7	4 804.6	**19 472.9**
Secondary natural		19.6	513.5				269.1	6 862.3	**7 664.5**
Grand Total	**43.1**	**23 132.3**	**8 559.1**	**0.4**	**193 709**	**0.2**	**23 986.8**	**14 012.6**	**238 156.7** **263 443.8**
(B) Percentage change: LC1990 (down) / LC 2014 (across):	**Artificial waterbody**	**Built up**	**Cropland**	**Mine**	**Natural**	**Natural shore**	**Plantation**	**Secondary natural**	**Percentage changed**
Artificial waterbody	100.0	-	-	-	-	-	-	-	**-**
Built up		88.3	2.0	-	-	-	0.7	9.0	**11.7**
Cropland		0.2	88.2		-	-	3.2	8.5	**11.8**
Mine				5.9	-	-	-	94.1	**94.1**
Natural		0.3	3.3	0.0	92.1	-	4.3	-	**7.9**
Natural shore						100.0			**-**
Plantation		0.5	0.2	-	-	-	74.7	24.7	**25.3**
Secondary natural		0.3	6.7	-	-	-	3.5	89.5	**10.5**

Several studies on the Maputaland Coastal Plain indeed provide evidence for a significant impact of forestry on the aquifer and its associated ecosystems within the Maputaland Coastal Plain (see Kelbe *et al.* 1995). In 1971, Tinley produced a report focusing on the St Lucia system where he re-highlighted to the importance of the fresh groundwater contribution to the health of the lake and argued the impact of the plantations on the groundwater resources feeding the system. Plantations on the eastern shores of Lake St Lucia were subsequently removed (mid 1990's–2006). The relative impact of climate and management, such as pine plantation removal was later assessed by Vaeret *et al*. (2009), who demonstrated, through modelling, that the act of removing forestry had a positive impact on the groundwater table in the eastern shores section of the reserve.

Bate *et al*. (2016) demonstrated that in the Mgoboseleni or Sodwana Bay area, which is within the quaternary catchment W70A, commercial plantations and woodlots induce 'a systematic drawdown in the immediate vicinity of the plantations' of up to 1 m per year, causing a 'cone of depression' under the plantation. Furthermore, they inferred that the cumulative impacts of this 'extend well beyond the peripheral edges of the plantations' impacting on local communities and the drainage system. Their models clearly illustrate that the drawdown caused by plantations is significantly greater than that of natural indigenous vegetation.

While it is difficult to access accurate up to date figures since the 2013/4 figures presented above, of the full current extent of plantations in the region, indications are that the eucalyptus plantations are

increasing in extent within the quaternary catchment W70A (see Figure D.13). This is likely to be partly in response to an imminent transfer of the Manzengwenya- and Mbazwana State Plantations (close to 20 000 hectares) to the tribal authority, under the Tembe Traditional Council, Mbila Traditional Council and the Mabaso Traditional Council (TMM) Forestry Company, who are the three tribal authorities involved in the company. In an SA Forestry Online article (2012) the TMM project is heralded as South Africa's biggest forestry land reform project. A representative from TMM outlined that, in addition to the large-scale commercial venture, they are assisting small growers to expand as well. Despite acknowledging that plantations use up water, forestry is considered by the TMM representative to be the only economic activity available to the region as tourism has up until now failed to deliver much needed economic development (SA Forestry Online 2012 http://saforestryonline.co.za/articles/land_and_community/sas_biggest_land_reform_forestry_project/). Estimates in the same article put the total area in the catchment under plantation at about **28 000** ha including the small grower wood lots. Work to fell and replant the neglected DAFF plantations has already started (see Figure D.12) initially with funding from the Development Bank of South Africa's (DBSA) Jobs Fund (Figure D.13). TMM have more recently indicated that they are exploring alternatives, mindfull of the water impact of Eucalyptus species on the greater area, and will be experimenting with Macadamia nut plantations in the near future.

Figure D.12. Harvesting of old Department of Agriculture, Forestry and Fisheries (DAFF) plantations to make way for new TMM forestry operations on Mbazwana plantation (Photo: Susan Janse van Rensburg, October 2018).

(A)

(B)

(C)

(D)

Figure D.13. A–D: Images indicating small growers new and expanding plantations, beyond previous extents close to the edge of Lake Sibaya (Photo: Susan Janse van Rensburg, July 2018).

D3.3. Drought, cyclones and/ or climate change?

The climate of the Maputaland Coastal Plain is described in Box D.2.

Box D.2. The climate of the KwaZulu-Natal Province explained by Prof. Chris Reason and Dr Ross Blamey

Prof. Chris Reason (professor) and Dr Blamey (researcher), Department of Oceanography, University of Cape Town

The MCP region lies within the summer rainfall region of South Africa with December and January being the wettest months although, on average, substantial monthly rainfall can occur from October through to the end of April. There are a variety of weather systems that produce rainfall in the region, ranging from small convective storms through to synoptic scale tropical temperate troughs (TTTs). TTTs or cloud bands tend to be most common in early to mid-summer (Manhique *et al.* 2011; Hart *et al.* 2013; 2018) while tropical storms, and the occasional tropical cyclone tend to occur in late summer (Mavume *et al.* 2009). While tropical cyclones directly impacting the region are relatively rare, in the summers when they do occur (e.g. 1984), they can make very substantial contributions to the annual totals. Moisture flux convergence over the region associated with the peripheral circulation of tropical storms tracking in the southern Mozambique Channel can also lead to substantial rainfall over the region on occasion. Other rainfall producing systems of importance to the region are mesoscale convective complexes (summer) which can contribute up to 15–20% of the annual total rainfall (Blamey & Reason 2009; 2013), cut-off lows (most common in the transition seasons (Taljard 1985; Singleton & Reason 2007) and ridging anticyclones.

The region experiences considerable rainfall variability at inter-annual through to decadal time scales. Time series of rainfall for northern KZN (Blamey *et al.* 2018) show a recent quasi-decadal dry spell existing over the region since about 2002. Since the early 2000's the region has experienced frequent dry summer periods (Blamey *et al.* 2018). It is well documented that El Niño events have a clear impact in the summer rainfall region in South Africa. Analysis of 1950–2016 South African Weather Service (SAWS) station data for the KZN North coast indicates that 2015–2016 was by far the driest summer (October–March) with 1982–1983 the next driest summer (Blamey *et al.* 2018). Hart *et al.* (2018) showed that cloud bands were more likely to occur over the southern African mainland during La Niña summers and more likely over Madagascar and the neighbouring South West Indian Ocean during El Niño. However, relatively small changes in the location of these cloud bands over South Africa can have a large impact on the rainfall received over various parts of the eastern half of the country. For example, mid-January 2013 was associated with flooding in the lowveld region of north eastern South Africa and in southern Mozambique (Manhique *et al.* 2015) due to persistent cloud band activity. However, much less rainfall occurred over northern KZN. Therefore, not all strong El Niño–Southern Oscillation (ENSO) events lead to substantial rainfall anomalies over the region; for example, rainfall totals were near average during the very strong 1997/98 El Niño. In addition, almost all the summers during 2002–2016 received below average rainfall whereas most of the 1984–1990 summers were wet, suggesting decadal variability.

It is known that for the South West Indian Ocean as a whole (i.e. the region extending from the southern African mainland to 90°E), the number of tropical cyclones shows a decreasing trend, but an increasing tendency in the strongest categories (3–5) (Malan *et al.* 2013; Mawren & Reason 2017). It is not known whether there are changes in the numbers of tropical storms impacting the northern KZN region. Quaternary catchment W70A is at the southern edge of the 'cyclone belt'. Cyclones have contributed to high water tables in the catchment for at least three of the four recorded high-water events (1977, 1984 and 2000), significantly 'topping up' the groundwater reserve. Some models are predicting a reduction in frequency of Tropical Systems making landfall and a northward shift in their paths (Malherbe *et al.* 2013), meaning fewer systems making landfall in this region. It has now been 18 years since significant rainfall from a tropical system has made landfall in quaternary catchment W70A.

Rainfall projections for this region in respect to climate change are uncertain (Engelbrecht *et al.* 2015). Given the dependency of this catchment on rainfall, improving with climate change related projections for rainfall is a crucial priority for determining the land use development trajectory of the region. There have been significant temperature increases of between 1.6 to 2° C between 1961 and 2010, at more than twice

the rate of the global average in southern Africa's subtropical region within which ULM lies (Engelbrecht *et al.* 2015). Under a low mitigation scenario, projections indicate further 'robust' warming of between 4 and 6° C in the 21st century. The projected temperature increases alone will have significant negative impacts on agricultural potential. Higher evaporation rates, an increased fire danger index, increase in heat waves and lower precipitation are likely to prevail in the MCP in the future (Engelbrecht *et al.* 2015). Projections in rainfall are characterised by higher levels of uncertainty compared with temperature projections (Munday & Washington 2017), however, increased moisture stress related to drought indices show clear projections of drying, resulting from drier soils linked to increased temperature and evaporation (Engelbrecht *et al.* 2015).

It is unclear if current trends in drier summers and fewer cyclones can be strongly attributed to climate change, as the region receives a lower priority for detection analyses then more densely populated areas such Cape Town. It however does seem likely that climate change is having some effect. A fundamental understanding of the climate system, including interactions between the ocean, atmosphere and the terrestrial system, is required in order to comprehend the changes experienced in the MCP region and to build confidence with the projected future climate change. The relative impact of climate variability and changes to the climate system need to be assessed in relation to socio-economic drivers of environmental degradation. Given the likelihood of climate change impacts in this region, combined with the high poverty levels, lack of economic opportunity and a high percentage of people dependent on wetlands and water resources for water and food, a holistic approach is required to water resources management that can ensure appropriate economic development that is water wise coupled environmental justice.

D3.4. The net effect; relative impacts of climate, land use and abstraction

'... it is important to realise that in any evaluation of the effect of future abstraction, from the lake and its catchment must be treated as ***an integrated aquifer system****, sensitive to long term changes in regional rainfall and connected to the ocean by seepage under the dunes …'* (Bruton 1979:298).

Hydrological models confirm that prolonged ***below average rainfall*** in combination with ***forestry*** are primary contributing factors to the dramatic decline in the groundwater table associated with the Lake Sibaya catchment (Weitz & Demlie 2015; Bate *et al.* 2016; Smithers *et al.* 2017). Up to **35% of the decline has been attributed to forestry** (Smithers *et al.* 2017). There is evidence from elsewhere in the MCP that the removal of plantation trees improves the levels of the groundwater table, tempering impacts of below average rainfall (Vaeret *et al.* 2009). Abstraction volumes for potable water for human use are currently considered as insignificant relative to drought and forestry (Weitz & Demlie 2015, Bate *et al.* 2016, Smithers *et al.* 2017), although this may increase over time as populations increase and with better abstraction data. Currently conflict between water requirements for human use water and forestry is increasing. For instance Smithers *et al*. (2017) demonstrated the system is currently oversubscribed when taking forestry water loss, drought and abstraction into account, compromising the ecological reserve and potential the long term sustainability of the system. In order to make water available for additional human use requirements for which water licence applications are being made, forestry would need to be removed. Removing 5 km^2 of forestry would release an estimated 1 MCM (million cubic meters)/yr of water (Smithers *et al.* 2017). Using these same figures from Smithers *et al*. (2017), the 45.6 km^2 increase in forestry between 1990 and 2013/14 equates to an additional draw on this system of 9.1 MCM per year [9 114 000 000 litres].

Lack of capacity to initiate economic alternatives to forestry renders the region extremely vulnerable, with low adaptive capacity, to current land use and projected climate change impacts on the water resource. For

forestry to be removed, alternative economic opportunities such as ecotourism are needed. Without adaptation, a social and ecological state collapse is possible in the near future, including the drying of Lake Sibaya and saltwater intrusion into the aquifer.

D4. Consequences of the water table decline in quaternary catchment W70A

D4.1. Wetland and peatland degradation

As previously stated, the region around Lake Sibaya in quaternary catchment W70A is rich in wetlands and peatlands. Grundling (2014) warned of the increased vulnerability of these wetlands resulting from prolonged period of drought, in combination with land use pressures such as cultivation, forestry plantations as well as urbanisation and increasing the threat of fire which can threaten peatlands. The region has experienced below average rainfall since 2001 and with 2015–16 being the driest on record since 1950 (Blamey *et al.* 2018). As these systems have dried out, two primary impacts have been observed:

I. Increased accessibility: As wetland systems dry out, they have become more accessible, enabling people to increase their use and exploitation of the wetland areas (KZN Wetland forum meeting in August 2016). This is evident, along the expanse of the entire coastal plain in quaternary catchment W70A, a point in case was the contentious planting of eucalyptus species into the Vazi Pan area (see Appendix C: Peat Pressures); and

II. Peatland fires: In August 2017, calls were received that the Vazi Peat system, north of Lake Sibaya and on the groundwater divide between the Kozi Bay and Lake Sibaya groundwater catchments) was on fire (see Figure D.14). Ordinarily in this peatland, the water table would fluctuate between 0+, and 50 cm below the surface, keeping the area wet and inflammable (Gabriel *et al.* 2018). On inspecting the peatland during these burns, it was found that the water table was 1.2–2.1 m below the soil surface (Pretorius 2017) and there were significant fires burning underground (see Figure D.15). The complete loss of the Vazi North Peatland (due to the lowered groundwater table making the peatland flammable) was heart-breaking to local Isibusiso Esihle Science Discovery Centre CEO Siphesihle Bukhosini "*Our wetland is dead! What have I got to show our children now*?". Subsequent to this a number of peatland fires have been noticed within the region and around the Lake Sibaya Area.

(A)

(B)

(C)

(D)

(E)

Figure D.14. Evidence of the Vasi Pan peat system burning: (A) Burning peatland with red ash (orange) and gaseous fumes emitted from the burning peat; (B) Sihle Bukhosini watching helplessly as her living laboratory burns away; (C) Young Eucalyptus trees plant just a few years too close to the wetland; (D) SAEON technician Siphiwe Mfeka goes on a rescue mission to retrieve data loggers that had been monitoring water level in the peatland; and (E) A panoramic of Vazi north peatland as it burns away (Photos: Susan Janse van Rensburg, August 2017).

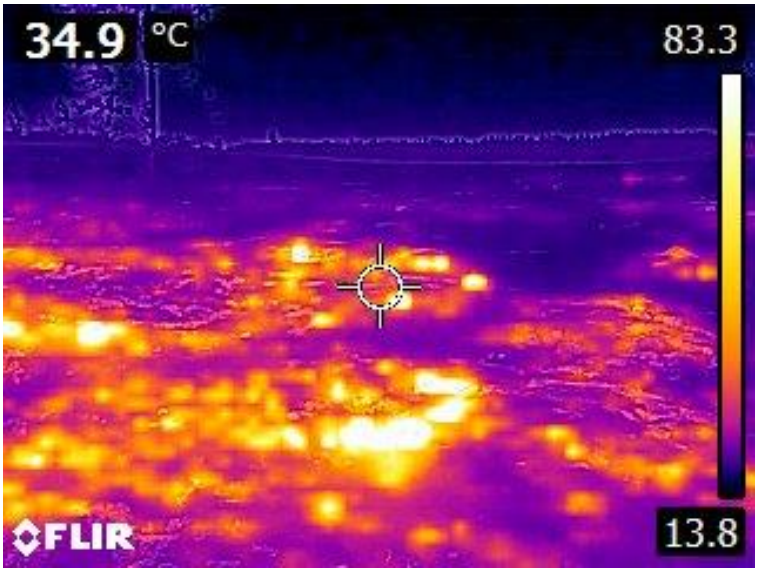


Figure D.15. Image taken with the thermal camera of the Vazi peatland while it was burning, lighter yellow patched indicate peatland burning hot underground, blue areas are cooler, note the skyline in the background for orientation (Photo: Susan Janse van Rensburg, August 2017).

D4.2. Lake Sibaya ecologic state under threat

Not only are the peatlands and wetlands around the region becoming degraded, but the ecology of Lake Sibaya itself is under serious threat. The groundwater recharge ecological reserve for Lake Sibaya is approximately 60% and the latest resource quality objectives recommend (DWS 2015) that lake should not be allowed to drop below 17.2 m amsl for more than 6 years. Lake levels have been below 17 m amsl since 2010 and continue to decline (October 2018). In addition, recommendations for the ecological reserve stipulate the drought threshold of the lake at 16.5 m amsl (DWS 2015). The main basin of the lake is currently less than 14.6 m amsl and declining (October 2018) and the southern basin is around 8 m amsl and declining. These low levels will be having an unprecedented impact on the ecological integrity of the lake. For example, there has been a major disruption of the littoral zone dynamics across the entire lake, which is important habitat for a large number of species in the lake, including many of the fish species.

The fact that the ecological reserve has clearly been compromised suggests drastic management responses are required. While below average rainfall is clearly a major contributor to this situation, forestry has also played a significant role in the decline there by exacerbating the drought conditions, and potential 'post

drought' recovery. Given that forestry is one of the impacts that can be managed at a local scale, the removal of at least a portion of forestry seems the only rational response to halting the decline.

D4.3. The socio-economic and livelihood impacts of the drought / ever-declining water levels

Economic activity within quaternary catchment W70A is considered limited, bulk infrastructure is lacking, unemployment is high, skills levels are low and the soil is nutrient poor. There is a strong coupling between water security, human well-being and ecosystem integrity within the region. All forms of socio-economic, agricultural and environmental use are entirely dependent on the groundwater with the catchment and are thus closely dependant on local rainfall. Many depend on wetlands for water, subsistence and livelihoods (Grundling 2014). As wetland systems and lakes dry out, so do the services they provide. ULM is considered one of the poorest areas in South African. Given the reliance on Lake Sibaya, wetlands and groundwater resources in the region, coupled with poverty and relatively low opportunity for economic activity, negative impacts on these systems are likely to have knock-on consequences for rural livelihoods.

Water security and environmental degradation within the MCP is pitted against the very real need for economic development. Redistribution programmes have focused on boosting community owned plantation forestry operations, but this a water-depleting activity (Von Roeder 2015; Weitz & Demlie 2015; Smithers *et al.* 2017). Communities contend that the limited **benefits accruing from forestry and tourism only benefit a few**, with growing confrontation potentially threatening the World Heritage Site Status of the iSimangaliso Wetland Park. The current decline in groundwater table is exacerbating this situation. A consequence of this is seen in the encroachment subsistence farming into swamp forests both outside the iSimangaliso Wetland Park WHS (see Figure D.16 A–E) and even within the iSimangaliso Wetland Park WHS (Figure D.17 A–F) near the entrance to Sodwana Bay. These swamp forests have been clearfelled, burnt and cultivated for bananas amadumbe's, sweet potato, pumpkin and other crops and the practice has expanded in recent times within the protected area (see Figure D.18 A–D). The reality is that the growing population in the area require food and locals believe they have no alternative as the usual areas they plant have dried up.

(A)

(B)

(C)

(D)

(E)

Figure D.16. Swamp forest being cleared and drained just outside the iSimangaliso Park near Sondwana bay just upstream of 'Tolla se Gat': (A) Groundwater stream being canalised; (B) and (C) a swamp forest recently cleared, while (D) and (E) being drained (Photo: Susan Janse van Rensburg, October 2018).

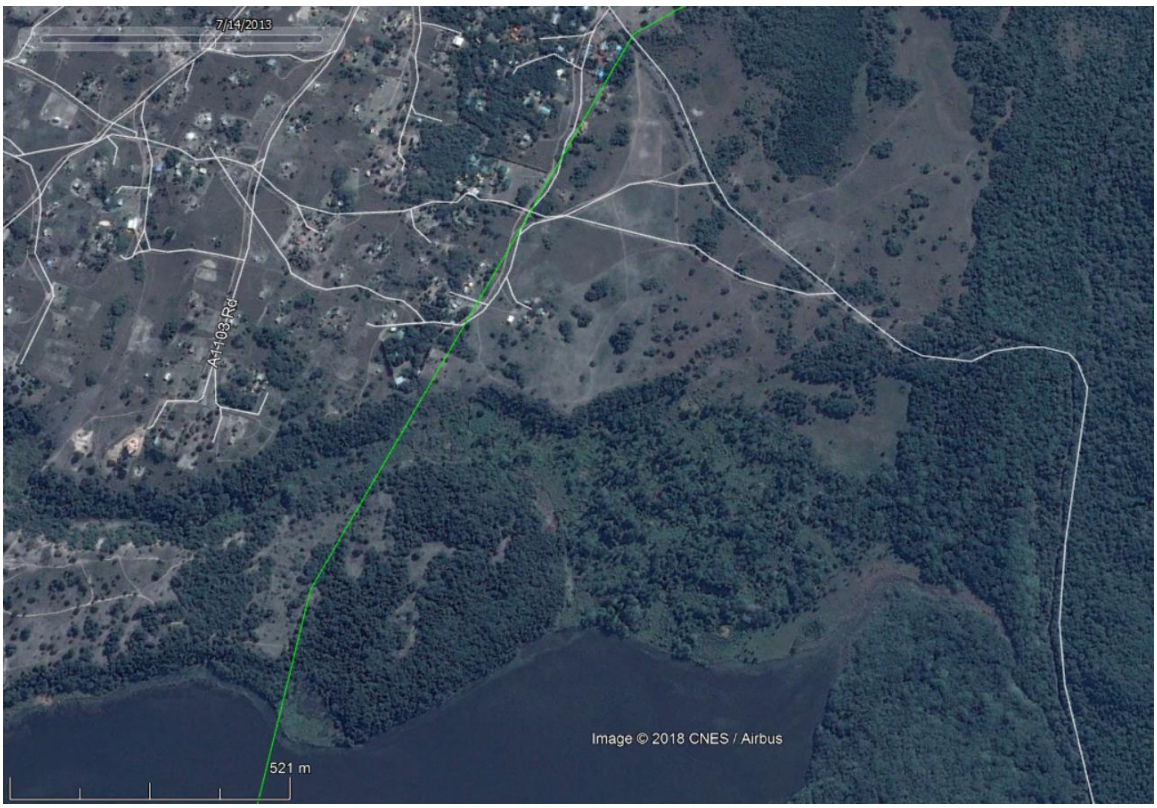
(A) (B)

(C) (D)

(E) (F)

Figure D.17. A large area of swamp forest cleared for cultivation within the iSimangaliso World Heritage Site in a contested area at the entrance to the Sodwana Bay gate. Images (A) and (B) showing the cutting out of swamp forest species in November 2017; (C) View of cleared area with bananas growing in background in an area cleared prior to clearing of foreground (November 2017); (D) Same location as above in April 2018, note alien invasive species coming in; (E) same location above in October 2018; and (F) a new area being cleared (October 2018) (Photos: Susan Janse van Rensburg).

(A)



(B)

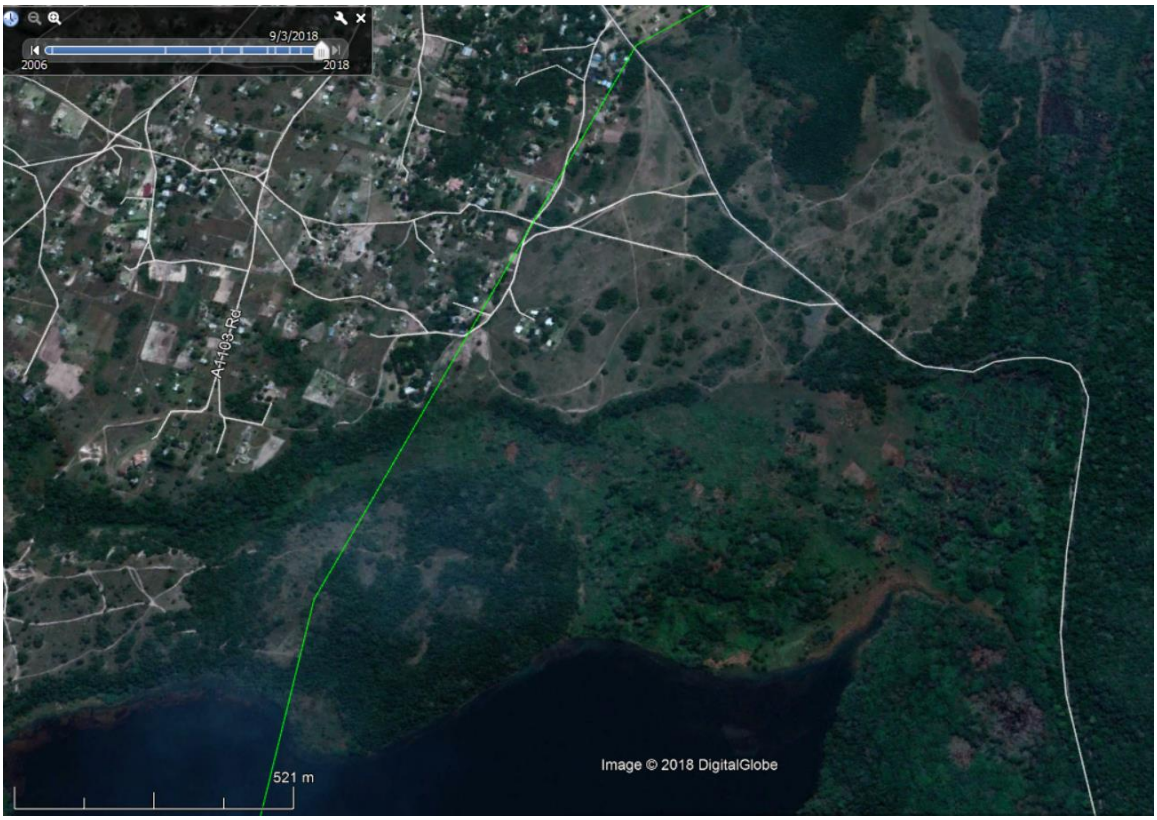


Figure D.18. Google earth images of the Mgobozeleni swamp forest at Sodwana bay being cleared. (A) August 2013 and (B) showing recent clearing within the protected area boundary (September, 2018).

D5. A unique area requiring unique treatment

The ULM Integrated Development Plan (IDP) (2017:14) vision reads: '*To be a people-centered premier socio-economic development and environmentally friendly service delivery municipality by 2035'*. Unlocking ecotourism potential combined with innovative, profitable, climate smart agricultural systems is envisioned. Ecotourism is considered a strategic sector for job creation and growing the South African (KwaZulu-Natal Government, 2017; State of the Nation Address, 2018) economy. Forestry in contrast has seen a decline in jobs in the sector due to increased mechanisation and negative growth trends in recent times (Clarke 2018). Under new leadership, the iSimangaliso Wetland Park is committed to addressing the tourism potential in the northern region, offering hope for genuine co-management and economic opportunity by focusing on realising the enormous ecotourism potential that exists within quaternary catchment W70A. In addition, recent engagements with the community, local stakeholders, TMM, SAEON and scientists by using a co-generative approach to assessing the situation have helped to catalised thinking on the potential of alternative crops to forestry which is now currently being explored.

The rising conflict between economic imperatives, conservation, social vulnerability, water security and climate change risk in quaternary catchment W70A epitomises the need for a common vision across sectors, the municipality, tribal structures and conservation bodies that guides integrated planning of climate resilience if water security is to be achieved. In addition, novel approaches to water resources management may be required to ensure management responses are flexible to the relative impact of both land use and climate change as we are moving into a new era where old rules, past trends and methodologies may no longer be appropriately useful. Exploring solutions as a collective with all parties represented and using social learning processes may be an important approach for ensuring long term success towards a more sustainable and economically viable future. As recommended by Colvin *et al*. (2007), an integrated approach is required to managing land, water and the environment using a cooperative governance approach across various government departments to ensure the long-term protection of this aquifer dependent ecosystem.

D6. References

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APPENDIX E: LIST OF INVASIVE SPECIES IN INLAND AQUATIC ECOSYSTEMS IN SOUTH AFRICA

The information of this Appendix E was extracted by Dr Tsungai Zengeya and Dr Andrew Skowno (South African National Biodiversity Institute) from the following resource:

Van Wilgen, B.W. & Wilson, J.R. (eds.). 2018. *The status of biological invasions and their management in South Africa in 2017*. South African National Biodiversity Institute, Kirstenbosch and DST-NRF Centre of Excellence for Invasion Biology, Stellenbosch, South Africa. DST-NRF Centre of Excellence for Invasion Biology: Stellenbosch, South Africa.

The column on legal status refers to status in terms of the alien and invasive species regulations. The categories are:

- Category 1(a): Species that must be "combatted or eradicated", and that are potential targets for eradication.
- Category 1(b): Species that must be controlled.
- Category 2: Species where cultivation, ownership and trade are allowed subject to the issuing of a permit, and that must be controlled in the absence of a permit.
- Category 3: Species that are subject to exemptions, but that cannot be further traded or propagated.
- Context-specific: Species that are listed in different categories depending on the area or ecosystem in which they are found.
- Prohibited: Species that are assumed to not yet be in the country, and for which a permit may not be issued.
- Unlisted: Alien species that are not listed in the regulations, but that have been reported as present in natural or semi-natural ecosystems in South Africa or on offshore islands.
- Species introduced as biological control agents are listed in the legal status column as 'Unlisted (Biocontrol agent with permit)', as all biological control agents would have been released under a permit from the former Department of Agriculture, Forestry and Fisheries.

Most entries in the column on introduction status are based on Blackburn *et al.* (2011)'s unified framework, and species in categories D1, D2 and E are considered invasive:

Presence in South Africa	High-level introduction status	Detailed introduction status according to the framework of Blackburn *et al.* (2011)
Absent	Not introduced, or eradicated	A0 (taxa that have no record of introduction in RSA)
		A1 (expanded to include taxa which were historically present in RSA but there is moderate evidence that they are no longer present)
Present	Introduced but not naturalised	B1 (in captivity or quarantine)
		B2 (in cultivation but no measures in place to prevent escape)
		B3 (released into the wild)
		C0 (some escape into the wild, but survival limited)
		C1 (escape and survival outside of captivity or cultivation, but no reproduction)
	Naturalised but not invasive	C2 (escape, survival, and reproduction outside of captivity or cultivation, not clear in population self-sustaining though)
		C3 (escape, survival, and reproduction outside of captivity or cultivation; population self-sustaining but not spreading)
	Invasive	D1 (escape, survival, reproduction and spread outside of captivity or cultivation; though no evidence of reproduction post-dispersal)
		D2 (escape, survival, reproduction, spread, and subsequent reproduction outside of captivity or cultivation; though spread as yet limited to a few localities)
		E (escape, survival, reproduction, spread to and subsequent reproduction at multiple sites outside of captivity or cultivation)

High-level grouping	Species	Common name	Legal status	Introduction status
Plant	*Azolla pinnata R.Br. subsp. asiatica*	Mosquito fern	1b	E
Plant	*Caesalpinia decapetala (Roth) Alston*	Mauritius thorn	1b	E
Plant	*Egeria densa Planch.*	Dense water weed	1b	E
Plant	*Eichhornia crassipes (Mart.)*	Water hyacinth	1b	E
Plant	*Mimosa pigra L.*	Giant sensitive plant	1b	E
Plant	*Ichthyophthirius multifilis*	No common name found	Unlisted	D2
Plant	*Salvinia molesta*	Kariba weed	1b	E
Plant	*Verbena bonariensis L.*	Wild verbena	1b	E
Plant	*Verbena brasiliensis Vell.*	Brazilian verbena	1b	E
Plant	*Glyceria maxima (Hartm.) Holmb.*	Reed meadow grass	Context specific	E
Plant	*Acorus calamus L.*	Calamus	Unlisted	E
Plant	*Alternanthera pungens Kunth*	Khaki burweed	Unlisted	E
Plant	*Melilotus indicus (L.)* All.	White sweet clover	Unlisted	E
Plant	*Nymphaea x marliacea Lat.-Marl.*	Hybrid water lily	Unlisted	E
Plant	*Phormium tenax*	New Zealand flax	Unlisted	E
Plant	*Sagittaria latifolia Willd.*	Common arrowhead	Unlisted	E
Plant	*Taxodium distichum (L.) Rich.*	Swamp cypress	Unlisted	E
Plant	*Pontederia cordata L.*	Pickerel weed	1b	E
Plant	*Senna bicapsularis (L.) Roxb.*	Rambling cassia	1b	E
Plant	*Senna hirsuta (L.)* (H.S. Irwin and Barneby,	Hairy senna	1b	E
Plant	*Senna occidentalis (L.) Link*	Stinking weed	1b	E
Plant	*Senna septemtrionalis (Viv.)*	Arsenic bush	1b	E
Plant	*Senna didymobotrya (Fresen.)*	Peanut butter cassia	Context specific	E
Plant	Juncus effusus L.	Common rush	Unlisted	D1
Plant	Acacia dealbata Link	Silver wattle	2	E
Plant	Acacia mearnsii De Wild.	Black wattle	2	E
Plant	Acacia longifolia (Andrews) Willd.	Long-leaved wattle	1b	E
Plant	Acacia saligna (Labill.) H.L. Wendl.	Port Jackson	1b	E
Plant	Prosopis velutina Wooton	Velvet mesquite	Context specific	E
Plant	*Nasturtium officinale R.Br.*	Watercress	2	E
Plant	*Alisma plantogo-aquatica L.*	Mud plantain	1b	E
Plant	*Lythrum hyssopifolia L.*	Hyssop loosestrife	1b	E
Plant	*Myriophyllum aquaticum (Vell.) Verdc.*	Parrot's feather	1b	E
Plant	*Nymphaea mexicana Zucc.*	Yellow water lilies	1b	E
Plant	*Melia azedarach L.*	Seringa	Context specific	E
Invertebrate	*Tarebia granifera*	Quilted melania snail	1b	E
Invertebrate	*Argulus japonicus*	Japanese fishlouse	Unlisted	D2
Invertebrate	*Gyrodactylus kherulensis*	Fish skin fluke	Unlisted	D2
Invertebrate	*Gyrodactylus kobayashii*	Fish gillworm	Unlisted	D2
Invertebrate	*Trichodina acuta*	No common name found	Unlisted	D2
Invertebrate	*Aedes aegypti*	Yellow fever mosquito	Unlisted	E
Invertebrate	*Culex pipiens*	Northern House Mosquito	Unlisted	E

Invertebrate	*Neochetina eichhorniae*	Mottled water hyacinth weevil	Unlisted (Biocontrol agent with permit)	Invasive
Invertebrate	*Neohydronomus affinis*	Waterlettuce weevil	Unlisted (Biocontrol agent with permit)	Invasive
Invertebrate	*Niphograpta albiguttalis*	Water hyacinth moth	Unlisted (Biocontrol agent with permit)	Invasive
Invertebrate	*Cherax quadricarinatus*	Red claw crayfish	1b	D2
Invertebrate	*Procambarus clarkii*	Red swamp crayfish	Prohibited	D2
Invertebrate	*Pseudodactlogyrus acheilognathi*	Gill flukes	Unlisted	D2
Invertebrate	*Artemia franciscana*	San Francisco brine shrimp	Unlisted	D2
Invertebrate	*Craspedacusta sowerbii*	Freshwater Jellyfish	Unlisted	D2
Invertebrate	*Trichocorixa verticalis*	No common name found	Unlisted	D2
Invertebrate	*Aedes albopictus*	Asian tiger mosquito	1b	E
Amphibian	*Amietophrynus gutturalis*	Guttural toad	Context specific	E
Amphibian	*Hyperolius marmoratus*	Painted reed frog	Context specific	E
Amphibian	*Sclerophrys gutturalis*	African common toad	Unlisted	D2
Bird	*Anas querquedula*	Garnaney	Unlisted	E
Bird	*Anas rubripes*	American black duck	Unlisted	E
Bird	*Aythya ferina*	Common pochard	Unlisted	E
Bird	*Anas platyrhynchos*	Mallard	2	E
Fish	*Micropterus salmoides*	Large-mouth bass	Context specific	Invasive
Fish	*Micropterus dolomieu*	Small-mouth bass	Context specific	Invasive
Fish	*Cyprinus carpio*	Common carp	Context specific	Invasive
Fish	*Gambusia affinis*	Mosquito-fish	Context specific	Invasive
Fish	*Lepomis macrochirus*	Bluegill	Context specific	Invasive
Fish	*Micropterus punctulatus*	Spotted bass	Context specific	Invasive

APPENDIX F: IUCN RED LIST CATEGORIES AND CRITERIA. VERSION 3.1 FOR ASSESSING IF SPECIES QUALIFY FOR THE CATEGORIES CRITICALLY ENDANGERED, ENDANGERED AND VULNERABLE

A. Population size reduction. Population reduction (measured over the longer of 10 years or 3 generations) based on any of A1 to A4

	Critically Endangered	Endangered	Vulnerable
A1	≥ 90%	≥ 70%	≥ 50%
A2, A3 & A4	≥ 80%	≥ 50%	≥ 30%

A1 Population reduction observed, estimated, inferred, or suspected in the past where the causes of the reduction are clearly reversible AND understood AND have ceased.

A2 Population reduction observed, estimated, inferred, or suspected in the past where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.

A3 Population reduction projected, inferred or suspected to be met in the future (up to a maximum of 100 years) *[(a) cannot be used for A3]*.

A4 An observed, estimated, inferred, projected or suspected population reduction where the time period must include both the past and the future (up to a max. of 100 years in future), and where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.

based on any of the following:

- **(a)** direct observation *[except A3]*
- **(b)** an index of abundance appropriate to the taxon
- **(c)** a decline in area of occupancy (AOO), extent of occurrence (EOO) and/or habitat quality
- **(d)** actual or potential levels of exploitation
- **(e)** effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites.

B. Geographic range in the form of either B1 (extent of occurrence) AND/OR B2 (area of occupancy)

	Critically Endangered	Endangered	Vulnerable
B1. Extent of occurrence (EOO)	< 100 km²	< 5,000 km²	< 20,000 km²
B2. Area of occupancy (AOO)	< 10 km²	< 500 km²	< 2,000 km²
AND at least 2 of the following 3 conditions:			
(a) Severely fragmented **OR** Number of locations	= 1	≤ 5	≤ 10
(b) Continuing decline observed, estimated, inferred or projected in any of: **(i)** extent of occurrence; **(ii)** area of occupancy; **(iii)** area, extent and/or quality of habitat; **(iv)** number of locations or subpopulations; **(v)** number of mature individuals			
(c) Extreme fluctuations in any of: **(i)** extent of occurrence; **(ii)** area of occupancy; **(iii)** number of locations or subpopulations; **(iv)** number of mature individuals			

C. Small population size and decline

	Critically Endangered	Endangered	Vulnerable
Number of mature individuals	< 250	< 2,500	< 10,000
AND at least one of C1 or C2			
C1. An observed, estimated or projected continuing decline of at least (up to a max. of 100 years in future):	25% in 3 years or 1 generation (whichever is longer)	20% in 5 years or 2 generations (whichever is longer)	10% in 10 years or 3 generations (whichever is longer)
C2. An observed, estimated, projected or inferred continuing decline AND at least 1 of the following 3 conditions:			
(a) **(i)** Number of mature individuals in each subpopulation	≤ 50	≤ 250	≤ 1,000
(ii) % of mature individuals in one subpopulation =	90–100%	95–100%	100%
(b) Extreme fluctuations in the number of mature individuals			

D. Very small or restricted population

	Critically Endangered	Endangered	Vulnerable
D. Number of mature individuals	< 50	< 250	**D1.** < 1,000
D2. *Only applies to the VU category* Restricted area of occupancy or number of locations with a plausible future threat that could drive the taxon to CR or EX in a very short time.	-	-	**D2.** typically: AOO < 20 km² or number of locations ≤ 5

E. Quantitative Analysis

	Critically Endangered	Endangered	Vulnerable
Indicating the probability of extinction in the wild to be:	≥ 50% in 10 years or 3 generations, whichever is longer (100 years max.)	≥ 20% in 20 years or 5 generations, whichever is longer (100 years max.)	≥ 10% in 100 years