2019
Strategic Environmental Assessment for Marine and Freshwater Aquaculture Development in South Africa

# APPENDIX A-2

## Freshwater Biodiversity and Ecology Specialist Assessment

# Freshwater Biodiversity and Ecology Specialist Assessment


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# ABBREVIATIONS & ACRONYMS

| | |
|---|---|
| AMD | Acid Mine Drainage |
| BGIS | Biodiversity Geographical Information System |
| CBA | Critical Biodiversity Area |
| CESA | Critical Ecological Support Area |
| CMA | Catchment Management Agency |
| C-Plan | Conservation Plan |
| CV | Coefficient of Variation |
| DAFF | Department of Agriculture Forestry and Fisheries |
| DDT | Dichlorodiphenyltrichloroethane |
| DEA | Department of Environmental Affairs |
| DEDEAT | Department of Economic Development, Environmental Affairs and Tourism |
| DNAPL | Dense Non-Aqueous Phase Liquid |
| DWS | Department of Water and Sanitation |
| EC | Eastern Cape |
| EDC | Endocrine Disrupting Chemical |
| EI | Ecological Importance |
| ES | Ecological Sensitivity |
| ESA | Ecological Support Area |
| FAO | Food and Agriculture Organisation of the United Nations |
| FEPA | Freshwater Ecosystem Priority Area |
| GAA | Global Aquaculture Alliance |
| IUCN | International Union for Conservation of Nature |
| KZN | KwaZulu-Natal |
| LNAPL | Lighter non-aqueous phase liquid |
| MTPA | Mpumalanga Tourism and Parks Agency |
| NEMA | National Environmental Management Act |
| NEM:BA | National Environmental Management: Biodiversity Act |
| NEM:PAA | National Environmental Management: Protected Areas Act |
| NFEPA | National Freshwater Ecosystem Priority Area |
| NMMU | Nelson Mandela Metropolitan University |
| NWA | National Water Act |
| MAP | Mean Annual Precipitation |
| PES | Present Ecological State |
| $PO_4$-P | Orthophosphate as phosphorus |
| RDM | Resource Directed Measures |
| RQOs | Resource Quality Objectives |
| SANBI | South African National Biodiversity Institute |
| SAPAD | South African Protected Areas Database |
| SDC | Source Directed Controls |

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| SEA | Strategic Environmental Assessment |
| SKEP | Succulent Karoo Ecosystem Plan |
| TIN | Total Inorganic Nitrogen |
| WC | Western Cape |
| WMA | Water Management Area |
| WWF | World Wildlife Fund |

# GLOSSARY OF TERMS

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| Alien species: | Means a) a species that is not an indigenous species; or b) an indigenous species translocated or intended to be translocated to a place outside its natural distribution range in nature, but not an indigenous species that has extended its natural distribution range by natural means of migration or dispersal without human intervention. |
| Alien invasive species: | See definition for “Alien species” and for “Invasive species”. |
| Aquatic critical biodiversity areas: | The linkages between catchment, important rivers and sensitive estuaries whose safeguarding is critically required in order to meet biodiversity pattern and process thresholds and are spatially defined as part of a bioregional plan or systematic biodiversity plan, available on the South African National Biodiversity Institute’s BGIS website. |
| Benthic organisms: | Aquatic organisms which live on, in, or near the bottom of water bodies. |
| Benthic flora: | Comprises plants that belong to the benthos. |
| Biodiversity: | Means the variability among living organisms from all sources including, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part, and also includes diversity within species, between species, and of ecosystems. |
| Carrying Capacity (water resources): | The maximum sustainable socio-economic scale that can be supported by available water resources while maintaining defined environmental conditions. |
| Critically endangered species: | Means any indigenous species listed as a critically endangered species in terms of section 56 of NEMBA (2004). |
| DDT: | Dichlorodiphenyltrichloroethane is a colourless, tasteless, and almost odourless crystalline organochlorine known for its insecticidal properties and adverse, long-lasting environmental impacts. |
| Dense Non-Aqueous Phase Liquids: | A dense non-aqueous phase liquid or DNAPL is a denser-than-water NAPL, i.e. a liquid that is both denser than water and is immiscible in or does not dissolve in water. The term DNAPL is used primarily by environmental engineers and hydrogeologists to describe a particular class of contaminants in groundwater, surface water and sediments. |
| Ecological Importance and Sensitivity (EIS): | Key indicators in the ecological classification of water resources.<br>The ecological importance of a river is an expression of its importance to the maintenance of biological diversity and ecological functioning on local and wider scales. Ecological sensitivity (or fragility) refers to the system’s ability to resist disturbance and its capability to recover from disturbance once it has occurred (resilience). Both abiotic and biotic components of the system are taken into consideration in the assessment of ecological importance and sensitivity. |
| Ecosystem function: | Describes a process that takes place in an ecosystem as a result of the interactions of plants, animals, and other organisms in the ecosystem with each other and/or their environment. |

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| Ecosystem goods and services: | The socially valued aspects or outputs of ecosystems that depend on self-regulating or managed ecosystem structures and processes. |
| Ecological infrastructure: | The naturally functioning ecosystems that produce and deliver services that are of value to society - fresh water, climate regulation, soil formation and disaster risk reduction. Ecological infrastructure is the nature-based equivalent of built infrastructure, thus equally important for providing services and underpinning socio-economic development. |
| Ecosystem structure: | Refers to both the composition of the ecosystem (i.e. various parts) and the physical and biological organisation defining how those parts are organized. |
| Endangered species: | Means any indigenous species listed as an endangered species in terms of section 56 of NEMBA (2004). |
| Endocrine-disrupting chemicals: | These are chemicals that can interfere with endocrine (or hormone) systems of humans and animals at certain doses. These disruptions can cause cancerous tumours, birth defects, and other developmental disorders. |
| Eutrophic: | Excessive richness of nutrients in a lake or other body of water, frequently due to run-off from the land, which causes a dense growth of plant life and algae and usually resulting in a depletion of dissolved oxygen. |
| Freshwater ecosystems: | All inland water bodies whether fresh or saline, including rivers, lakes, wetlands, subsurface waters and estuaries. |
| Freshwater Ecosystem Priority Area (FEPA): | FEPA identified in terms of the National Freshwater Ecosystem Priority Areas project (NFEPA) and represents strategic spatial priorities for conserving freshwater ecosystems and supporting sustainable use of water resources. These are categorised in the NFEPA River FEPA layer available on the South African National Biodiversity Institute's BGIS (Biodiversity Geographic Information Systems) website and includes the associated sub-quaternary catchment. |
| Hydrological drought: | Occurs when low water supply becomes evident, especially in streams, reservoirs, and groundwater levels. |
| Hypereutrophic: | Lakes that suffer from problems arising due to excessive plant and algal growth due to a high supply of growth nutrients. These lakes have little transparency due to the dense overgrowth of algae or aquatic flora. The overgrowth of algae often suffocates the fauna below the water depths, and this might create dead zones beneath the water surface. |
| Indigenous species: | Means a species that occurs, or has historically occurred, naturally in a free state in nature within the borders of the Republic of South Africa, but excludes a species that has been introduced in the Republic as a result of human activity. |
| Introgression: | Introgression, also known as introgressive hybridization, is the movement of a gene (gene flow) from one species into the gene pool of another by the repeated backcrossing of an interspecific hybrid with one of its parent species (e.g. Nile tilapia and Mozambique tilapia). |
| Invasive species: | Means any species whose establishment and spread outside of its natural distribution range- (a) threaten ecosystems, habitats or other species or have demonstrable potential to threaten ecosystems, habitats or other species; and (b) may result in economic or environmental harm or harm to human health. |
| IUCN Red List of Threatened Species: | Also known as the IUCN Red List or Red Data List is the world's most comprehensive inventory of the global conservation status of biological species. |
| Lighter non-aqueous phase liquids: | A groundwater contaminant that is not soluble in water and has lower density than water, in contrast to a DNAPL which has higher density than water. |
| Mesotrophic: | Lakes with an intermediate level of productivity. Mesotrophic lakes are in the boundary between oligotrophic lakes and eutrophic lakes. These lakes have medium-level nutrient concentrations and are usually clear water with submerged aquatic plants. |

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| Mountain catchment areas: | High water yield areas, located in the mountains that contribute significantly to the overall water supply in the country. |
| Non-target species: | Species not specifically targeted, but which may be affected by an action. |
| Oligotrophic: | A lake characterized by a low accumulation of dissolved nutrient salts, supporting only a sparse growth of algae and other organisms, and having a high oxygen content owing to the low organic content. |
| Phytoplankton: | Also known as microalgae are freely floating, often minute organisms that drift with water currents. Like land vegetation, phytoplankton contains chlorophyll and uses carbon dioxide, releases oxygen, and converts minerals to a form which animals (e.g. fish) can use. |
| Polyculture: | Polyculture is the production of two or more cultured species in the same physical space at the same time, often with the objective of producing multiple products that have economic value. They may be a combination of animals, plants and animals, aquatic species only, or aquatic and terrestrial species. |
| Precautionary principle: | A concept whereby uncertainty regarding consequences leads to a decision to forego an activity, even one with benefits, if the consequences might be serious or irreversible. |
| 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). The degree to which ecological conditions of an area have been modified from natural (reference) conditions. |
| Resource Directed Measures: | To ensure the protection of water resources, by protecting ecosystem functioning and maintaining a desired state of health of aquatic and groundwater dependent ecosystems. |
| Risk assessment: | A process for determining the nature, severity and probability of risks. |
| Resilience: | The capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks. |
| Source Directed Controls: | Controlling impacts on the water resource through the use of regulatory measures such as registration, permits, directives and prosecution, and economic incentives such as levies and fees, to ensure that the Resource Quality Objectives are met. |
| Triploid fish: | Are sterile because they have 3 sets of chromosomes instead of two and for this reason are not able to reproduce. Sometimes used with invasive aquaculture species to minimize the impacts of escapes on wild populations. |
| Water Management Area: | An area established as a management unit in the National Water Resource Strategy within which a catchment management agency will conduct the protection, use, development, conservation, management and control of water resources. |
| Water Reserve: | Defined as the quantity and quality of water required to (a) provide a basic water supply for all people, and (b) to “protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource”. |

# 1 SUMMARY

This Specialist Study Report presents a strategic assessment of the potential implications for freshwater biodiversity and ecology that may be caused by proposed future aquaculture operations in nine selected study areas of South Africa.

The introduction provides an overview of freshwater aquaculture in South Africa, set against the context of freshwater biodiversity, water resources, climate change and the country's legal and statutory framework (Section 2). This provides the backdrop for the subsequent sections of this report that focus on the nine specific study areas and their particular opportunities and constraints for possible freshwater aquaculture developments and operations.

The descriptions of the freshwater systems and the aquatic biota present in the aquatic ecosystems in each of the nine study areas provide an overview of the potential opportunities and constraints that characterize each of the areas selected for evaluation (Section 4). It is crucial that these opportunities and constraints are properly considered by both project proponents and relevant authorities before any proposed aquaculture project is allowed to proceed in terms of this SEA.

For each of the nine study areas, a description is provided of the existing aquatic ecosystems and of the sensitivities of each area or parts of each area to potential aquaculture operations (Section 4). Data availability and data uncertainty (i.e. limitations of existing data) are detailed for each of the nine study areas and provide the basis for recommendations on sourcing the best possible information to support decision making on sustainable aquaculture operations.

A wide range of potential impacts associated with different types of freshwater aquaculture production systems affecting aquatic ecosystems and freshwater biota are described, in Section 5.

In the case of small-scale or so-called 'artisanal' operations, great care will need to be taken to ensure that all proposals for new aquaculture operations are able to adapt to the existing circumstances (especially water availability and prevailing water quality considerations), comply with the requirements of applicable legislation, and are sustainable in the long-term. In the case of larger-scale operations, or groups of small-scale operations, it may be possible to 'streamline' the planning, construction and operational requirements for proposed operations (or groups of operations) so that there is a greater degree of synergy, while economies of scale can be achieved with regard to all operational activities.

The risk and opportunity assessments presented in this report (Section 6) provide details of the potential outcomes, likelihood of occurrence, and consequences should such risks eventuate. Key risks are the release (or escape) of cultured species and associated parasite / disease communities and their potential long-term impact on aquatic ecosystems; and the risks associated with different aquaculture production systems and their water use, effluent discharge, and general management during operations. An associated issue is the need for qualified food health experts to ensure that aquaculture products do not pose any health risks to those individuals and communities that consume the products.

Mitigation measures that cover the planning, construction, operation and decommissioning phases of possible aquaculture operations are presented in Section 7. Note however that the availability of water resources and the water quality characteristics of several of the study areas pose constraints that will be both technically difficult and expensive to resolve. Best management practices and principles that underpin effective and efficient management of freshwater aquaculture operations are provided (Section 8). The proponent for each new freshwater aquaculture facility should demonstrate clearly how the project will be operated and managed, including details of their monitoring activities (Section 9). These monitoring activities must be captured formally, such as in a detailed Environmental Management Programme (EMPr).

The section on gaps in knowledge provides an overview of the sufficiency of the available data and knowledge, while emphasizing the need to source or generate particular types of additional information that would provide greater certainty for decision making (Section 10).

Finally, this project component provides an interactive on-line tool that allows interested parties to interrogate sensitivity data for a particular area and see which particular variables / rated criteria are driving the assessed Sensitivity ratings. This should inform actions around how to reduce assessed risk in any area. The interactive tool can be accessed via the following link: https://www.smsgis.co.za/sea-for-aquaculture-in-rsa/

# 2 INTRODUCTION

This Specialist Study Report investigates the potential implications of inland freshwater aquaculture on freshwater aquatic ecosystems and surface water resources. This is done for each of the proposed aquaculture species and production systems and in each of the nine study areas. Both national and international literature sources have been reviewed and several discussions have been held with personnel from provincial departments involved with aquaculture.

## 2.1 Changes in this document

This (third draft) report has incorporated a number of changes, some of which have stemmed from stakeholder engagement since submission of the second draft report, and some of which have resulted from innovation within the project team. The outputs presented here include the following main changes since the last draft report was submitted for comment, namely:

- The Sensitivity rating tables (Appendix 2) have been critiqued and some ratings have been adjusted as deemed appropriate (e.g. SANBI IUCN fish data and NFEPA FishsancALLspp data sensitivity ratings have been adjusted, such that the lowest rated variable is Low, as opposed to Medium in previous drafts);

- Modified terrestrial areas have been mapped, using data from the SANBI (2017) modified habitat layer – these maps have been provided for information purposes only. While they do provide an indication of catchments where the terrestrial sensitivity of an actual land-based aquaculture facility siting may be low, it is however stressed that the landuse layer has little bearing on the aquatic sensitivity layer, and so has not been used in the sensitivity ratings (see Section 3.4.1);

- The assignment of Sensitivity Scores per area has been adjusted, so that where a part of a quaternary has been rated with regard to a particular variable (e.g. Protected Areas data), only that portion of the quaternary is accorded this value, as opposed to the whole quaternary;

- More accurate assessment of Sensitivity data has been allowed for, by development of spatial GIS mapping tools, to ensure that the highest rated Sensitivity category for any area is shown in the hard copy maps;

- Allowance has been made for more detailed interrogation of the variables driving the actual rating of each area – an interactive link has been provided, allowing users to identify their quaternary of concern and query the rating of different variables (see Section 4.3.6 for link;

- Summary data for each study area have been provided, highlighting the proportion of each area rated Low, Medium, High or Very High for each of the assessed rating categories;

- Trout and Tilapia “Presence” data have been included in the baseline descriptions of each study area - while these data do not have status as scientifically validated data, they do, however, provide a useful layer against which to interpret some of the sensitivity data relating to this study.

- The assumption of “no aquaculture” in protected areas has been changed to reflect what is stated in the NEM:PAA (Act 57 of 2003), namely that aquaculture activities are not permitted inside Protected Areas without written Authorisation through the relevant authorities.

- The definitions of respectively "Alien species" and "Invasive species" in the Glossary and text were changed and aligned with NEM:BA (Act 10 of 2004).

## 2.2 Overview of the ecological implications of freshwater aquaculture as experienced internationally

Freshwater aquaculture is a fast-growing industry internationally, with the potential to contribute significantly to food security and economic development in many areas (Boyd and McNevin, 2015). Water is the primary requirement for aquaculture and the quality and quantity of the available water determines which species and production systems are suitable and can be considered for a particular location. There has however also been a growing concern around the past and potential future impacts of aquaculture on aquatic ecosystems, which have triggered numerous studies and calls for tighter controls on the industry, including the development of global standards for farming certain species and to address the potential negative impacts of aquaculture (e.g. WWF, 2006, 2009; IFC, 2007). Internationally, aquaculture operations using alien species have proved to be very successful in places such as the Far East.

Concerns around the ecological impacts of freshwater aquaculture systems include biodiversity impacts and losses associated with the accidental or intentional release of alien species into native systems, and the potential changes in water resource quality as a result of introductions (Dudgeon *et al*., 2006). The ecological impacts of invasive and alien species span all levels of biological organization from genetic level impacts to ecosystem level and may involve cascading ecosystem-wide impacts (Ciruna *et al*., 2004). However, there are a number of other issues, relating to freshwater resources that are frequently raised and highlighted in the literature; these include:

- Land use modifications, which include alterations to wetlands and pans and the conversion of cropland to accommodate aquaculture facilities or its water requirements (Martinez-Porchas and Martinez-Cordova, 2012);

- Excessive use of freshwater (Boyd and McNevin, 2015);

- Nutrient pollution – the passage of excess food and fish waste into natural surface water ecosystems increases the levels of nutrients in the water, potentially increasing plant productivity, affecting grazer biomass and faunal community structure and changing aquatic habitat type / condition. Excessive organic nutrients may also increase biological and chemical oxygen demand, thus potentially reducing oxygen to critical levels and stressing aquatic life (Serpa and Duarte, 2008);

- Chemical inputs including antibiotics, anti-foulants and pesticides that may have unintended consequences for freshwater organisms, as well as human health in receiving environments (Science for Environment Policy, 2015); and

- Diseases and parasites that transfer between farmed and wild species – Peeler and Feist (2011) note that high stocking densities in many aquaculture systems and genetic homogeneity among farmed populations can increase disease prevalence, the passage of which into natural systems cannot readily be controlled, while the introduction of alien aquaculture species into new geographic areas will inevitably also increase the range of their pathogens and may result in host-switching in new environments.

The actual ecological impacts of aquaculture on inland water ecosystems have been found globally to vary significantly depending on the aquaculture species, the production system, and the vulnerability, rarity and sensitivity of the affected ecosystem (Pillay, 2004). It must be noted that land-based farming systems, whilst transforming landscapes, have evolved over time to improve production efficiency and not necessarily to minimize impacts on natural systems. Inevitably, the development of land-based agriculture systems far pre-dates more recent public concerns about potential impacts on natural resource systems.

In an effort to collect data on the distribution and possible invasion of alien species globally, the Food and Agriculture Organisation of the United Nations (FAO) initiated a Database on Introductions of Aquatic Species (DIAS), which includes records of species introduced or transferred from one country to another. The effects of aquaculture and, in particular, the spread of invasive aquaculture species that pass across or through international boundaries, and their impacts on aquatic ecosystems, has also been raised as a complicating aspect of freshwater aquaculture (Ciruna *et al*., 2004), where aquaculture may result in unintended consequences on an international scale, complicating control and management options.

With regard to the spread of non-native aquaculture species into natural aquatic ecosystems, Ciruna *et al*. (2004) stress the need for comprehensive biodiversity risk and benefit assessments prior to the introduction of any new species that might become invasive in some areas, as well as the need to curb or prohibit the further spread of aquaculture species that are known to be invasive. Not all alien species are invasive or cause ecological damage, and many provide considerable economic benefits.

## 2.3 Freshwater aquaculture in South Africa

### 2.3.1 Biodiversity implications

Freshwater aquaculture has been established as an industry in South Africa for several decades, with production of rainbow trout (*Oncorhynchus mykiss*) being the oldest and best-established aquaculture activity, with commercial production commencing in the 1960s after nearly a century of trout rearing to support sport trout fisheries (Stander and Brink, 2009). According to the Department of Agriculture, Forestry and Fisheries (DAFF) 2016 Aquaculture Yearbook (DAFF, 2016) the following freshwater species were farmed per province during 2015:

- Sharptooth (African) catfish (*Clarias gariepinus*) – Eastern Cape, Free State, Gauteng, Limpopo and North West provinces;
- Tilapia (*Oreochromis mossambicus, Oreochromis niloticus, Tilapia rendalli*) – Eastern Cape, Gauteng, KwaZulu-Natal, Limpopo, Mpumalanga, Northern Cape, North West, Western Cape provinces;
- Marron crayfish (*Cherax tenuimanus*) – Eastern Cape.
- Brown trout (*Salmo trutta*) and Rainbow trout (*Oncorhynchus mykiss*) - Eastern Cape, KwaZulu-Natal, Mpumalanga, Western Cape provinces; and
- Ornamental species – Free State, Gauteng, KwaZulu-Natal, Limpopo, Western Cape provinces.

Of the South African aquaculture farms identified by DAFF (2015 data), the greatest number (74) produce Tilapia, followed by 38 that produce trout (rainbow or brown trout), with the other contributing species being produced at a limited number of farms (<15 farms nationally) (Figure 1).

Sharptooth catfish and Mozambique tilapia are indigenous to at least parts of South Africa, while all of the other species are alien, with numerous species of fish and invertebrates included in the ornamental category.

Of the potential crustacean aquaculture species, only marron crayfish (*Cherax tenuimanus*) are included in DAFF records of freshwater aquaculture systems in South Africa (DAFF, 2016). However, Du Preez and Smit (2013) noted that at least four freshwater crayfish species have been imported or considered for importation into South Africa, including redclaw crayfish (*Cherax quadricarinatus*), red swamp crayfish (*Procambarus clarki*), yabby (*Cherax destructor*) and marron (*Cherax tenuimanus*). As a result of such imports, breeding populations of redclaw have established in the Komati River system and of red swamp crayfish in an impoundment on the Crocodile River near Dullstroom (Du Preez and Smit, 2013). Although yabby are also farmed in the Free State, this species has not yet established populations in the wild (Picker and Griffiths, 2011).

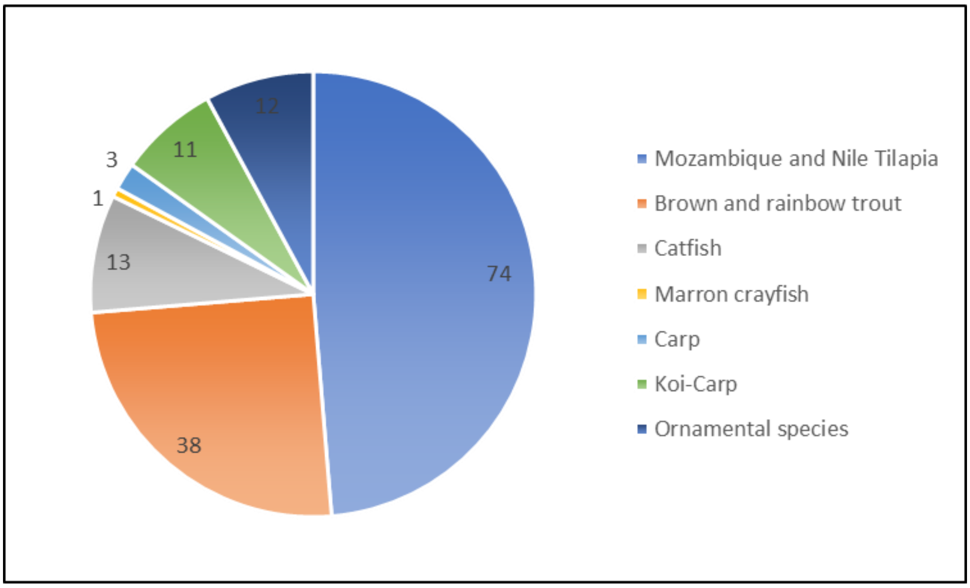



Figure 1. Number of aquaculture farms for different freshwater species in South Africa* (DAFF, 2016).

** Species included in the scope of this assessment are: Sharptooth (African) catfish, Marron crayfish, Mozambique tilapia, Nile tilapia, and brown and rainbow trout.*

Issues of parallel introductions of disease and parasites have also been raised, with Du Preez and Smit (2013) reporting the occurrence of breeding populations of the invasive alien parasitic platyhelminth, *Temnocephala chaeropsis* on red swamp crayfish in KwaZulu-Natal. Two other species of temnocephalan parasites have been found in South Africa in the Free State and Gauteng, both associated with imports of marron crayfish. These parasites also parasitise freshwater crabs and shrimps, and their introduction via alien crayfish potentially poses a significant threat to indigenous freshwater crustaceans.

Picker and Griffiths (2011) associate all of the above parasite species with populations in the wild outside of their natural range. African sharptooth catfish, indigenous to the warmer east-flowing watercourses and the Orange-Vaal River system are now commonly found in some of the major river systems of the Eastern and Western Cape. Although this species is fully established in the Berg and Breede mainstream rivers in the Western Cape, their invasion status in the Olifants-Doring Gouritz systems still needs to be determined. Also, it is important to note that while their ability to invade headwater/tributary habitat has been scientifically proven, very little is known about the potential impacts in these sensitive habitats (Ellender *et al.,* 2015). Some of these translocations is a result of inter-water basin water transfers; others have been deliberate translocations for food and angling purposes (Roodt-Wilding *et al*., 2010). Mozambique tilapia, which have been translocated widely, now occur in extra-limital populations in all major river systems in the country, although their inland extent is limited by low winter temperatures. Nile tilapia were initially introduced into dams in KwaZulu-Natal, however self-sustaining wild populations have since managed to establish in the Komati River and Limpopo Rivers (Picker and Griffiths 2011). Invasion of the Limpopo system has also occurred, this time via tributaries of the Limpopo River in Zimbabwe (Canonico *et al*., 2005), emphasising the vulnerability of shared rivers to management activities in neighbouring countries. The wide environmental tolerances, trophic adaptability, and high reproductive rates of many tilapia species predispose them for success as invasive species (Canonico *et al*., 2005), and one of the adverse effects of Nile tilapia is in altering habitat quality through feeding aggressively on aquatic vegetation.

One of the biggest threats posed by Nile tilapia is however its ability to hybridize with the native Mozambique tilapia. In the Limpopo River system, for example, native Mozambique tilapia have been replaced throughout their natural range in this system by "red hybrid populations" (Nile/Mozambique hybrids), with a subsequent loss of genetic integrity (van der Waal and Bills, 2000).

Brown trout have also been linked to a population decline of several indigenous fish species in cold water habitats (e.g. Small scale redfin and Slender redfin), as have rainbow trout. Shelton *et al.* (2015a) found that the densities of small fish species endemic to the Cape Floristic Region were 89 – 97% lower in streams invaded by rainbow trout than in streams where these aliens did not occur, citing size-selective predation as the main reason for the decline in indigenous fish in this region. Predation by both brown and rainbow trout also affects aquatic invertebrate community structures, resulting, in some systems, in changes in habitat quality, where grazing invertebrates are removed from the system, and benthic rocks and cobbles become overgrown with macro-algae as a result (Cambray, 2003). Other habitat-altering aquaculture species include the red swamp crayfish (*Procambarus clarkii*) which burrows into river banks and earth dam walls (Picker and Griffiths, 2011), causing bank collapse, erosion and sedimentation. Nunes *et al*. (2016) describes this species as a high-impact invader that alters the structure and functioning of the ecosystems it invades. It spread swiftly after its introduction into Kenya's Lake Naivasha, destroying its floating and submerged aquatic plants, and with them food and refuge for fish and other aquatic animals.

Australian red claw crayfish *Cherax quadricarinatus* have also been described by several studies as highly destructive habitat altering species, feeding voraciously on plants and destroying indigenous fish nesting sites and habitat (e.g. Picker and Griffiths, 2011; Nunes *et al*., 2016) as well as affecting local fisheries by feeding on fish caught in nets (De Moor, 2002; Nunes *et al*., 2016).

Expansions of populations of alien species into Western Cape waters, often as a result of aquaculture activities and deliberate introductions by anglers, are of particular biodiversity concern, given that almost all indigenous fish in river systems in this area are range-restricted endemics (Tweddle *et al.,* 2009; Garrow and Marr, 2012; Ellender *et al.,* 2017), and that of the 19 recognised indigenous species in the Cape Floristic Region, 70% are listed as Critically Endangered or Endangered (Picker and Griffiths, 2011; Garrow and Marr, 2012). De Moor (2002) notes that the naturally depauperate (in terms of indigenous fish) waters of the Western Cape are particularly vulnerable to invasion by alien fish species.

The previous discussion highlights that, despite current relatively limited freshwater aquaculture production, aquaculture activities in South Africa are nevertheless associated with similar concerns from a freshwater ecosystem perspective to those raised in international literature. These include:

- Impacts on indigenous fauna including endemic and/or IUCN listed red data fish species as a result of competition, predation or habitat alteration and fragmentation (e.g. tilapia, trout, sharptooth catfish, carp);

- Water quality effects, with the water quality downstream of aquaculture production systems being associated with elevated nutrients, low concentrations of dissolved oxygen, and high levels of suspended organic sediments that reduce instream habitat quality;

- Imports of disease and parasites; and

- Habitat-altering fauna (e.g. common carp, *Cyprinus carpio* change aquatic habitats by increasing turbidity which can affect aquatic plant growth and change habitat quality for indigenous fish and other taxa). The red swamp crayfish, (*Procambarus clarkii*) is present in southern Africa and poses risks to the integrity of farm dam walls and aquatic vegetation (Picker and Griffiths, 2011; Nunes *et al.,* 2016)

Additionally, many of South Africa's inland aquatic ecosystems are already highly modified and lend themselves to invasion by alien species including aquaculture escapees. Invasion of many rivers by alien wattle trees (e.g. *Acacia saligna* and *Acacia mearnsii* in the Western Cape) means that indigenous riverine vegetation is often reduced or absent as a result of shading, and cover and shelter in instream habitats are thus reduced, making indigenous fish increasingly vulnerable to predation, while erosion or sedimentation of fine silt as a result of poor land use practices may alter substrate type in pools and backwaters, reducing the availability of suitable breeding / nesting areas for some indigenous fish species (Le Maitre *et al*., 2000).

Poor ecosystem resilience as a result of such impacts potentially renders aquatic ecosystems more vulnerable to invasion by introduced species. This issue is explored in more detail in the following section, in the context of water resources as a whole in South Africa.

### 2.3.2 Water resource context

All aquaculture production systems require water resources and many aquaculture operations may affect the quality of the resource for downstream users. Water resource condition, availability and sensitivity thus become critical components to address in any consideration of the implications of different aquaculture activities in different parts of the country. This section provides background context to surface water resources in South Africa.

South Africa is an arid country with a mean annual precipitation (MAP) of 490 mm, which is well below the world average of 860 mm (DWAF, 1986). The rainfall is unevenly distributed both seasonally and spatially, and the mean annual potential evaporation across the country exceeds MAP by a factor of at least three (Midgley *et al*., 1994). These climatic features result in surface freshwater resources that are in relatively short supply, and which are unevenly distributed across the country. The total mean annual runoff (MAR) of the country is estimated at approximately 50 000 $Mm^3$/year (Basson *et al*., 1997; Pitman, 2011), of which about 60% originates from less than 20% of the country's surface area (Midgley *et al*., 1994). More significant perhaps is the fact that many areas of the country experience high inter-annual and intra-annual variability in precipitation, as reflected in the high co-efficient of variation (CV) of annual precipitation. Large tracts of South Africa display an inter-annual rainfall CV >40%, which is high by global standards (Otter *et al*., 2007). Generally, the country displays a westward increase in the CV of rainfall from less than 20% in the higher rainfall areas mainly along the eastern seaboard, to over 40% in the Northern Cape (Schulze, 2011). This is amplified in the CV of runoff (50 – 300%), largely as a result of high rates of evaporation across most of South Africa. Furthermore, the CV of runoff increases with reducing mean annual precipitation. The implication of this is that drier areas of the country are likely to be additionally impacted by greater levels of rainfall inconsistency from year to year, and substantially greater inconsistency in runoff. This needs to be borne in mind in siting of aquaculture industries with an inherent reliance on streamflow.

At present, South Africa is well past the halfway mark in terms of the exploitation of its conventional freshwater resources (largely surface water) (DWA, 2012). Many regions of the country already experience severe water shortages and the demand for freshwater far exceeds the local supply in the large inland economic centres and some coastal metros, such as Cape Town, Port Elizabeth and Durban. The problem of ensuring that an adequate water supply is available to meet society's needs is worsened during periodic severe droughts (DWA, 2012). This problem is also accentuated by the continued growth in South Africa's population, which was recently (June 2017) estimated to be approximately 55 million, and by increased rates of urbanisation and water use (StatsSA, 2017).

In past decades, water resource development focused predominantly on structural solutions such as the construction of water storage reservoirs and large-scale water transfer schemes (DWAF, 1986; Basson *et al*., 1997). The combined capacity of large and small water supply reservoirs in South Africa amounts to some 37 000 $Mm^3$; this is equivalent to almost 74 percent of the country's MAR and represents a very high level of "resource capture" (Ashton and Haasbroek, 2000). Most of the water-deficient inland areas of South Africa currently receive major proportions of their water via large and expensive inter-basin transfers, and a high degree of reliance on structural (construction) solutions still dominates water resources planning approaches in the country. Many of these structures are likely to facilitate the transfer of aquaculture escapees and other potentially invasive alien aquatic species into new river systems. Estimates made in 1996 of the anticipated future water use in the country suggest that demands for water will likely increase by between 28% (agricultural sector) and 219% (domestic use) by 2030 (Basson *et al*., 1997). Such predictions imply that the effective limit of the country's exploitable water resources will be reached within the next 15 to 20 years, and that freshwater availability is likely to continue to decline. This implies that South Africa will experience a worsening chronic water scarcity in future. It will therefore no longer be possible to reconcile future water demand and supply without the development of further high-cost supply options, or the development of new and innovative water supply and water reuse options such as desalination and water imports from other African countries to the north (Smakhtin *et al*., 2001). This situation highlights the pressing need for the national Department of Water and Sanitation (DWS) to continue to ensure that all uses of the country's scarce freshwater resources are legitimate (*i.e.*, they are properly licenced) and sustainable. This has application to both abstractive and non-abstractive (e.g. polluting, diverting, altering) uses of surface water for aquaculture activities. In the case of trout aquaculture activities, these species have a high reliance on cold water of a high quality – thus often targeting water from mountain catchment areas with high sensitivity.

### 2.3.3 Climate change context

Climate change has been identified as one of the country's key threats on its path towards sustainable future development and an equitable society (DEA, 2011). Climate change is not however expected to have a uniform impact across the country and is projected to be accompanied by increased variability in precipitation and temperature, adding another layer of uncertainty to the availability and acceptable use of scarce and increasingly unpredictable water resources (Stuart-Hill *et al*., 2012). Schulze (2011) found for example that the transitional zone between the winter and summer rainfall area (Figure 2a; 2b; 2c) in the western interior of South Africa appears to be an area of high sensitivity and of inconsistent change. This inconsistency has the potential to reduce the certainty of water supply in this transitional zone, which includes portions of three study areas considered in this assessment (i.e. parts of the Western Cape, Eastern Cape and Vaalharts areas).

Schulze (2011) furthermore found that in general, modelled results showed an often, substantial increase in year-to-year variability of hydrological responses into the future as a result of climate change. Some of the more sensitive components of the hydrological cycle assessed were found to be changes in base flows, hydrological droughts and surface runoff losses from irrigated lands, which changed dramatically across sometimes very short distances and in some cases reversed trends (e.g. from positive to negative). Again, this has relevance for planning of aquaculture production systems, and the wider land-based agriculture system, where water resource availability will be increasingly uncertain going into the future.

From a fish biodiversity perspective, climate change predictions highlight severe levels of potential threat to some indigenous populations. Reizenberg *et al*. (2018) for example note that predicted increases in water temperature and rainfall variability, and decreases in total runoff may have severe consequences for Cape Floristic Region fishes, where the remaining endemic fish populations are now largely restricted to headwater habitats where small changes in river temperature or run-off could have dramatic effects on abundance, distribution and species survival. These authors also note that the interplay between predicted hydrological changes and the impacts of alien invasive fish is a further cause for concern, with the distributions of key alien species apparently largely driven by temperature thresholds.

Stuart-Hill *et al.* (2012) set water resource availability against a backdrop of other factors, such as the need to meet resource requirements of high numbers of impoverished populations and that water quality in South Africa is deteriorating; this is likely to be exacerbated by a 2 – 3°C increase in temperature that will speed up most chemical reactions markedly. The study highlights a number of "windows of opportunity" to facilitate timeous climate change adaptation, including the following measures, all of which have great relevance to the freshwater aquaculture industry:

- Water allocation reform approaches designed to improve the equity of water allocations must be updated to take account of climate change adaptation requirements;
- Illegal water abstractions must be reduced;
- Deteriorating water quality must be curbed;
- Ecosystem services must be enhanced to aid poor and vulnerable communities;
- Biodiversity conservation must be actively promoted when development is planned – this is because biodiverse catchment areas are essential to maintaining and improving the resilience of ecological communities to climate change and in reducing climate related risks and vulnerabilities; and

- The importance of the water-energy-food security nexus must be appreciated, given that the production of food (including, clearly, from aquaculture) relies strongly on the availability of sufficient water – in both quantity and quality, as well as a reliable source of energy.

It must be noted that a 2 to 3°C rise in water temperature also offers an opportunity for aquaculture to farm with species in an expanded area of warmer water (this increase in temperature can also provide opportunities for such species to invade new territories as well).

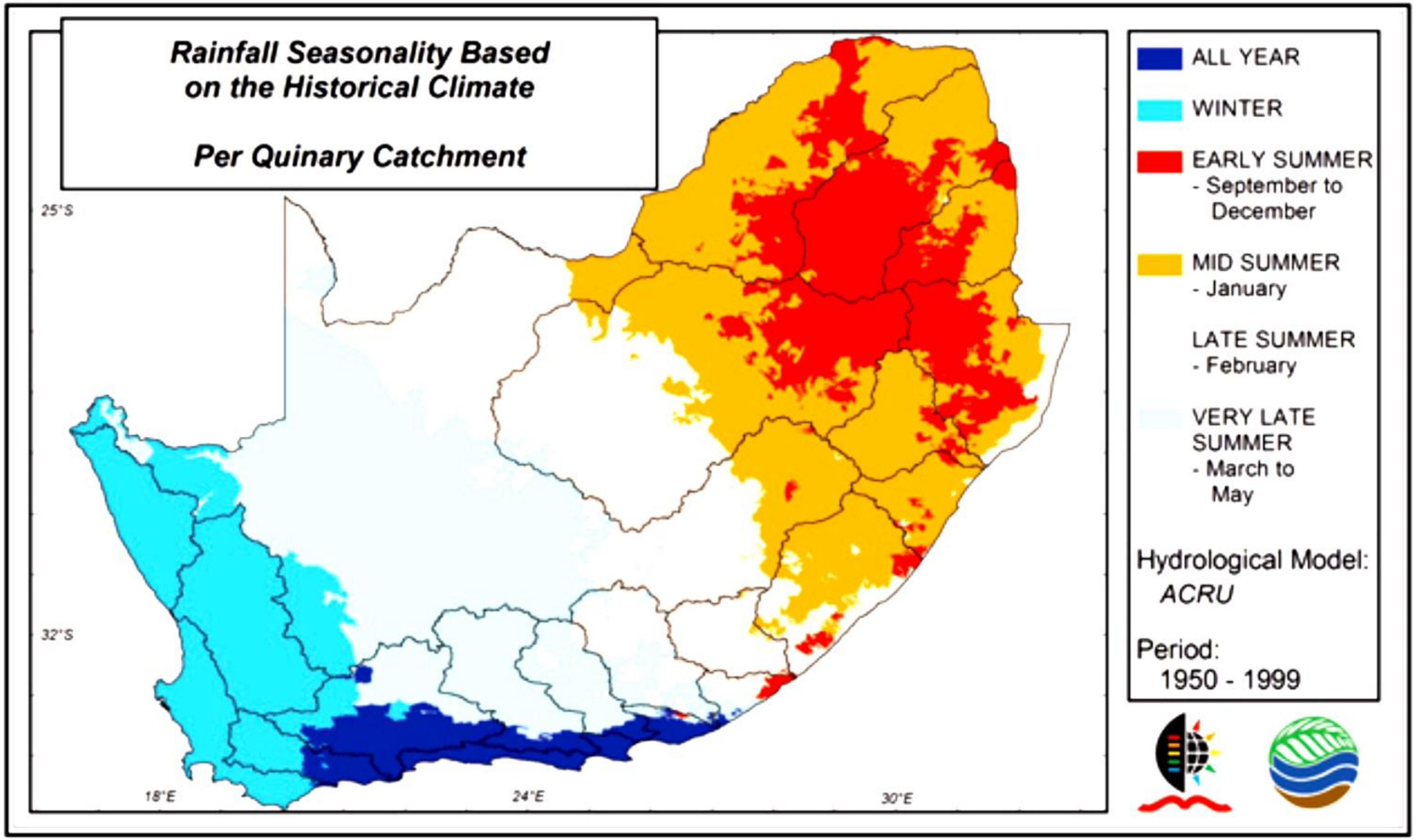



Figure 2a. Example of the transitional zone between the winter and summer rainfall area (a) being an area of inconsistent change between General Circulation Models (GCMs). After Schultze (2011).

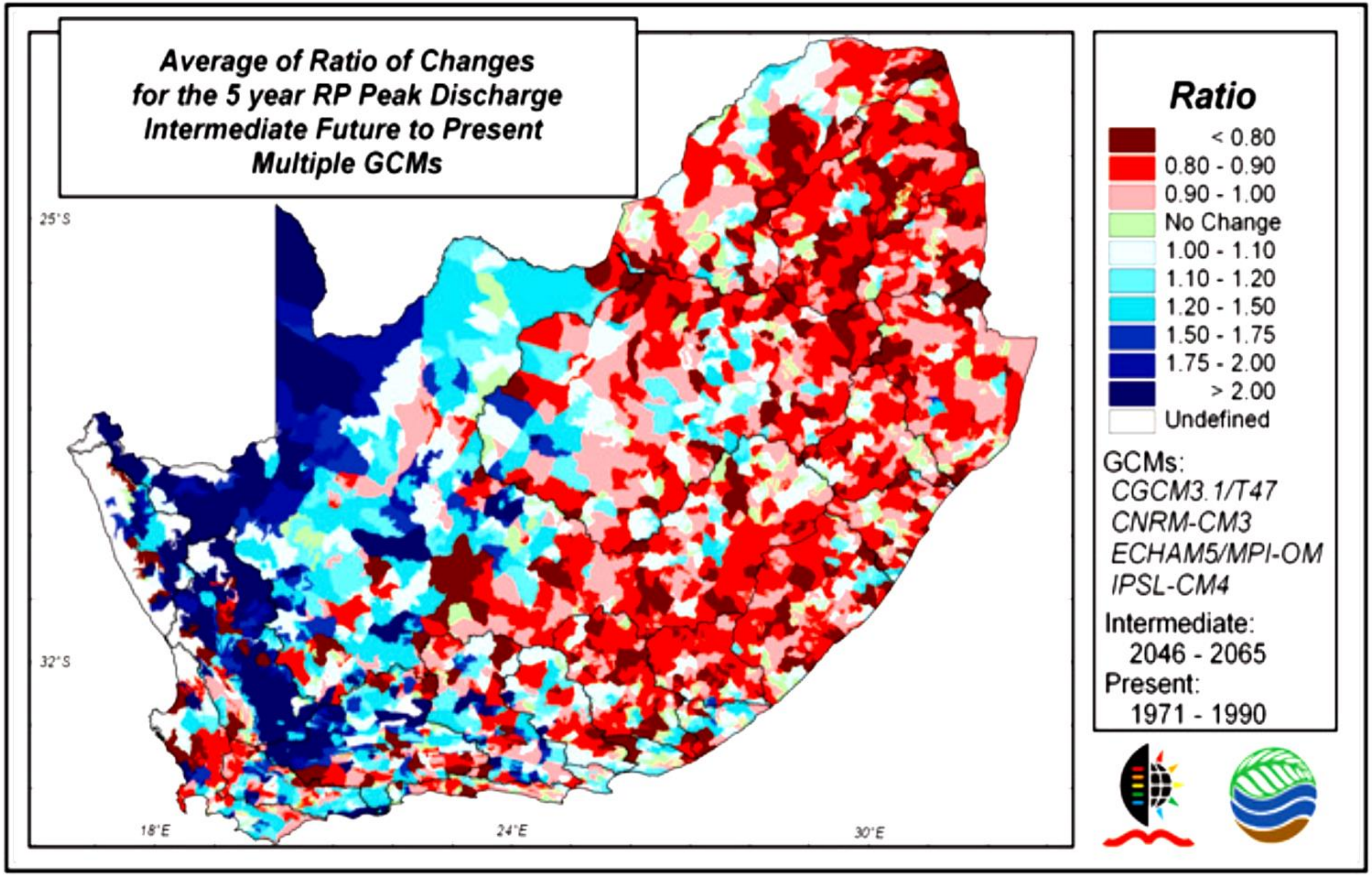



Figure 2b. Example of the transitional zone between the winter and summer rainfall area and of high sensitivity to climate change (RP: Return Period).

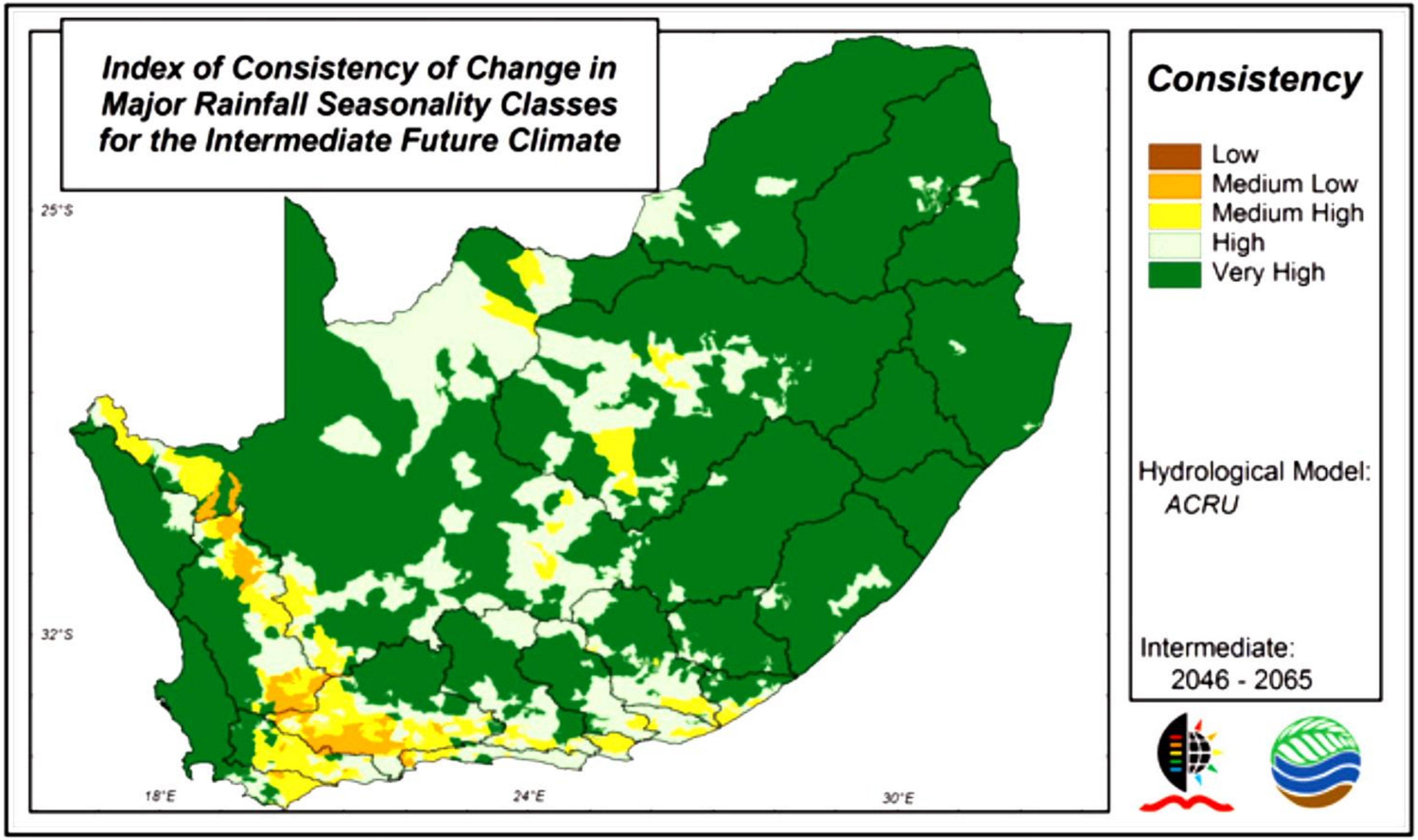



Figure 2c. Example of the transitional zone between the winter and summer rainfall area by the low index of consistency of change.

## 2.4 Legal context

The legal framework underpinning freshwater aquaculture development in South Africa primarily consists of the following National Acts of Parliament:

- The National Environmental Management Act (NEMA) (Act 107 of 1998);
- The National Environmental Management: Biodiversity Act (NEM:BA) (Act 10 of 2004);
- The National Environmental Management: Waste Act (Act 59 of 2008);
- The National Environmental Management: Protected Areas Act (NEM:PAA) (Act 57 of 2003); and
- The National Water Act (NWA) (Act 36 of 1998).

These Acts are supported by numerous national and provincial policies, gazetted regulations, and development planning documentation (DAFF, 2013), of which the most relevant to freshwater aquaculture activities revolve around the Environmental Impact Assessment (EIA) regulations (NEMA, 1998), the issues related to the use of alien species (NEMBA, 2004) and issues around water use (NWA).

This section is not a comprehensive review of all the legal requirements for authorisation associated with freshwater aquaculture activities and studies such as Rana (2010) should be consulted for more detailed information. The South African legislation is moreover subject to ongoing review and revision and the triggers and thresholds presented in this document might also change in the future. Nevertheless, and in some cases depending on the scale of the activity or extent of resources affected**,** Table 1 summarises key components of legislation that would need to be considered in proposals for aquaculture activities, or in planning the over-arching legal context of the assessment. Table 1 should be used as a guideline, and moreover that it also excludes the plethora of authorisations required for the building of roads and other infrastructure for aquaculture operations, as well as buildings and other structures outside of the floodplain or riparian areas. Section 3 in Part 1 of the Strategic Environmental Assessment (SEA) Report provides further legal context regarding aquaculture as a whole.

Table 1. Summary of key legislation for consideration in planning freshwater aquaculture systems. Note that this table is intended to be informative rather than exhaustive and that legislation is subject to ongoing change that might outdate this information.

| Act | Application |
|---|---|
| **1. Environmental legislation** | |
| National Environmental Management Act (NEMA) (Act 107 of 1998) | Environmental authorisation is required for listed and specified activities. Triggers for authorisation in terms of NEMA vary between provinces and in different zones (e.g. in or near Protected Areas, urban areas, agricultural areas etc., depending on the activity and its proximity to a watercourse – for example, outside of urban areas the trigger for environmental authorisation for Activity 12 in Listing Notice 1 is within 32m of a watercourse, but in urban areas the trigger is only within the watercourse itself) and are currently included in the updated EIA Regulations of April 2017 (see Listing Notices 1 and 2 of April 2017).<br><br>The development and related operation of facilities, infrastructure or structures for aquaculture (Activity 6 of Listing Notice 1 of 2014 – as amended) will likely trigger an application for authorization.<br><br>Any activities that entail movement (including infilling or excavation) of sediment (rocks, sand, roots etc.) from in or next to rivers or wetlands potentially trigger this act. The volume of sediment that triggers the act varies – currently 5 m³ or 10 m³ for non- |

[1] This information adapted from Rountree *et al* (2016)

| Act | Application |
|---|---|
| | urban and urban areas.<br><br>Activity 6 of Listing Notice 1 pertains to "The development and related operation of facilities, infrastructure or structures for aquaculture of—<br><br>(i) finfish, crustaceans, reptiles or amphibians, where such facility, infrastructure or structures will have a production output exceeding 20 000 kg per annum (wet weight);<br><br>(ii) molluscs and echinoderms, where such facility, infrastructure or structures will have a production output exceeding 30 000 kg per annum (wet weight); or<br><br>(iii) aquatic plants, where such facility, infrastructure or structures will have a production output exceeding 60 000 kg per annum (wet weight); excluding where the development of such facilities, infrastructure or structures is for purposes of sea-based cage culture in which case activity 7 […] applies".<br><br>Listing Notice 3 relates to triggers for environmental authorisation for various activities in specific identified geographical areas, with Activity 13 in particular providing restrictions on the location of "The development and related operation of facilities of any size for any form of aquaculture" in different provinces. |
| National Water Act (NWA) (Act 36 of 1998) | Licensing and/or registration of water uses is required, depending on the use contemplated and (in some situations) the scale of use, where water use is broadly defined in Section 21 of the NWA as follows:<br><br>21(a) taking water from a water resource;<br>21(b) storing water;<br>21(c) impeding or diverting the flow of water in a watercourse;<br>21(d) engaging in a stream flow reduction activity contemplated in section 36;<br>21(f) discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit;<br>21(g) disposing of waste in a manner which may detrimentally impact on a water resource;<br>21(i) altering the bed, banks, course or characteristics of a watercourse |
| The National Environmental Management: Biodiversity<br><br>Act (NEM:BA) (Act 10 of 2004) | Regulates the use, management and control of alien and invasive species. Indicates which species are prohibited and species for which permits are required prior to farming and associated activities being implemented. Indicates what level of farming activities (including what types of systems) are acceptable in specific areas in South Africa, for each alien/invasive species.<br><br>Section 57(1) of the National Environmental Management: Biodiversity Act, Act 10 of 2004 (NEM:BA) prohibits the carrying out of a restricted activity involving a specimen of a "listed protected or threatened species" without a permit. "Listed threatened or protected species include those listed by the Minister in terms of section 56(1) and include species described as critically endangered, endangered, vulnerable and protected".<br><br>Listing Notice 598 of 2014 (Alien and Invasive Species Regulations, 2014) defines alien species and outlines permitting and other requirements for their cultivation (if any).<br><br>LN 864 of 2016 (Alien and Invasive Species Lists, 2016) lists (currently) registered alien and invasive species. |

| Act | Application |
|---|---|
| The National Environmental Management: Protected Areas Act (NEM:PAA) (Act 57 of 2003) | This is the primary statute for the regulation and administration of protected areas, as it provides for the manner in which the different statutes governing protected areas should interact. The NEM: PAA not only deals with national parks, but also with other protected areas.<br><br>Section 50(5) prohibits development, construction and farming in a national park, nature reserve and world heritage site unless prior written approval has been obtained from the management authority. |
| The National Environmental Management: Waste Act (Act 59 of 2008) | This legislation outlines requirements for the disposal of waste – in an aquaculture context, this might pertain to the disposal of sediment and sludge from ponds as well as the disposal of animal waste, effluent and other products. |

| 2. Aquaculture / Agriculture specific legislation | |
|---|---|
| The Animal Diseases Act (Act 35 of 1984) | Provides for the control of animal diseases and parasites and includes measures to promote general animal health |
| The Genetically Modified Organisms Act (Act 15 of 1997) | Provides for measures to promote the responsible development, production, use and application of genetically modified organisms. |
| The Animal Improvement Act (Act 62 of 1998) | Provides for the breeding, identification, and utilisation of genetically superior animals in order to improve their production and performance |
| 6. Animals Protection Act (Act 71 of 1962) | Consolidates and amends the law relating to the prevention of cruelty to animals |
| Conservation of Agricultural Resources Act (Act 43 of 1983) | Provides for control over utilisation of natural agricultural resources in order to promote the conservation of the soil, water resources and vegetation |
| Agricultural Pests Act (Act 36 of 1983) | Provides for measures by which agricultural pests may be combated and/or prevented |
| Draft Aquaculture Bill | To promote the development of an equitable, diverse, viable and competitive aquaculture sector; to create a harmonised enabling regulatory environment.<br><br>It includes the provision that each municipality must ensure that its integrated development plan in terms of the Municipal Systems Act, 2000 (Act 32 of 2000) or other applicable municipal legislation recognises and includes the national aquaculture development plan and any applicable provincial aquaculture development plan; where suitable. |

Most aquaculture ventures would be unlikely to proceed without the need for an authorisation in terms of the above legislation, or at least for some level of site-specific ground-truthing and risk assessment (e.g. in terms of NEMA, NEMBA and the NWA), including a license for water allocation. This is particularly necessary in light of the scale at which this particular assessment has been carried out – often at sub-quaternary or even quaternary scale. A requirement to undertake ground-truthing at a site-specific scale also offers potential relief to prospective aquaculture developers who may have been prejudiced by the conservative approach of this assessment, which is overtly risk-averse, and thus is more likely to have classified some areas as sensitive due to uncertainty. Therefore, the Planning Phase Best Practice and Mitigation Measures (Section 6.1 of this report) require verification of actual key freshwater aspects pertaining to the assessed study areas. This said, it is also noted that

[2] This information adapted from DAFF (2017)

in the ornamental fish industry it is legal to breed and sell listed, permitted exotic fish, provided they are kept in tanks (D. Impson, CapeNature, pers. comm.). South Africa, as many other countries, is in the process of making specific regulatory provision for aquaculture and a Draft Aquaculture Bill is currently available.

**South Africa's National Water Act (NWA)**

South Africa's political transition to democracy created a broad awareness that new water legislation was needed to redress the inequities of previous political dispensations and to take account of its unique situation. A large part of this realization was based on the pressing need to redress the many inequalities of the past and to provide safe and wholesome supplies of water to those communities that previously had to rely on unreliable water sources of dubious quality (Asmal, 1998). The increased demand for water has escalated rapidly and has increased the pressure on dwindling resources. While the volume of water required to meet the basic human needs of all South Africans is relatively small, a relatively large volume of additional water is needed to grow food and provide for the material needs of the growing South African population.

In response to this need, a comprehensive process of public participation led to the development of new water resource management policies and legislation (DWAF, 1996; DWAF, 1997; 1998a; 1998b; 1998c; 1999a; 1999b; Republic of South Africa, 1998). The present South African National Water Act (NWA, Republic of South Africa, 1998) ranks among the best in the world in terms of its scope and intent, as well as the democratic and participative manner in which it was developed. In essence, the Act aims to balance the long-term protection of all surface and groundwater resources with prudent water resource utilisation, while promoting economically sound development, and ensuring that all water use is equitable and sustainable.

Importantly, the National Water Act has replaced all earlier rights to the use of water based on land ownership with a system of administrative authorisations. This is a fundamental and critically important change to the country's water resource management policies and approaches. All water (surface water and groundwater) is now to be managed within the framework of the Integrated Water Resource Management (IWRM) philosophy. The basic approaches of IWRM promote equitable access to and sustainable use of water resources by all stakeholders at catchment, regional, national and international levels (Harris and Haasbroek, 1999). Statutory Catchment Management Agencies (CMAs) are being formed to manage all water resources within defined Water Management Areas (WMAs), a tangible move towards implementing the strategies of IWRM and achieving the objectives outlined in the National Water Act (Harris and Haasbroek, 1999). The Department of Water and Sanitation retains the overall (national) responsibility for custodianship of South Africa's water resources.

The NWA mandates the Minister and the Department of Water and Sanitation (DWS) to evaluate every application to use water, including, but not restricted to applications to:

- Modify streamflow volumes and patterns by in-channel operations;
- Extract water from a watercourse for use in off-channel operations;
- Modify the channel form (width, depth and direction of flow) of a stream or river; and
- Discharge any effluent after use to a watercourse.

In addition, the NWA requires the Minister and the DWS to provide a clear and unequivocal response to every applicant who applies for a water use permit or an effluent discharge permit. In the case of each successful application, the DWS must provide the applicant with a clear set of guidelines or measurable limits regarding the:

- Volume of water that can be used and any timing or duration limits to such use;
- Details of any special actions that must be taken when withdrawing or storing the water;
- Details of any monitoring of water quantity or water quality that may be needed;
- Any specific conditions or limitations that may apply with regard to the proposed water use in the event of prolonged local or regional drought, or other natural disaster; and
- Details of any pre-treatment that must be undertaken before any effluent is discharged to the stream or river where the water was originally drawn from.

A project is currently being undertaken by DWS to develop risk-based inland water quality guidelines for South Africa which will eventually replace the current Water Quality Guidelines series, including Volume 6, Agricultural Use: Aquaculture (DWAF, 1996). Guidelines and standards for aquaculture effluent quality (and quantity) monitoring have however been developed by organisations such as the Global Aquaculture Alliance (GAA), the IFC (e.g. environmental, health, and safety guidelines for aquaculture) and the Aquaculture Stewardship Council and could possibly be adapted for South African conditions. Key variables (at different threshold levels), related to aquaculture practices are considered in these standards such as pH, total suspended solids, phosphorus, total ammonia nitrogen, biochemical oxygen demand, dissolved oxygen and salinity (Boyd *et al*., 2008a).

## 2.5 Key links to other Specialist Studies of this SEA

The following important issues are linked to the Marine Biodiversity and Ecology and Socio-Economic Specialist Studies:

- The effects of freshwater aquaculture on estuarine and marine ecosystems – changes in water quality as well as potential biodiversity changes as a result of escapee aquaculture species may affect estuarine and potentially even marine ecosystems downstream. Such effects are not specifically considered in this study, but are addressed in the Marine Biodiversity and Ecology Specialist Study;

- The effects of aquaculture waste on human health – parasites, bacteria and other waste generated in aquaculture systems may have knock-on human health impacts for downstream water users. These issues are addressed in the Socio-Economic Specialist Study of this scientific assessment.

# 3 SCOPE OF THIS STRATEGIC ISSUE STUDY

This study focuses on freshwater aquaculture activities in South Africa, where the term freshwater is used interchangeably with “inland aquatic ecosystems” as defined by Driver *et al.* (2011), and thus excludes all marine/estuarine based aquaculture systems and the effects of inland aquaculture on estuarine and marine ecosystems.

The term “Inland aquatic ecosystems” includes watercourses as defined in the National Water Act (NWA) (Act 36 of 1998) and their riparian areas up to the 1:100 year floodline, or the outer edge of the riparian area, whichever is the greater; and all other natural wetlands (see definitions in Section 2.1).

The scope of this study covers nine strategic freshwater aquaculture focus areas and five target aquaculture species (i.e. Nile tilapia, Mozambique tilapia, African sharptooth catfish, Brown and Rainbow trout and Marron crayfish), as well as various production systems (instream dams and off-channel systems) that are proposed per study area (refer to Part 1: Section 4 of the SEA Report), all of which are briefly described in the sub-sections below. Each of these aspects is then considered and its implications are assessed from an ecological point of view by taking into account the following factors:

- Ecological sensitivities of the nine selected study areas;

- Water resource quality impacts associated with each production system (including on-site harvesting, cleaning and live packaging of aquaculture products, but excluding processing);

- Threats posed to indigenous instream biota;

- Risks and opportunities presented under different scenarios; and

- Mitigation and best management practices to be considered for different aquaculture practices.

The information presented in this Specialist Study Report is derived from international and local studies and assessments; the experience and learning that have been documented in a number of peer reviewed journal articles, books and reports; and available spatial data relating to various aspects of aquatic ecosystem sensitivity and importance in South Africa. These materials are listed in the reference list contained in Section 12 of this report.

## 3.1 Definitions

The following definitions have been applied to this study:

i) **Resource quality** – the NWA defines this as the quality of all the aspects of a water resource including:

(a) *the quantity, pattern, timing, water level and assurance of instream flow;*

(b) *the water quality, including the physical, chemical and biological characteristics of the water;*

(c) *the character and condition of the instream and riparian habitat; and*

(d) *the characteristics, condition and distribution of the aquatic biota.*

ii) **Watercourse,** as defined by the NWA, refers to:

*a river or spring;*

*a natural channel in which water flows regularly or intermittently;*

*a wetland, lake or dam into which or from which water flows; and*

*any collection of water which the Minister may, by notice in the Gazette, declare to be a watercourse, and a reference to a watercourse includes, where relevant, its bed and banks.*

iii) **Water Resource** – according to the NWA, this includes a watercourse, surface water, estuary or aquifer – and is thus assumed in this study to include the bed, banks, instream and riparian habitat, and associated plant and animal communities. Aquatic ecosystems are the resource base on which all other uses depend (Rowlston, 2011) and an important component of the Ecological Reserve is to protect aquatic ecosystems.

iv) **Wetland** - the NWA defines wetlands as:

"*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*."

v) **Aquatic ecosystem** – the South African National Classification System for wetlands and other aquatic ecosystems (Ollis *et al*., 2013) defines an aquatic ecosystem as follows:

*"An ecosystem that is permanently or periodically inundated by flowing or standing water, or which has soils that are permanently or periodically saturated within 0.5m of the soil surface".*

Rivers, wetlands, estuaries and marine systems are all included in the definition of Aquatic Ecosystems. The National Classification system does however make a primary differentiation between Inland, Estuarine and Marine systems, with rivers and wetlands both falling into the definition of **Inland aquatic systems**, defined as follows:

*"an aquatic ecosystem with no existing connection to the ocean. These ecosystems are characterised by the complete absence of marine exchange and/or tidal influence".*

Estuaries and marine areas that conform to the definition of wetlands lie outside of Inland areas and are not considered in this study.

## 3.2 Study Areas

Nine study areas have been stipulated for inclusion in this assessment, as shown in Figure 3 (refer to Part 2 of the SEA Report). These fall within and/or across all nine of South Africa's Water Management Areas (WMAs) and all nine South African provinces.

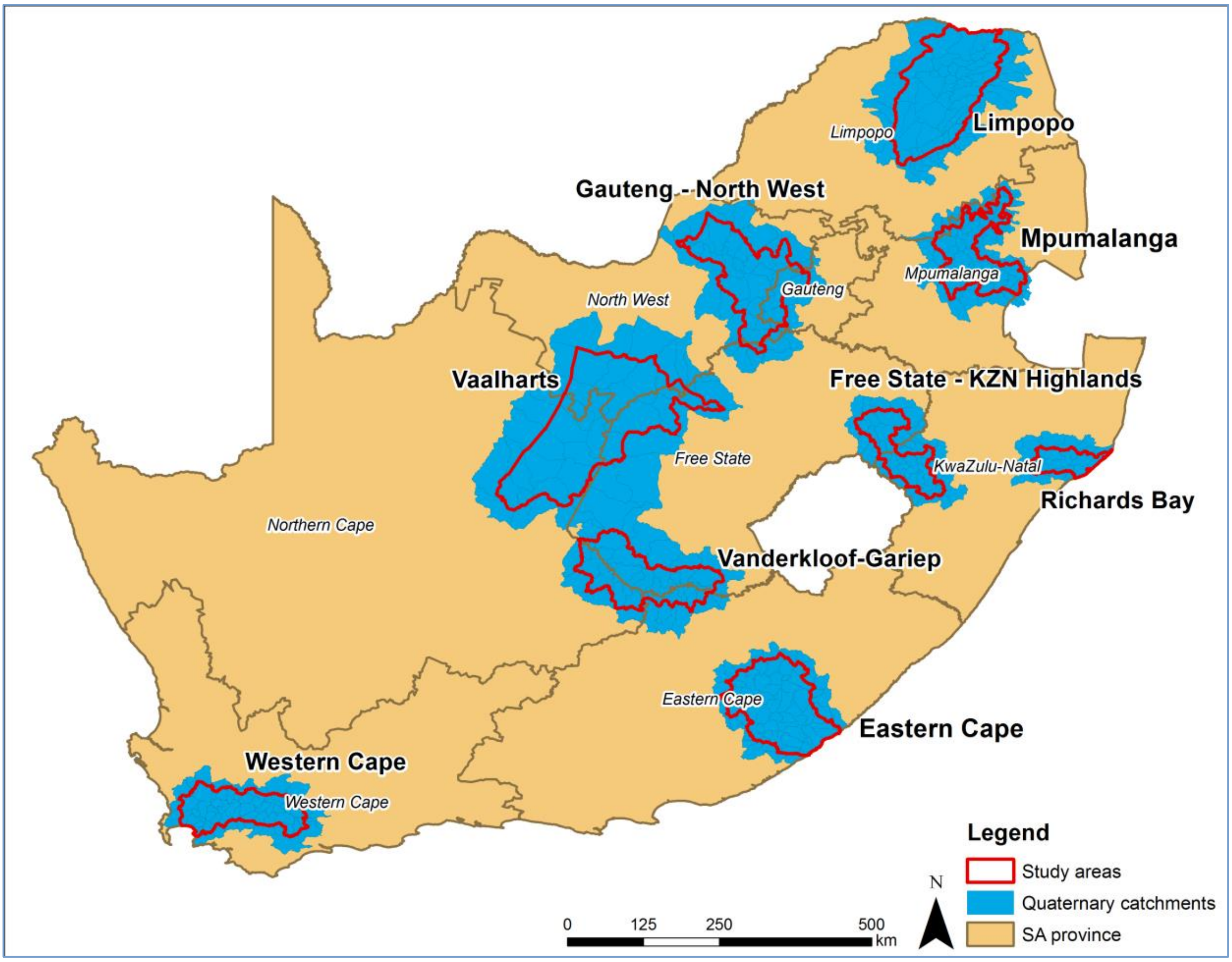



Figure 3. Extent of the quaternary catchments linked to in the nine study areas.

## 3.3 Inclusion of aquaculture species and production methodologies

This assessment focuses on six target freshwater aquaculture species only (refer to Part 1: Section 4 of the SEA Report), namely:

- African sharptooth catfish (*Clarias gariepinus*);
- Mozambique tilapia (Oreochromis mossambicus);
- Nile tilapia (Oreochromis niloticus)
- Marron crayfish (*Cherax tenuimanus*);
- Brown trout (*Salmo trutta*);
- Rainbow trout (Oncorhynchus mykiss).

**Error! Reference source not found.** summarises the target aquaculture species and production methods proposed or consideration in each of the nine strategic aquaculture focus areas (or study areas).

Table 2. Summary of target freshwater aquaculture species and potential production methods proposed for consideration in each of the study areas.

| Species | Study Areas | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Production System | Eastern Cape (1) | Free State – KwaZulu-Natal Highlands (2) | Gauteng - North West (3) | Limpopo (4) | Mpumalanga (5) | KwaZulu-Natal - Richards Bay (6) | Western Cape (7) | Free State – Vaalharts (8) | Free State – Vanderkloof-Gariep (9) |
| **African Sharptooth catfish** | | | | | | | | | |
| Dam cage-culture | | | x | x | | x | | x | x |
| Ponds | | | x | x | | x | | x | x |
| Recirculating aquaculture system (RAS) | | | x | x | | x | | x | x |
| Flow-through (tanks) | | | x | | | | | | |
| **Mozambique tilapia** | | | | | | | | | |
| Ponds | x | | x | x | x | x | | | |
| Recirculating aquaculture system (RAS) | x | | x | x | x | x | | | |
| **Nile tilapia** | | | | | | | | | |
| Recirculating aquaculture system (RAS) | x | | x | x | x | x | | | |
| **Rainbow and Brown trout** | | | | | | | | | |
| Dam cage-culture | x | x | | | x | x | x | | x |
| Ponds | x | x | | | x | x | x | | x |
| Recirculating aquaculture system (RAS) | x | x | | | x | x | x | | x |
| Flow-through (raceways and tanks) | x | x | | | x | x | x | | x |
| **Marron** | | | | | | | | | |
| Recirculating aquaculture system (RAS) | x | | | | | x | | | |

## 3.4 Assumptions and Limitations

This Specialist Study Report must be read with the following assumptions, limitations and exclusions in mind.

### 3.4.1 Exclusions

This study focuses on inland surface water resources only and excludes other aquatic resources such as groundwater, estuarine or marine ecosystems. It is however clear that the impacts of freshwater aquaculture activities could well extend to estuarine and potentially even to marine systems, where these are located at the outflows of affected rivers. Such impacts, particularly in the case of estuaries located near to freshwater aquaculture activities, could have profound ecological implications for estuary function and condition. This issue must be addressed in the broader assessment.

Groundwater is considered only briefly, from the perspective of possible impacts of the infiltration of polluted aquaculture effluent into groundwater resources. No consideration has been made of the potential use (or implications) of either groundwater or direct precipitation as sources of water for aquaculture.

Terrestrial areas are not considered in this assessment, other than in the inclusion of maps of "modified" (i.e. transformed) terrestrial areas, using data from the SANBI (2017) modified habitat layer. These maps have however been provided for information purposes only. While they do provide an indication of catchments where the terrestrial sensitivity of an actual land-based aquaculture facility siting may be low, it is however stressed that the landuse layer has little bearing on the aquatic sensitivity layer, and so has not been used in the sensitivity ratings. This is because the sensitivity ratings are driven by mainly instream factors, that consider amongst other issues fish species of concern, downstream catchments, conservation planning domains and priorities and other factors outlined in detail in Section 4.3. Thus even where terrestrial areas are heavily modified, instream parameters could (and often do) result in high sensitivity ratings. The modified terrestrial area maps do however help to highlight the fact that although the scale of mapping of sensitivity (at quaternary catchment scale) means that the whole quaternary appears to be implicated, <u>the sensitivity ratings apply only to watercourses within these areas</u>.

.The study furthermore considers the risk of only the most significant activities associated with aquaculture production. Activities such as the construction of facilities and infrastructure could clearly also result in significant impacts. These would, it is assumed, be managed through detailed design and planning permission and mitigation measures on a site by site basis.

### 3.4.2 Selection of study areas

The study area identification process was carried out prior to any involvement of the authors of this Specialist Study. Although the selection process (refer to Part 2 of the SEA Report) considered *inter alia* aquatic ecosystem sensitivity and the presence of species of concern with regard to their biodiversity or other impacts, the nine study areas of this specialist assessment do not represent areas that have any strategic significance from the perspective of the protection or management of inland aquatic resources. As a result, they are considered independently in this assessment, as separate study areas.

### 3.4.3 Data limitations

One of the outputs of this study is the spatial mapping of sensitive aquatic ecosystems. These maps are used in the Risk Assessment, to determine areas where there is high confidence that impacts to aquatic ecosystems associated with aquaculture activities would be low. However, the accuracy of the spatial data used is in many cases limited by the scale at which the data are available – quaternary and sub-quaternary level data, as well as the generally low levels of ground-truthing that have informed the collation of these data. A limitation of the outputs of this study is thus the lack of structured, consistent ground-truthing of any of the study areas. **This means that sensitivity maps may over-emphasise the extent of areas of high and very high sensitivity. This limitation is an important one and can be addressed only by ground-truthing and the collection, collation and verification of more accurate data.**

### 3.4.4 Use of these findings

Finally, it is emphasised that this assessment is made from the perspective of freshwater resources, and highlights areas where different aquaculture activities would potentially be associated with lesser or greater degrees of environmental risk or risk to the water resource. The assessment is not intended to provide guidelines as to where aquaculture activities might or might not be financially or practically viable – for example, with regard to meeting the water quality or quantity requirements for different target species.

It is also noted that the intended purpose of the SEA is to provide a "fast track" for the establishment of new freshwater aquaculture facilities, where the environmental Risk of such facilities is considered acceptable (with criteria determining what is "acceptable" defined later in this report). Failure of some proposed facilities to meet these criteria does not mean that the proposed facilities may not proceed – it means simply that they may not proceed in terms of the legislative fast tracking enabled by the SEA.

# 4 DESCRIPTION OF STUDY AREAS

This section describes the location of the nine study areas, the main catchments that occur in each study area, how the natural water quality is impacted by human activities and land use, and the associated implications for the proposed aquaculture activities.

## 4.1 General water quality considerations

Human activities have had a series of profound effects on the background water quality in South Africa's rivers, dams, wetlands and reservoirs, as well as adverse impacts on several groundwater systems. These impacts are superimposed onto natural water quality conditions (Figure 4) that characterise different river systems across the country.

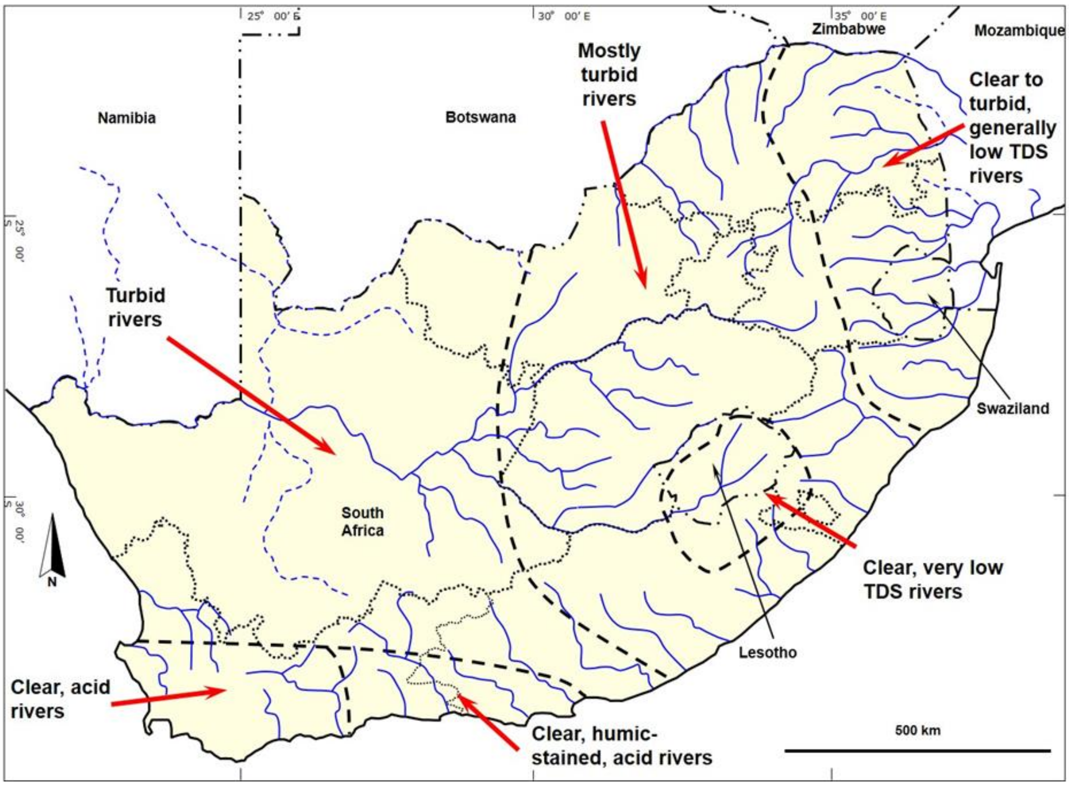



Figure 4. Map showing the different types of natural background water types in South Africa (adapted from Dallas and Day, 2004).

In many areas, several different sets of activities have combined to exert complex changes in water quality resulting in the water quality of many areas of the country being compromised to the extent that it poses serious risks to human health and to the natural environment. Figure 5 illustrates the distribution of the different types of natural and anthropogenic effects on water quality across the country in relation to the nine study areas considered in this SEA.

The details of the background water quality issues that characterise the study areas are shown in **Error! eference source not found.**. The approximate locations of the nine study areas are numbered 1 to 9 in Figure 5.

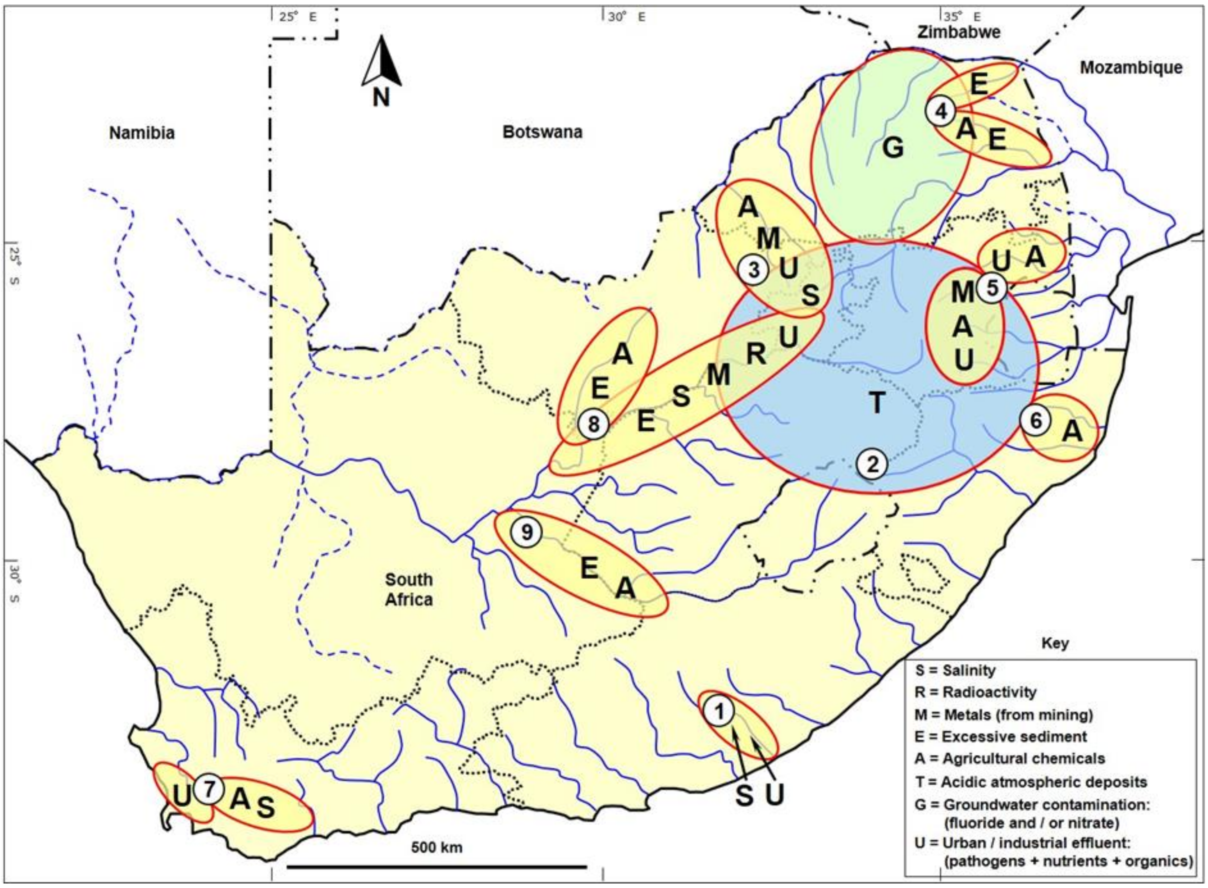



Figure 5. Map showing the various types of background water quality issues that have been recorded for the nine study areas, with study areas numbered: (1) Queenstown-East London, (2) Free State-KwaZulu-Natal highlands, (3) Gauteng-NorthWest, (4) Limpopo, (5) Mpumalanga, (6) Richards Bay, (7) Western Cape, (8) Vaalharts and (9) Free State Vanderkloof-Gariep. Data from DWS.

## 4.2 Description of the Study Areas

Supporting baseline maps showing these study areas and their main hydrological and other relevant features are provided in Appendix 1 (Figure A1.1 – 1.9) to this Specialist Study Report. Indigenous fish species of concern listed per study area are species that have, according to the Red List of South African Fish Species, been categorised to be either Critically Endangered, Endangered, Vulnerable or Data Deficient. The assessment was initiated in 2016 and completed in March 2018 (http://speciesstatus.sanbi.org/partners/).

### 4.2.1 Eastern Cape – Buffalo River system (Study Area 1)

- **Water Management Area:** Mzimvubu to Keiskamma (#12)

- **Affected primary catchments:** Buffalo River and Great Kei River catchments.
- Overview of river systems:
  - Rainfall, though often variable between years, is received during every month of the year ensuring that river flows are less seasonally variable than elsewhere in the country.
  - Rivers flow south-eastwards towards the coast, entering estuaries.
  - The upper catchment areas are relatively heavily populated and sustain extensive areas of intensive livestock ranching – principally sheep, goats and cattle – as well as extensive forestry areas where rainfalls are higher. Subsistence agriculture characterizes most of the Great Kei catchment.
  - Numerous small and large dams on the river systems provide crucial sources of water to the larger towns, farms and some informal settlements close to towns. Many smaller rural communities rely on run-of-river for their water supplies.
- **Indigenous fish species of concern:** Enteromius amatolicus (O'Brien et al., 2017), Enteromius pallidus (Chakona, 2018a), Oreochromis mossambicus (in press), Pseudobarbus sp nov keiskamma (Ellender et al., 2017), Pseudobarbus trevelyani (Chakona, 2018c), Sandelia bainsii (Chakona et al., 2018).
- Existing water quality conditions:
  - Saline effluents discharged from tanneries in King William's Town, cause elevated concentrations of dissolved salts and metal ions in the middle and lower reaches of the Buffalo River.
  - Discharges of treated, partially treated and untreated urban and industrial effluent, as well as contaminated runoff from urban centres and informal settlements, result in the Buffalo River containing large numbers of pathogenic organisms and high concentrations of nutrients, salts and Endocrine Disrupting Chemicals (EDCs).
  - Toxic blooms of the cyanobacterium, *Microcystis aeruginosa* occur frequently in the major water supply reservoirs located close to East London.
  - Vulnerable soils and relatively soft geological formations (e.g. sandstone and siltstone) characterize much of the Great Kei River catchment. Poor agricultural practices and heavy rainfall events cause extensive soil erosion throughout the area. The eroded soil is transported as high concentrations of suspended sediment in the Great Kei River and its tributaries.
- Main threats affecting aquatic ecosystems:
  - Discharge of tannery effluents and domestic plus light industrial effluents in the Buffalo River system; uncontrolled discharge of contaminated runoff and sewage effluent from formal and informal settlements.
  - High concentrations of suspended sediments in the Great Kei River system.
- **Estuaries included in study area:** Buffalo River and Great Kei River.

**Water quality implications for proposed aquaculture operations in this area:**

- Cool water temperatures and lower concentrations of dissolved salts in the headwater reaches of the feeder streams to the Buffalo River system make these streams suitable for the cultivation of trout.
- Lower inter-annual variability in rainfall across the Buffalo River system plus the prevalence of numerous farm dams and small impoundments make the area less vulnerable to water supply problems.
- High concentrations of dissolved salts and high water temperatures make most of the lower reaches of the rivers and streams forming the Buffalo River system unsuitable for trout cultivation.
- The cultivation of marron and catfish is possible in carefully controlled off-channel systems along the river (which may require water temperature adjustments during winter months). However, the poor quality of the water available from the lower reaches of the Buffalo River indicates that it would likely need to be pre-treated before being used for aquaculture operations, if the final product is to pass food safety tests.
- High concentrations of nutrients and resulting blooms of toxic cyanobacteria in dams along the lower reaches of the Buffalo River mean that all fish cultured in untreated river water could be contaminated and therefore pose a potential health risk to humans.
- Any uneaten fish food and fish waste (e.g. faeces) could further enrich the already eutrophic waters of the lower Buffalo River system and accentuate the problems caused by toxic cyanobacteria blooms in downstream water supply reservoirs, and their associated human health risks.

### 4.2.2 Free State – KwaZulu-Natal Highlands (Study Area 2)

- **Water Management Area:** Upper Vaal (#8) and Tugela (#7)
- **Affected primary catchments:** upper Vaal River and Tugela River catchments.
- Overview of river systems:
  - The area receives relatively high rainfall (750-900 mm/year); the Tugela and Upper Vaal rivers are crucial sources of reliable water for the Witwatersrand – the country's economic hub.
  - The upper catchment areas of the two river systems are not heavily populated and support large areas of forestry as well as tourism and some livestock ranching – principally sheep and cattle. The many rural communities rely on subsistence agriculture for their livelihoods.
- **Indigenous fish species of concern:** *Enteromius pallidus* (Chakona, 2018b), *Labeo rubromaculatus* (Chakona and Bills, 2018), *Oreochromis mossambicus* (in press).
- Existing water quality conditions:
  - Atmospheric depositions derived from the Highveld coal-fired power plants and heavy industries contain low concentrations of sulphur and nitrogen oxides and have a moderately acidic pH (5.5 – 6.5). When the natural buffering capacity from the carbonate salts in the soil is exhausted, the excess acid interacts with clay particles. Silica, iron, manganese and aluminium ions are released into the soil water and washed into streams and rivers, leading to a gradual build-up of aluminium, manganese and iron in the surface waters.

  - The stream and river waters in this area have low concentrations of total dissolved salts and nutrients, with almost no detectable concentrations of pesticides except for streams located near intensive feedlot operations.

- Main threats affecting aquatic ecosystems:

  - Gradually increasing concentrations of aluminium manganese and iron caused by acidic atmospheric deposition; slowly increasing concentrations of suspended sediments as a result of stream and river bank erosion.

**Water quality implications for proposed aquaculture operations in this area:**

- The cool, highly oxygenated waters of the headwater streams and rivers are suitable for cultivation of trout.
- Any uneaten fish food and fish waste (e.g. faeces) released into the waterbodies could gradually enrich the nutrient-poor waters of these rivers and streams, which would gradually increase the concentrations of nutrients.
- Importantly, these mountain river and dam systems are a critical water supply area for the Witwatersrand. As a result, it may be difficult to obtain the necessary water use licences from DWS to conduct aquaculture operations in any of the main public water supply reservoirs.
- In the case of privately owned dams / reservoirs on farms, all of these systems have to be licenced by DWS and subject to a dam safety inspection certificate if the volumetric capacity of a dam is greater than 50 thousand cubic metres at full supply level. Farm dams that are smaller than the 50 thousand cubic metre limit could apply for exemption and be used for aquaculture operations provided that any effluent that is discharged from these operations complies with effluent discharge licence conditions.

### 4.2.3 Gauteng – North-West: Crocodile (West) and Marico river systems (Study Area 3)

- **Water Management Area:** Crocodile (West) and Marico (#3).
- **Affected primary catchments:** Groot Marico, Magalies and Mooi River systems.
- Overview of river systems:
  - The Marico River flows in a north-westerly direction from its headwaters to its confluence with the upper Limpopo River on the border with Botswana.
  - The Mooi River flows in a west-south-westerly direction from its Witwatersrand headwaters to the Vaal River.
  - The Magalies River flows eastwards from its headwaters to Hartbeespoort Dam.
  - The upper catchments are heavily urbanized, while intensive agriculture and mining occurs along most of the middle reaches. The lower reaches sustain large areas of game ranching and some iron and platinum mines.
  - The upper reaches of the Mooi River contain several large gold and uranium mines, as well as several large towns and cities.

    - Many rural communities rely on the three rivers for their water supplies and depend on subsistence agriculture.
    - The upper reaches of the Magalies River support a few small aquaculture operations where trout and carp are raised (e.g. Maloney's Eye).

- **Indigenous fish species of concern:** *Enteromius pallidus* (Chakona, 2018b), *Oreochromis mossambicus* (in press).
- Existing water quality conditions:
    - The many chrome and platinum mines produce acidic effluent and acid mine drainage (AMD), though the quantities are far lower than those associated with Witwatersrand gold mines or the Mpumalanga coal mines.
    - Return flows and seepage from agricultural lands result in elevated concentrations of pesticides, salts and nutrients reaching the rivers and their tributaries, eventually flowing into the Crocodile, Mooi and Groot Marico rivers.
    - Discharges of large volumes of treated, partially treated and untreated urban effluent, especially from the northern and western areas of the Witwatersrand, as well as contaminated runoff from urban centres and informal settlements, result in the Crocodile River containing large numbers of pathogenic organisms and high concentrations of nutrients, salts and low to moderately high concentrations of EDCs. All of these substances pose health risks to humans and livestock that may consume the water.
    - Discharges of partially treated and untreated light industrial effluents result in elevated concentrations of metal ions in the main rivers draining the Witwatersrand area to the north-west and west.
    - Dense blooms of the toxic cyanobacterium, *Microcystis aeruginosa* occur annually in the hyper-eutrophic (extremely enriched) Hartbeespoort Dam.
- Main threats affecting aquatic ecosystems:
    - High concentrations of nutrients and pathogenic organisms derived from urban waste discharges; presence of metal ions; presence of pesticides and increasing concentrations of dissolved salts.

**Water quality implications for proposed aquaculture operations in this area:**

- High concentrations of dissolved salts, nutrients and metal ions and high water temperatures make most of the rivers and streams forming the Crocodile (West) and Marico River systems unsuitable for trout cultivation.
- In some of the cooler headwater streams of the upper Magaliesberg tributary to the Crocodile River (West), the cooler water temperature and relatively good water quality is suitable for the cultivation of trout (e.g., at Maloney's Eye).
- The cultivation of tilapia and catfish is possible in carefully controlled off-channel systems along the rivers. However, the poor quality of the water available from most of the rivers indicates that the water would likely need to be pre-treated before being used for aquaculture operations, if the final product is to pass food health safety tests. In addition, low to very low water temperatures during the winter months mean that water in an aquaculture operation might need to be heated during this period to

avoid fish deaths.

- Relatively "clean water impoundments" such as those located on the rivers that drain the northern slopes of the Magaliesburg Mountains (e.g., Buffelspoort Dam catchment) have good water quality and could be suitable for aquaculture operations. However, high water temperatures would make it very difficult to culture trout in these rivers and impoundments, but other fish species may be suitable.

- High concentrations of nutrients and the resulting blooms of toxic cyanobacteria in many small and large water supply reservoirs in the area to the south of the Magaliesberg Mountains mean that all fish cultured in untreated river water could be contaminated and therefore pose a potential health risk to humans.

- The Mooi River receives runoff that is contaminated with radionuclides from mines in its upper catchment. These radionuclides pose a health risk to humans if fish are cultured in aquaculture operations that use radionuclide contaminated water.

- Any uneaten fish food and fish waste (e.g. faeces) could further enrich the already eutrophic waters of the lower reaches of these river systems and accentuate the problems caused by toxic cyanobacteria blooms in water supply reservoirs, with their associated human health risks.

- High concentrations of dissolved metal ions in the main stem of the Crocodile River mean that any fish species cultivated in untreated water from this river system are likely to be contaminated and may not pass food safety tests.

### 4.2.4 Limpopo: Levhuvhu-Mutale / Letaba-Shingwedzi river systems (Study Area 4)

- **Water Management Area:** Limpopo (#1) and Levhuvhu and Letaba (#2).

- **Affected primary catchments:** upper Levhuvhu and Mutale catchments; Sand River catchment; Great Letaba River and upper Shingwedzi catchment.

- Overview of river systems:

  - Almost all of the rivers drain northwards or north-eastwards towards the Limpopo River system, except the Shingwedzi River which drains eastwards to the lower Limpopo River system. The upper catchment areas receive moderate to good rainfalls (400-500 mm/year), with rainfall decreasing steadily to the north and east, reaching 250-300 mm/year close to the Limpopo River. Summer (rainy) season river flows are high whilst winter (drier) season river flows often decrease almost to zero or near zero, particularly in the lower reaches of the rivers.

  - The upper catchment areas are heavily populated and sustain extensive areas of intensive agriculture – principally citrus and sub-tropical fruits – as well as extensive forestry. The upper catchments also contain several small and medium-sized mines that produce gold, some silver and tin, and corundum.

  - The lower (drier) portions of the catchments support numerous small and large communities – most of the residents rely on subsistence agriculture for their livelihoods. Some of the drier portions of the lower catchments support game farming.

  - Numerous small and large dams on the river systems provide crucial sources of water to the larger towns and rural communities, while groundwater supplies are utilized by farming operations and smaller communities. The smaller rural communities rely on hand-dug wells and the run-of-river for their water supplies.

- **Indigenous fish species of concern:** *Enteromius pallidus* (Chakona, 2018b), *Labeo ruddi* (Marr *et al*., 2018), *Oreochromis mossambicus* (in press).
- Existing water quality conditions:
  - The necessity to control the mosquito vector of malaria by spraying with DDT has resulted in the presence of DDT and its breakdown components in the lower Mutale and Levhuvhu rivers.
  - The extensive areas of subsistence cultivation and poor land management techniques have resulted in elevated concentrations of suspended sediments in the middle and lower reaches of the Mutale, Levhuvhu and Great Letaba rivers.
  - Return flows and seepage from the extensive orchards and agricultural lands result in elevated concentrations of pesticides, salts and nutrients reaching the Great Letaba River and its tributaries.
  - Discharges of urban and industrial effluents, as well as contaminated runoff from the towns, smaller urban centres and informal settlements (many lacking access to functioning sanitation systems) pollute the Levhuvhu and Great Letaba rivers and their tributaries. Pollutants include large numbers of pathogenic organisms and high concentrations of nutrients and low concentrations of salts and EDCs. All of these substances pose health risks to humans and livestock that may consume the water.
  - Extensive areas of over-grazing plus areas where land management practices are not effective, contribute elevated concentrations of suspended sediments to the river systems.
  - Many of the illegal gold mining activities in the Giyani Greenstone Belt (Shingwedzi catchment) use mercury to recover alluvial gold. This results in periodic concentrations of mercury in the river water.
  - High concentrations of nitrate and fluoride are present in many groundwater aquifers. Almost all the nitrate is of natural origin with a few small areas showing minor or moderate elevations in nitrate concentrations caused by human agricultural activities.
- Main threats affecting aquatic ecosystems:
  - Abstraction of large volumes of water during the dry season results in very low river flows, particularly in their lower reaches. Presence of urban effluents with bacterial contaminants, and elevated concentrations of suspended sediments. Presence of break-down products of DDT from malaria control programmes.

**Water quality implications for proposed aquaculture operations in this area:**

- High concentrations of DDT and its breakdown products make it very difficult to culture any fish species if the water is not treated to remove these organic contaminants. Fish cultured in untreated water would likely contain unacceptable concentrations of organic contaminants and may therefore be unfit for human consumption or for export.
- The high ambient water temperatures make most of the rivers and streams in these river systems (except, perhaps, the headwaters of the Mutale River) unsuitable for trout. However, the culture of tilapia and sharptooth catfish is possible in off-channel systems using these warmer waters.

- The presence of pathogenic organisms in the rivers makes it imperative that all water to be used in aquaculture operations is evaluated and, if necessary, pre-treated to remove high concentrations of dissolved salts, nutrients and pathogens.

- The presence of pesticide residues in rivers and streams draining intensively cultivated areas means that all fish that are cultured in untreated water probably would likely be unfit for human consumption.

- The presence of mercury residues in rivers draining the Giyani Greenstone belt towards the Shingwedzi River mean that fish cultured in these waters could be unfit for human consumption.

- Any uneaten fish food and fish waste (e.g. faeces) could further enrich the waters of the lower reaches of these river systems and could lead to water quality problems for downstream communities.

### 4.2.5 Mpumalanga – Eastern Highveld river systems (Study Area 5)

- **Water Management Area**: Inkomati (#5), Usuthu to Mhlatuze (#6), and upper Vaal (#8).

- **Affected primary catchments:** upper Komati and Vaal catchments plus upper Crocodile (East) catchment – these are all part of the larger Komati River basin.

- Overview of river systems:

    - The upper reaches of streams and rivers in the Inkomati system provide critically important water supplies to the Witwatersrand via the Vaal River water transfer system, as well as essential water supplies for several thermal power plants.

    - Several open-cast coal mines are located in the upper reaches of the Komati River system and in the upper reaches of the Vaal River system.

    - Many shallow natural lakes (pans) occur across the upper reaches of the three river catchments.

    - Small towns and rural communities obtain the water from the streams and rivers in the three catchments.

    - Extensive areas of maize and potato farming are slowly being converted to open cast coal mining areas.

    - Extensive areas of forestry are present in the upper reaches of the three catchments.

- **Indigenous fish species of concern:** *Chetia brevis* (Roux and Hoffman, 2017a), *Chiloglanis emarginatus* (Roux and Hoffman, 2018), *Enteromius pallidus* (Chakona, 2018b), *Enteromius treurensis* (Roux and Hoffman, 2017b), *Kneria sp nov South Africa* (Roux and Hoffman, 2017c), *Labeo ruddi* (Marr *et al.*, 2018), *Oreochromis mossambicus* (in press).

- **Other important / endangered biota:** Bullfrog populations near Lake Chrissie.

- Existing water quality conditions:

    - Due to the varying levels of iron pyrite in the Highveld coal ore-bodies, the numerous operating and defunct coal mines contribute large volumes of acid mine drainage (AMD) to the river systems. The presence of AMD results in lowered pH values (sometimes to very low values around pH 3.0), and elevated concentrations of metal ions (especially aluminium, iron, manganese, cadmium, zinc and cobalt) and total dissolved salts, dominated by sulphate.

- Acidic atmospheric depositions from the large coal-fired power plants on the Highveld deplete the buffering capacity of the upland soils and contribute to the acidic soil water which releases heavy metals (especially iron, manganese and aluminium) that eventually are washed into all the rivers.
- Return flows and seepage from commercial agricultural lands result in elevated concentrations of pesticides, salts and nutrients.
- Discharges of urban and industrial effluents, as well as contaminated runoff from larger towns, smaller urban centres and informal settlements (many lacking proper and/or functioning sanitation systems and wastewater treatment systems), contribute large numbers of pathogenic organisms and high concentrations of nutrients, salts and low to moderate concentrations of EDCs to the rivers.
- Many residents of the smaller urban centres and rural communities located in the catchment lack access to appropriate sanitation and wastewater treatment systems or, where these systems are present, they seldom work effectively. Discharges of treated, partially treated and untreated urban effluent, as well as contaminated runoff from urban centres and informal settlements, result in many of the rivers containing large numbers of pathogenic organisms and high concentrations of nutrients, salts and low to moderately high concentrations of EDCs.
- Intensive beef cattle production units produce effluents that contain nutrients, and varying concentrations of pharmaceutical compounds (e.g., antibiotics), as well as pathogenic organisms (e.g. *Giardia*, *Cryptosporidium*), that could pose significant adverse health effects to humans and wildlife.

- Main threats affecting aquatic ecosystems:
  - Presence of acidic seepage from coal mining operations, together with raised concentrations of metal ions; Presence of DDT and its breakdown products in waters draining rural and peri-urban areas where malaria is controlled; Presence of increased concentrations of nutrients and pathogenic organisms derived from domestic effluent discharges.

**Water quality implications for proposed aquaculture operations in this area:**

- The cool, highly oxygenated waters of those headwater streams and rivers which do not receive any acidic mine drainage are suitable for the cultivation of trout.
- The warmer, lower reaches of streams and rivers in this area appear to be suitable for the culture of catfish and tilapia. However, care must be taken to ensure that all water used in any aquaculture operations has been certified as free from pesticide residues.
- Any uneaten fish food and fish waste (e.g., faeces) released into the waterbodies from off-channel and in-channel aquaculture operations would gradually enrich the nutrient-poor waters of these rivers and streams. In turn, this could gradually increase the concentrations of nutrients in the water supply to downstream communities.
- Importantly, the mountain river and dam systems are important sources of potable water for a wide range of downstream users and for transfer to the Witwatersrand. Therefore, it will be necessary to ensure that all water discharged from aquaculture operations is pre-treated to ensure that that it meets the effluent discharge criteria set by DWS.

### 4.2.6 KwaZulu-Natal, Richards Bay area – Umfolozi and Lower Mkhuzi river systems (Study Area 6)

- **Water Management Area:** Usuthu to Mhlatuze (#6)
- **Affected primary catchments:** catchments of the lower Mhlatuze and Nseleni rivers.
- **Overview of river systems:**
  - The rivers in this area flow in a south-easterly direction towards the coast, draining large areas of catchment that support numerous scattered communities. Most of these communities rely on water drawn by hand from the rivers and streams, and practice extensive subsistence agriculture and raising of small livestock herds (mainly goats and sheep).
  - Closer to the coast, there are extensive areas of irrigated sugar cane.
  - Also close to the coast, there are extensive areas of forestry.
  - The coastal Lake Mzingazi near Richards Bay is one of very few natural lakes in South Africa.
- **Indigenous fish species of concern:** Ctenopoma multispine (O'Brien et al., 2017), Enteromius pallidus (Chakona, 2018b), Marcusenius caudisquamatus (Maake, 2017), Oreochromis mossambicus (in press).
- **Existing water quality conditions:**
  - Irrigation of commercial croplands is extensive and return flows and seepage from the agricultural lands (sugar cane dominating) and forestry areas result in elevated concentrations of salts, pesticides and nutrients reaching the rivers.
  - While the lower reaches of the rivers in question are affected by water quality impacts such as untreated effluents and agrichemical pollutants, many tributaries and headwaters are unaffected by these impacts and are relatively pristine.
  - Many residents from the numerous small urban centres and the large rural population do not have access to appropriate sanitation systems or effective wastewater treatment systems. Discharges of treated, partially treated and untreated urban and light industrial effluent, combined with contaminated runoff from urban centres and informal settlements, result in the rivers containing large numbers of pathogenic organisms and high concentrations of nutrients, salts and EDCs.
- **Main threats affecting aquatic ecosystems:**
  - Reduced volumes of water available for other uses after irrigation abstractions during winter months; increased concentrations of salts, pesticides, nutrients and suspended sediments.

**Water quality implications for proposed aquaculture operations in this area:**

- The high ambient water temperatures make most of the rivers and streams in these river systems unsuitable for trout.
- The cultivation of marron, tilapia and catfish is possible in carefully controlled off-channel systems along the rivers. However, the poor quality of the water available from the rivers indicates that it would need to be tested and, if necessary, pre-treated before being used for aquaculture operations, if the final product is to pass food safety tests.

- The presence of pathogenic organisms in most of the rivers makes it imperative that all water to be used in aquaculture operations is pre-treated to reduce the high concentrations of dissolved salts, nutrients and pathogenic organisms.
- The presence of pesticide residues in rivers and streams draining intensively cultivated areas mean that all fish that are cultured in untreated water would likely be unfit for human consumption.
- Any uneaten fish food and fish waste (e.g. faeces) could further enrich the waters of the lower reaches of these river systems and could lead to water quality problems for downstream communities.

### 4.2.7 Western Cape – River Systems in Cape Town to Swellendam area (Study Area 7)

- **Water Management Area:** Breede (#18) and Berg (#19).
- **Affected primary catchments:** Eerste River, Berg River and Breede River.
- **Overview of river systems:**
    - The Eerste River flows west-south-westwards to the coast, passing through extensive vineyards around Stellenbosch.
    - The Berg River flows north-north-westwards from the mountainous areas near Stellenbosch, to the Atlantic Ocean north of Cape Town.
    - The Breede River flows in an east-south-easterly direction to the Indian Ocean.
    - The headwaters of the three river systems provide crucial water supplies to the Greater Cape Town Metropolitan area and towns such as Stellenbosch, Paarl, Wellington and Vredenburg-Saldanha.
    - The headwaters of the three catchments also support some large areas of commercial forestry and agriculture (e.g. vineyards and orchards).
    - The study area receives very variable rainfalls with high inter-annual variability as well as spatial variability across the study area. This makes the entire area vulnerable to the adverse effects of periodic droughts, which would likely be exacerbated by climate change.
- **Indigenous fish species of concern:** Galaxias sp nov breede (Chakona and Jordaan, 2017), Galaxias sp nov riviersonderend (Chakona, 2017), Pseudobarbus burgi (Jordaan et al., 2017), Pseudobarbus capensis (Impson et al., 2017), Pseudobarbus skeltoni (Chakona et al., 2017), Pseudobarbus sp nov breede (Jordaan and Chakona, 2018), Sandelia capensis (Chakona, 2018d).
- **Existing water quality conditions:**
    - Most of the rivers to the east of the Cape Town metropolitan area (e.g. Eerste River) receive large volumes of contaminated surface runoff from urban areas and informal settlements in their mid to lower reaches, including discharges of treated, partially treated and untreated domestic and industrial effluent. The receiving urban rivers contain large numbers of pathogenic organisms and high concentrations of metal ions, nutrients, salts and Endocrine Disrupting Compounds (EDCs).

  - In the Breede River system, the elevated concentrations of dissolved salts from the naturally saline soils and groundwater are aggravated by saline return flows of groundwater from the intensive irrigation agricultural land-use in this catchment.

  - Irrigation return flows from areas of intensive agriculture in the Breede River valley contain a wide variety of agro-chemicals (fertilisers and pesticides) and high concentrations of dissolved salts.

  - The lower reaches of the Berg River receive naturally saline groundwater inflows that are worsened during dry periods and periodic droughts by evaporative concentration effects.

  - The upper reaches of the Berg River feed into the Berg River Dam which is a critical water supply element for the greater Cape Town metropolitan area.

- **Main threats affecting aquatic ecosystems:**

  - Increased concentrations of nutrients and pathogenic organisms derived from urban effluent discharges; Presence of increased concentrations of dissolved salts and pesticides derived from irrigated areas.

  - Over-abstraction of surface water is a significant threat, especially for tributary streams.

  - A potential future threat is groundwater abstraction and the excessive use thereof.

  - Invasive alien vegetation is considered a major threat to aquatic ecosystems.

**Water quality implications for proposed aquaculture operations in this area:**

- High concentrations of dissolved salts and high water temperatures (except in the cooler, highly oxygenated headwater streams of, for example, the upper Berg River) make most of the rivers and streams forming these river systems unsuitable for trout.

- The cooler waters of the upper Berg River and the upper Eerste River suggest that these would be suitable for the culture of trout. However, it will be important to ensure that any aquaculture operations do not jeopardize the quantity or quality of the water in these two systems because they are crucial for the supply of potable water to Cape Town.

- The cultivation of tilapia and catfish is possible in carefully controlled off-channel systems along the lower reaches of the streams and rivers, where the water is warmer. However, the poor quality of the water available from the rivers indicates that the water would likely need to be pre-treated before being used for aquaculture operations, if the final product is to pass food safety tests.

- High concentrations of salts, nutrients and pesticide residues in the lower reaches of the Breede River mean that all fish cultured in untreated river water could be contaminated and therefore pose a potential health risk to humans.

- The middle reaches of the Berg River provide water for extensive vineyards. These warmer waters would likely be suitable for the cultivation of tilapia, provided that the concentrations of dissolved salts and nutrients do not exceed the limits specified for aquaculture operations. Importantly, river flows in the middle reaches of the Berg River are becoming increasingly variable and this may jeopardize aquaculture operations.

- The water would have to be tested for undesirable contaminants and, if necessary, pre-treated before use.

- Any uneaten fish food and fish waste (e.g. faeces) could further enrich the waters of the lower Breede River system and Berg River system, and could lead to unacceptable water quality for downstream communities.

### 4.2.8 Vaalharts river systems (Study Area 8)

- Water Management Area: Lower Vaal (#10)
- **Affected primary catchments:** Lower Vaal and Harts river catchments.
- Overview of river systems:
  - The lower Vaal River flows in a south-south-westerly direction from the Witwatersrand area to its confluence with the Gariep/Orange River.
  - The lower Vaal River is a crucial source of water to many towns and smaller communities along its length, as well as numerous farming operations (maize cultivation as well as cattle and sheep ranching).
  - Several mines located relatively close to the lower Vaal River also rely on the river for their water supplies and for the discharge of their effluents. The Harts River is a tributary of the lower Vaal River and the catchment supports extensive areas of irrigated agriculture.
- Indigenous fish species of concern: None.
- Existing water quality conditions:
  - The numerous active and defunct gold and uranium mines in the Witwatersrand complex contribute large volumes of AMD to the middle and lower reaches of the Vaal River system – both passively and by active de-watering of mines. Large volumes of “unaccounted for water” leak from the potable water supply reticulation systems across the Witwatersrand complex, enter the active mines and mined-out areas, and aggravate the AMD problem. The AMD results in lowered pH values and elevated concentrations of metal ions and total dissolved salts, dominated by sulphate, as well as relatively high levels of radioactivity in certain tributary rivers – such as the Mooi River – that flow into the Vaal River.
  - The numerous cities, towns and smaller urban centres are surrounded by informal settlements; many of these settlements lack formal sanitation systems.
  - Many of the wastewater treatment plants within the Witwatersrand complex – particularly those that serve smaller communities – do not function effectively with the result that large volumes of treated, partially treated and untreated domestic and industrial effluent enter the Vaal River system.
  - Return flows and seepage from agricultural lands result in elevated concentrations of pesticides and nutrients reaching the Vaal River and its tributaries.
  - Discharges of urban and industrial effluents, as well as contaminated runoff from larger cities, smaller urban centres and informal settlements, contribute large numbers of pathogenic organisms and high concentrations of nutrients and salts, as well as low to moderately high concentrations of EDCs to the Vaal River.
  - Blooms of the toxic cyanobacterium, *Microcystis aeruginosa* have been recorded from impoundments located along the Vaal River (e.g. Bloemhof Dam).

  - Heavy industries in the Vanderbijlpark area – principally iron and steel works – contribute additional quantities of inorganic and organic compounds to the Vaal River. There is also a growing concern around the presence of Dense Non-Aqueous Phase Liquids (DNAPLs) in groundwater around the iron and steel mills. The presence of DNAPLs makes the groundwater unfit for all human uses. In addition to the DNAPLs, the groundwater in many areas contains the lighter non-aqueous phase liquids (LNAPLs) typically associated with leakage from underground fuel storage depots.

  - Discharges of treated, partially treated and untreated urban effluent, as well as contaminated runoff from urban centres and informal settlements, result in the rivers containing large numbers of pathogenic organisms and high concentrations of nutrients, salts and low to moderately high concentrations of EDCs in the Vaal River.

  - Return flows and seepage from intensively farmed agricultural lands along the Harts River system result in elevated concentrations of salts, pesticides and nutrients reaching the Harts River, and eventually flowing into the lower Vaal River system.

- Main threats affecting aquatic ecosystems*:*

  - Presence of low radioactivity levels in the Mooi River and in the lower Vaal River water; Increased concentrations of dissolved salts and organic compounds derived from mining and industrial operations; Presence of increased concentrations of nutrients and pathogenic organisms derived from urban effluent discharges; Presence of toxic cyanobacteria growths; Presence of increased concentrations of dissolved salts and pesticides derived from irrigation return flows.

**Water quality implications for proposed aquaculture operations in this area:**

- High water temperatures in these river systems make the waters unsuitable for the culture of trout.
- High concentrations of dissolved salts, nutrients and metal ions and high water temperatures make most of the rivers and streams forming the Vaal and Harts river systems unsuitable for aquaculture operations.
- The cultivation of tilapia and catfish is possible in carefully controlled off-channel systems along the rivers. However, the poor quality of the water available from the rivers indicates that the water would need to be tested and, if necessary, properly pre-treated before being used for aquaculture operations, if the final product is to pass food health safety tests.
- High concentrations of nutrients and pesticide residues in the many small and large water supply reservoirs in this area mean that all fish cultured in untreated river water could be contaminated and therefore pose a potential health risk to humans.
- Any uneaten fish food and fish waste (e.g., faeces) could further enrich the already eutrophic waters of the lower reaches of the Vaal River system and accentuate the problems caused by toxic cyanobacteria blooms, with their associated human health risks.
- Data from the Department of Water and Sanitation water quality database have confirmed that high concentrations of dissolved salts and metal ions, as well as low concentrations of radionuclides, are present in the Vaal River. This means that any fish species that is cultivated in untreated water from this river system could be contaminated by metal ions especially, as well as radionuclides. If this happens, it is possible that the final products would be unlikely to pass food safety tests.
- Careful checks need to be made to ensure that no DNAPL or LNAPL contaminants are present in water used for aquaculture operations, because these compounds could render all cultured fish unsafe for human consumption.
- Careful checks need to be made of radioactivity levels in water drawn from the Vaal and Mooi river

systems to make sure that the water is fit for use in aquaculture operations.

### 4.2.9 Vanderkloof – Gariep System (Study Area 9)

- Water Management Area: Lower Orange (#14)
- **Affected primary catchments:** Gariep / Orange River system.
- Overview of river systems:
  - The Gariep / Orange River flows in a westerly to north-westerly direction from the Lesotho border to the very large Gariep and Vanderkloof dams. Many of the tributary rivers feeding into the upper reaches of the Gariep / Orange River (e.g. Caledon and Kraai rivers) drain areas that are underlain by vulnerable, soft mudstone, siltstone and sandstone geological formations. This results in naturally high loads of suspended sediments in all these rivers.
  - Small towns along the Gariep / Orange River (e.g., Bethlehem) rely on the river for their water supplies.
  - Extensive areas of sheep and goat ranching occur in the catchment.
- **Indigenous fish species of concern:** *Enteromius pallidus* (Chakona, 2018b).
- Existing water quality conditions:
  - Overgrazing of vegetation on the easily erodible rocks and soils of the feeder catchments that flow into the Caledon and Kraai rivers, together with heavy summer rainfall events, increase the already naturally high concentrations of suspended sediments, which make their way downstream to the Gariep Dam.
  - Many smaller urban centres and rural communities in the upper catchment of the Caledon and Kraai rivers lack access to appropriate sanitation systems and, where systems are present, they seldom work effectively. Inflows from these areas contribute low concentrations of nutrients and salts to the Gariep / Orange River.
  - Discharges of treated, partially treated and untreated urban effluent, as well as contaminated runoff from urban centres and informal settlements along the Caledon River (including Maseru in Lesotho), result in the Caledon River containing large numbers of pathogenic organisms, high concentrations of nutrients and salts, and moderately high concentrations of EDCs. These are washed into upper Gariep / Orange River and then into the Gariep Dam downstream.
  - Most of the suspended sediment that is washed into the Gariep Dam is retained within the basin of this dam and the outflow from the Gariep Dam to the Vanderkloof Dam downstream contains noticeably less suspended sediment.
- Main threats affecting aquatic ecosystems:
  - Presence of increased concentrations of nutrients and pathogenic organisms derived from urban effluent discharges; Increased concentrations of dissolved salts and pesticides derived from irrigated areas.

**Water quality implications for proposed aquaculture operations in this area:**

- High water temperatures and high concentrations of suspended sediment in the Gariep Dam make the waters unsuitable for the culture of trout, especially during the warmer summer months.
- Extremely high concentrations of suspended sediment in the Gariep Dam make the reservoir unsuitable for aquaculture operations except, possibly, for off-channel cultivation of catfish and/or tilapia, using water that has had the suspended sediment removed.
- The cooler waters of the Vanderkloof Dam and the dramatically lower concentrations of suspended sediment make the waters of this reservoir theoretically suitable for the cage culture of trout. However, there is still a risk that water temperatures may be too high for trout to tolerate, especially during the summer months.
- The cultivation of tilapia and catfish is possible in carefully controlled off-channel systems along the interconnecting river between the Gariep and Vanderkloof dams. However, the water should be checked regularly to ensure that its quality is suitable for an aquaculture operation.
- Any uneaten fish food and fish waste (e.g. faeces) would further enrich the waters of the lower reaches of the Gariep / Orange River system and could disadvantage nearby downstream communities and farming operations that rely on the river for their water. Communities located further away downstream are unlikely to be affected because of the dilution factor with distance.

## 4.3 Identification of ecologically sensitive areas

The study areas included in this assessment include a wide variety of aquatic ecosystems, each of which may have different sensitivities to the kinds of impacts that are likely to be associated with freshwater aquaculture ventures. This section outlines the approach taken to, and the outcomes of, identifying areas within each of the nine selected study areas that have varying sensitivities to the likely impacts of freshwater aquaculture. The resultant sensitivity layers form a critical informant of the Risk Assessment outlined in Section 6 of this report, and also provide a useful spatial guide to mitigation, since impacts on some sensitive areas may be avoidable through mitigation rather than through site avoidance. Note however the impact of limitations in data accuracy on the assignment of sensitivity to different areas (see Section 3.4.3).

### 4.3.1 What is meant by sensitivity?

Ecological sensitivity (or fragility) refers to the system's ability to resist disturbance and its capacity to recover from disturbance once it has occurred (resilience) (Resh *et al*., 1988) with both abiotic and biotic components being taken into consideration in the assessment of ecological importance and sensitivity (Kleynhans *et al*., 2005a).

Freshwater ecosystems (rivers and wetlands) are considered to be sensitive to the following key impacts associated specifically with aquaculture, and described in more detail in Section 5 of this report:

- Water quality changes (including turbidity, nutrient enrichment and associated changes in dissolved oxygen availability);
- Biodiversity changes as a result of:
  - Changes in the genetic structure of wild populations of indigenous species that may result from species introduced into the system from aquaculture;

  - Invasion by alien aquaculture species with the resulting displacement of indigenous species; and
  - Invasion by alien or indigenous parasites or diseases associated with the aquaculture species;
- Hydrological changes; and
- Changes in habitat quality as a result of any of the above changes (e.g. increased sediment, changes in water flows and nutrients, aquatic plant or animal community structure), as well as changes that affect bank and bed stability and morphology (e.g. as a result of in- or near-channel construction).

The extent to which the above issues are likely to be of concern is likely to vary spatially, depending on the type, condition and sensitivity of the affected system. This section outlines an approach to spatial mapping of aquatic ecosystem sensitivity, using rated categories to illustrate the sensitivity of different areas / river reaches to the above key impacts. Four levels of sensitivity have been mapped, as listed below, using the rating criteria and mapping approaches outlined in Section 4.3.2:

- **Very High sensitivity** – any of the above impacts would potentially be associated with changes in ecosystem drivers or responses that would be associated with very high levels of ecological significance - avoidance, mitigation or management of such impacts to acceptable levels of risk would be realistically unlikely, albeit not impossible;
- **High sensitivity** – potentially associated with changes in ecosystem drivers or responses that would be considered of high (negative) ecological significance – avoidance, mitigation or management of such impacts to acceptable levels of risk would be realistically unlikely, albeit not impossible;
- **Moderate sensitivity** – potentially associated with moderate but still significant changes in ecosystem drivers or responses – the likelihood of achieving effective mitigation through reasonable design or management interventions is however high;
- **Low sensitivity** – the above impacts would be unlikely to be associated with any change in ecosystem drivers or responses in these areas.

### 4.3.2 Methodology for sensitivity mapping

#### 4.3.2.1 Approach overview

In this study, available relevant spatial data were rated as to their sensitivity (as defined in Section 4.3.1) to the impacts likely to be associated with aquaculture development. Assignment of overarching sensitivity scores per area was based on the highest sensitivity rating for any rated attribute – i.e. using the maximum rule. Thus, for example, if a quaternary was rated Low sensitivity for some criteria, Medium for others and High for one criterion, the rating of HIGH would be accorded that quaternary as a whole and reflected in the Sensitivity Maps provided in Appendix 3 to this report.

In order to allow a more in-depth analysis of the Sensitivity maps produced in this exercise, which do not (in hard copy) indicate which factors drive the assignation of particular sensitivity ratings to a particular area, two additional approaches were included in this study, namely:

- Interrogation of spatial data to allow for summary data to be derived, showing the proportion of each study area that has been assigned Low, Medium, High and Very High sensitivity ratings for each rated attribute; and
- The compilation of a "live" on-line map that allows users to interrogate the data driving the assignment of an overarching sensitivity score for any area – this system, developed for this

project by Spatial Modelling Solutions (SMS), allows users to click on any quaternary within the study areas and see on a pull-down list what variables are driving its Sensitivity scores.

#### 4.3.2.2 Data availability

The following spatial data were utilised in the development of sensitivity layers:

i. National Freshwater Ecosystem Priority Area (NFEPA) data:

Since these data are available at a national level, and include spatial data relating to rivers, wetlands, catchments, fish and other biodiversity data, they were used as the default spatial layer in this assessment. However, as a result of some of the data constraints (see Box below), NFEPA data were supplemented or exchanged for more accurate or more recent data where these were available. Thus provincial Critical Biodiversity Area (CBA) data were utilised instead of NFEPA wetland data for assessment areas in KwaZulu-Natal, Eastern Cape, Western Cape and Gauteng; more recent (DWS, 2014) data relating to modelled river condition were used instead of NFEPA Present Ecological State (PES) data and provincial conservation officials were asked to provide updated / ground-truthed data regarding threatened (and other) fish distributions (see sections below for further discussion as to each of these supplementary datasets and their application in the sensitivity assessment).

The following NFEPA datasets were used in deriving sensitivity maps, using the specific data fields and ratings outlined in Appendix 2 to this report, namely:

- NFEPA Rivers
- River FEPAS
- Fishsanc
- Fishsanc All spp
- NFEPA Wetlands.

Note that even where supplementary fish data were available, NFEPA Fish Sanctuary and Fish Species data were in all cases retained in the system, as these datasets cover the full study area.

**NFEPA data constraints:**

NFEPA data are generally provided at the level of sub-quaternary catchments, with main stem rivers mapped at a scale of 1:500 000. However, the dataset is far from perfect, and the mapping and rating of wetland presence, extent and condition in particular is problematic in many areas. The data also considerably under-represent other watercourse types, such as the ephemeral water courses and their alluvial flood plains in drier areas of the country in particular (e.g. Northern Cape and parts of the Free State).

Concerns have also been raised by some specialists in this field as to the accuracy of NFEPA data with regard to fish species distributions and river condition. No spatial data can confidently be considered 100 % accurate, and always requires ground-truthing/ in-field verification if it is to inform project-level decision-making.

ii. SANBI supplementary fish species data:

This dataset comprised only taxa for which the status had been re-assessed between 2016 and 2018 (http://speciesstatus.sanbi.org/partners/). These taxa have been rated as to the degree of threat to each, using the IUCN Red List species data.

iii. Supplementary provincial fish species data:

Provincial conservation agencies were approached for additional data regarding fish species distributions and/or other concerns. Of these, only the Mpumalanga Tourism and Parks Agency (MPTA) provided such data, which have been incorporated as a rated supplementary dataset (MPTA data of concern – **Appendix 2**). These data are mainly at a sub-quaternary level, and include MPTA-generated ratings of areas where no aquaculture should occur (primarily because of the occurrence of species of conservation concern and the Mpumalanga freshwater biodiversity sector plan), and areas where restricted or tightly controlled aquaculture activities could be supported, subject to detailed risk assessments. In addition, fish species occurrence and conservation status data at a sub-quaternary level were provided from the MARXAN data, used in the generation of the Eastern Cape CBA maps (Department of Economic Development, Environmental Affairs and Tourism (DEDEAT), 2017);

iv. Additional fish data included in the Succulent Karoo Ecosystem Plan (SKEP):

These data (Driver *et al*., 2003) relate to the presence and number of endemic fish species in the SKEP planning domain were also utilised;

v. Present Ecological State (river condition) as well as Ecological Importance and Ecological Sensitivity data:

These measures of river condition, importance and sensitivity were modelled at a national level for the main river channels through quaternary catchments (DWS, 2014). It is acknowledged that under ideal circumstances they should be ground-truthed and are inherently inaccurate at the level of individual sites. In the context of the current project, they do however represent the best available mapped measure of river condition and ecological importance and sensitivity.

vi. Critical Biodiversity Area assessments (CBAs):

Aquatic CBA data exist for all provinces except the Free State. In the case of Limpopo, North West, Northern Cape and Mpumalanga, the aquatic CBAs are however derived wholly from the NFEPA data and, for this reason, only NFEPA data were used for these provinces. In the Free State, CBAs do not include aquatic ecosystems, other than at the level of FEPA catchments and wetland clusters, with NFEPA data believed to considerably under-represent aquatic ecosystem extent in this area. More accurate aquatic CBAs are currently being finalised in this province but were not available in time for this assessment, and NFEPA data were thus used.

More detailed provincial CBAs however have been produced for Gauteng, Eastern Cape, Western Cape and KwaZulu-Natal, and in these cases, the relevant provincial CBA and Ecological Support Area (ESA) data were utilised, in place of FEPA data, as follows:

- **Gauteng** – The Gauteng C-Plan v3.3 Critical Biodiversity Area data were utilised – these include CBAs and Ecological Support Areas (ESAs). The identified CBAs include 32% of the FEPA priority catchments, while an additional 24% are included as ESAs. In all, over 56% of the FEPA priority catchments are included in Protected Areas, CBAs and Ecological Support Areas (GDARD, 2014);
- **Eastern Cape** – The CBA plan for this province is currently being prepared, but the data themselves were made available, courtesy of Dr P. Desmet (NMU) and Dr G. Hawley (EOH

Coastal & Environmental Services). Terrestrial land use data delineating "natural" areas were also included as a surrogate measure to infer likely least-impacted river condition;

- **Western Cape** – The Western Cape used FEPAs, supplemented with Fine Scale Planning data to derive provincial CBAs and ESAs (Pool-Stanvliet *et al.,* 2017).

vii. Protected areas:

Aquaculture activities are not permitted inside Protected Areas without written Authorisation through these authorities. This means that the short-circuiting of application processes sought through the SEA might not apply to applications for infrastructure development within conservation areas. For this reason, Protected Areas were included in the sensitivity layer, noting that in the event that the relevant authorities approved a proposed aquaculture facility, the "sensitivity" imposed as a result of its location within a Protected Area would fall away. The spatial extent of Protected Areas was obtained from the South African Protected Areas Database (SAPAD,2017).

The National Environmental Management: Protected Areas Act, 2003 (NEMPAA) NEMPAA was enacted to regulate the system of protected areas in South Africa and to provide for their management. Any commercial activity carried out in a protected area (which would include marine protected areas and sensitive estuaries or conservation worthy catchment areas) requires the written authorisation of the management authority, which will usually be SANParks or a provincial conservation authority.

*The above datasets represent the most comprehensive set of data that could be gathered by the study team within the time-frames of this assessment. It is recognised that in some cases there may be additional data that have not been included, and that there are some mapping and data collation processes currently under way that may outdate the data utilised here. For this reason, the sensitivity assessment has striven to be as transparent as possible, and to avoid the development of complex weighting or data amalgamation systems. This means that the Sensitivity Layers should be readily interpretable and could also be easily updated as better and more accurate data become available, or as circumstances change.*

#### 4.3.2.3 Dealing with data mapped at different scales

The data used in the sensitivity analyses have not all been mapped at the same scale – some have been mapped at quaternary scale; some at sub-quaternary scale; some are linear and some (e.g. Protected Areas data) take no cognisance of catchments. In order to develop sensitivity maps that included all of these data without losing resolution, the following measures were adopted:

- Data that extended over parts of quaternaries were left as such, and sensitivity mapping, which reflects the highest sensitivity category assigned per area, takes cognisance of rated categories that extend only partially into quaternaries, by assigning scores for that category only to the portion of the quaternary to which the rated scores apply – this is a different approach to that taken in the previous version of this assessment, which extrapolated scores applied to a partial area of the quaternary to the whole quaternary;

- River data that are linear (e.g. PES data) remain linear in the Sensitivity assessments.

#### 4.3.2.4 Data not included in sensitivity mapping

- *Resource Quality Objectives*: In addition to the data used above, it was initially proposed that the Ecological Target Categories for meeting gazetted Resource Quality Objectives should also inform sensitivity mapping. However, these data are limited in current application and were not readily available as mappable units within the time frames of this study, and have thus rather been referred to in the pre-approval check-list for proposed aquaculture activities, rather than being mapped spatially;

- *DWS water quality data*: Water quality data for routine DWS river and dam monitoring sites in the study areas were provided by Resource Quality Information Services (RQIS) (was RQS, IWQS, HRI), Department of Human Settlement, Water and Sanitation (was Department of Water and Sanitation and previously Department of Water Affairs). Although these data were initially included in early drafts of the sensitivity layers, they are too spatially sparse to be really useful in an assessment such as this, and moreover did not lend themselves to mapping at similar scales to the other variables. They were thus excluded.

### 4.3.3 Criteria for mapping sensitivity to key impacts

Table A2.2 (in Appendix 2 to this report) provides the rating scores and other criteria applied to the data used in the development of the various sensitivity layers presented in Appendix 3 to this report (Figure A3.1 – 3.19). The scale and origins of these data are summarised in Table A2.1 in Appendix 2, which also indicates which data are applicable to the rating of which particular impact sensitivities.

The derivation of rating scores was carried out by the project team, resulting in ratings of Low, Medium, High and Very High sensitivity as defined in Section 4.3.1. Where data already included scores / qualitative categories, these were used e.g. Ecological Importance (EI) and Ecological Sensitivity (ES) data are presented in LOW to VERY HIGH classes, and these were retained. The following notes apply to specific rated categories:

- In general, aquatic ecosystems categorised as CBAs were rated as Very High sensitivity and ESAs as Moderate sensitivity, taking cognisance of management objectives for these categories, as presented by Job *et al.* (2008) for the Western Cape fine-scale conservation planning assessments;

- NFEPA data were rated considering the biodiversity implications of impacts to important fish populations, and both the number of affected threatened species and their threat status were individually considered, as shown in Table A2.2 (Appendix 2);

- Other biodiversity factors, including the proximity of important frog or bird habitats or Ramsar wetlands, were also included using NFEPA RANK data from the NFEPA wetlands layer;

- Where supplementary fish data were available (e.g. MPTA data), these were rated separately from NFEPA data, to prevent double counting and thus possible elevation of sub-quaternary catchment importance;

- Terrestrial (i.e. non-marine) protected areas were all accorded a sensitivity rating of Very High, compatible with their status as areas in which aquaculture is not promoted (but see notes on the implications of proposed aquaculture sites located in Protected Areas in Section 4.3.2).

### 4.3.4 Dealing with issues of data uncertainty

Many of the data accessed in the sensitivity assessment are presented at sub-quaternary or even quaternary level only, and there are some systems for which there were no data available. Sensitivity rating in this study has taken a deliberately risk-averse approach to addressing these issues. Thus, some areas may be accorded a higher sensitivity than they may actually warrant. Such issues usually relate either to the scale of existing data on which the sensitivity assessment has been based, or to the paucity of data for some areas. In such cases, ground-truthing and /or the collection of additional verified data would be necessary informants to adjust the sensitivity of a particular area under consideration. It must also be borne in mind that although several criteria have been considered in the assignment of sensitivity ratings, the highest sensitivity rating for any of the criteria for which data are available has in all cases been allocated to the system or sub-quaternary catchment.

### 4.3.5 Dealing with mitigation in sensitivity mapping

Different freshwater ecosystem types may have different levels of sensitivity to impacts likely to be associated with aquaculture activities, as will those located in different regions, and those in different conditions – for example, aquatic ecosystems that support remnant populations of threatened fish or other species may have very high sensitivity to biodiversity change as a result of alien invasion. It is however clear that some of the above impacts lend themselves to mitigation, which would decrease the risk of the impact occurring. Table A2.1 in Appendix 2 highlights the sensitivity rating type (i.e. biodiversity, water quality, hydrology and habitat quality) most applicable to each rated variable. These rating types provide guidance as to where to focus appropriate mitigation to reduce Risk ratings in different areas. For example, if the Sensitivity Type driving the overarching Sensitivity Rating in a particular area is water quality, then mitigation measures should focus on addressing threats to water quality.

### 4.3.6 Outputs of Sensitivity Assessments

The sensitivity assessment process was intended to generate multiple maps for each assessment criteria, showing sensitivity to water quality, biodiversity, hydrology and habitat quality changes. The initial results showed the layers were very similar across all groupings, largely reflecting the issue of data scale, as well as the links between the above impact categories. Therefore, single sensitivity maps were developed for each study area. To improve clarity and allow some differentiation between different drivers of sensitivity to be identified, these layers are also with Protected Area layers turned off.

The following sections provide a summary of the sensitivity analyses for each study area and should be read with the associated maps (see Appendix 3: Figures A3.1–A3.19) and study area descriptions included in Section 4.2 of this report.

More detailed interrogation of the variables driving the actual rating of each study area can be derived through the following link, which allows users to identify their quaternary of concern and query the rating of different variables:

Summary data for each study area are also provided, highlighting the proportion of each area rated Low, Medium, High or Very High for each of the assessed rating categories.

### 4.3.7 Results of Sensitivity Assessments

The results of the Sensitivity Assessments are shown in Appendix 3 to this report, as a series of coded maps.

Appendix 3 also includes separate figures for each study area, showing the extent of Protected Areas as well as NFEPA flow data (ephemeral or perennial rivers), Free Flowing rivers and rivers with Flagship status. Note that only NFEPA rivers are shown, and not all drainage lines – NFEPA rivers being the largest of the rivers, shown at a scale of 1:50 000 maps.

The following sections provide quick summaries of the results of the Sensitivity assessments. These differ from those presented in previous drafts in that they now include updated IUCN national fish data [http://speciesstatus.sanbi.org/taxa/lineage/538/], as provided to this study team in July 2019.

The section includes summary graphs, showing for which proportions of the study areas as a whole each attribute was rated Low, Medium, High or Very High. These graphs allow for the main drivers of overarching sensitivity per study area to be readily identified.

#### 4.3.7.1 Eastern Cape (Figure A3.1 - 3.2 and Figure 8)

Figure A3.1 shows most of the study area as having been accorded a high sensitivity rating, with portions in the south eastern and north western parts of the site being rated as Very High Sensitivity and only a relatively small area in the north east of the site being accorded Moderate sensitivity. No areas are rated of Low sensitivity. Main stem rivers throughout the study area are rated high and very high, reflecting their (modelled) PES categories of A, B and C, D respectively and /or their seasonal nature (Figure A3.2). In addition, some of the perennial rivers to the south might afford limited opportunities for aquaculture water supply even if off-channel cultivation of low-risk species is considered.

The Nahoon/ Buffalo systems in the north-west of the study area have a very high rating – and the inset to Figure A3.2 indicates that this is driven largely by the importance of these and their upstream catchments as fish support areas in the NFEPA and datasets.

No assigned Free Flowing or Flagship rivers occur in the study area (Figure A3.2) and the extent of protected areas is limited and does not play a major role in determining high sensitivity areas. Ephemeral rivers are abundant in the drier northern parts of the study area – these systems would both be at higher risk of impact from some aquaculture activities (e.g. abstraction and water quality impacts) but would also themselves potentially pose a risk to sustainable aquaculture production systems, if water supply is not assured.

Figure 6 illustrates that the revised SANBI IUCN threatened fish species data resulted in most of the site being rated as of High or Very High sensitivity as shown in Figure A3.1 (Appendix 3), with Table A2.2 showing that “High” and “Very High” ratings for this attribute reflect the presence of 1-2 or >2 threatened fish species at a quaternary level. Note that the Eastern Cape Fish MARXAN data, from the Eastern Cape CBA layers, show a much lower area scored as High and Very High at a sub-quaternary scale. However, these data, as shown in Table A2.2, reflect different aspects, with a “Medium” sensitivity in the Eastern Cape data reflecting at least one fish species of concern in the area, but where confidence in its presence is Low. High and Very High Sensitivity ratings for this category in fact reflect Moderate and High Confidence that the fish species is present. This means that the two datasets must be regarded as complementary and one cannot be used in place of the other. It does however indicate that ground-truthing of river reaches downstream, at and upstream of a proposed site would need to be carried out in this study area, to improve data confidence in the allocation of area sensitivity.

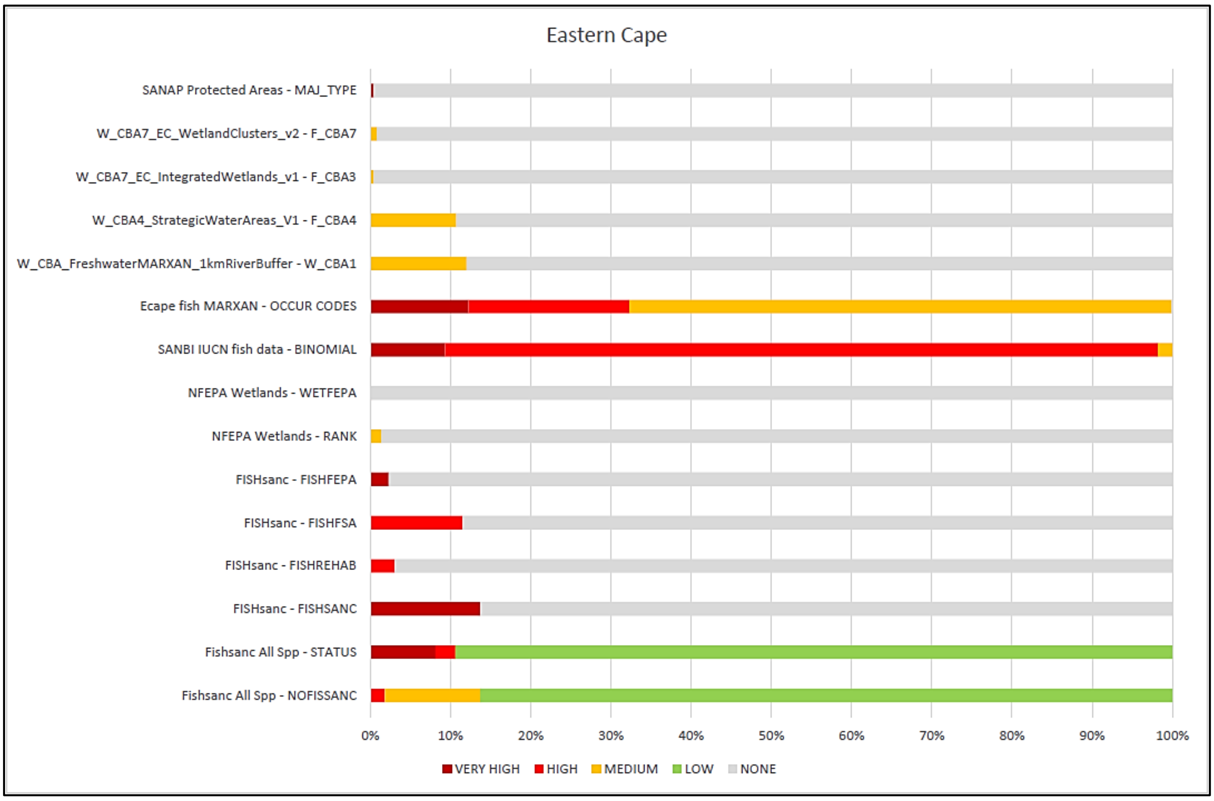



Figure 6. Summary data for the Eastern Cape study area, showing sensitivity ratings for each attribute considered in the assignment of overall sensitivity scores, and the geographical extent (% of the whole study area) that each assigned sensitivity class for each attribute occupies.

#### 4.3.7.2 Free State – KwaZulu-Natal Highlands (Figure A3.3 – 3.4 and Figure 7)

Sensitivity data for this study area show High and Very High sensitivity ratings across much of the southern portion of the site, although the northern (Free State) section of the site is primarily Medium sensitivity only. This might reflect a paucity of data in the Free State, where in the absence of a detailed CBA layer, the sensitivity assessment had to rely mainly on NFEPA data.

The High and Very High sensitivity ratings are driven in part by important rivers in high-lying mountain stream areas (e.g. the Meul River and Pleasant Gift River in the north east, which flow into the Wilge River (Upper Vaal catchment), the Majeneni River, Putterill River and associated tributaries that flow into the Thukela catchment to the east, and the Boesmans, Mooi and Rensburgspruit rivers and minor tributaries that flow eastwards.

Figure 7 shows however that again SANBI IUCN Fish data account for most of the rating of the study area as High or Medium.

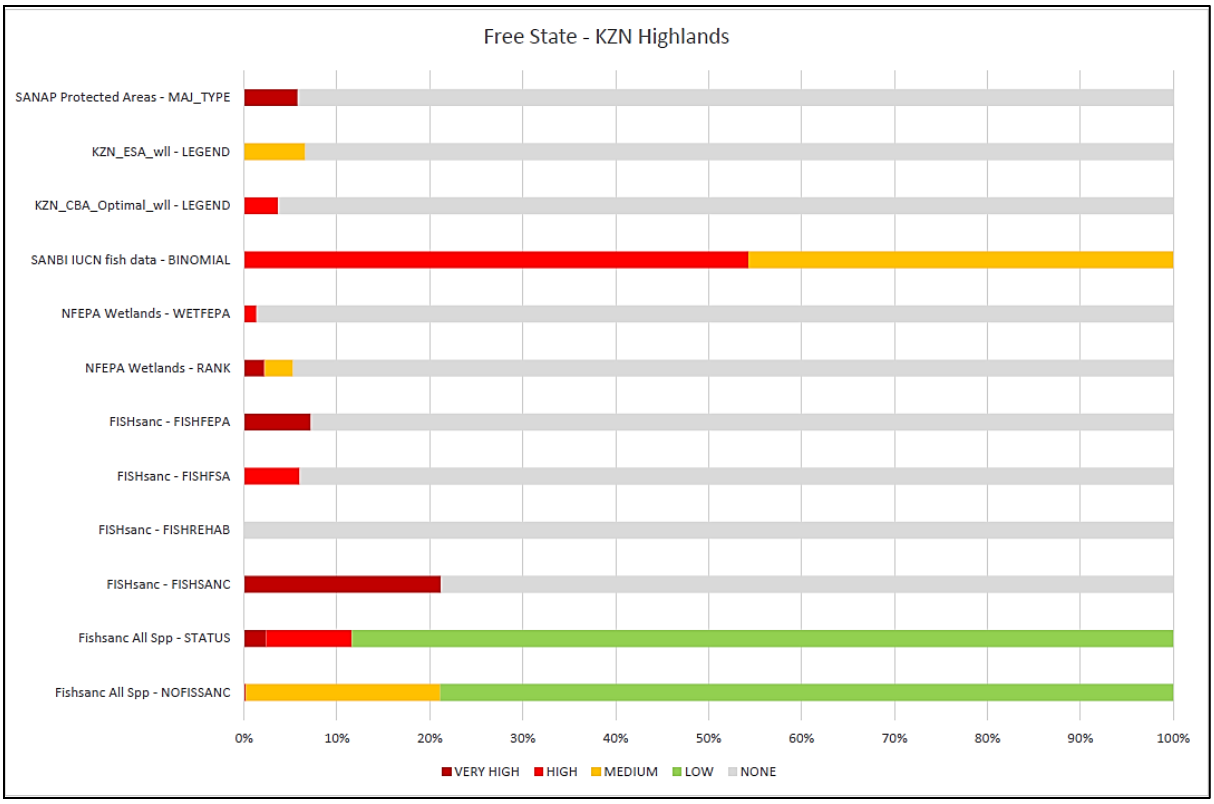



Figure 7. Summary data for the Free State – KwaZulu-Natal Highlands study area, showing sensitivity ratings for each attribute considered in the assignment of overall sensitivity scores to different parts of the study area rated.

#### 4.3.7.3 Gauteng – North-West (Figure A3.5 - 3.6 and Figure 8)

The sensitivity map (Figure A3.5) shows areas of High and Very High sensitivity in the northern (Elands, Kosters and Groot Marico rivers), eastern (Skeerpoort, Sterkstroom, Hex rivers) and south eastern parts of this study area (Mooi, Loopspruit, Rooikraalspruit rivers) with areas of Medium and (limited) Low sensitivity occurring in the west, draining into the Middle Vaal catchment.

Figure 8 shows that High and Medium sensitivity rating by area is driven mainly by SANBI IUCN national data, while NFEPA FEPA and fish support areas (*Enteromius motebensis*) drive the allocations of Very High sensitivity.

There are a few protected areas in this study area, but they are relatively small. No flagship or free flowing rivers occur in the area (Figure A3.6).

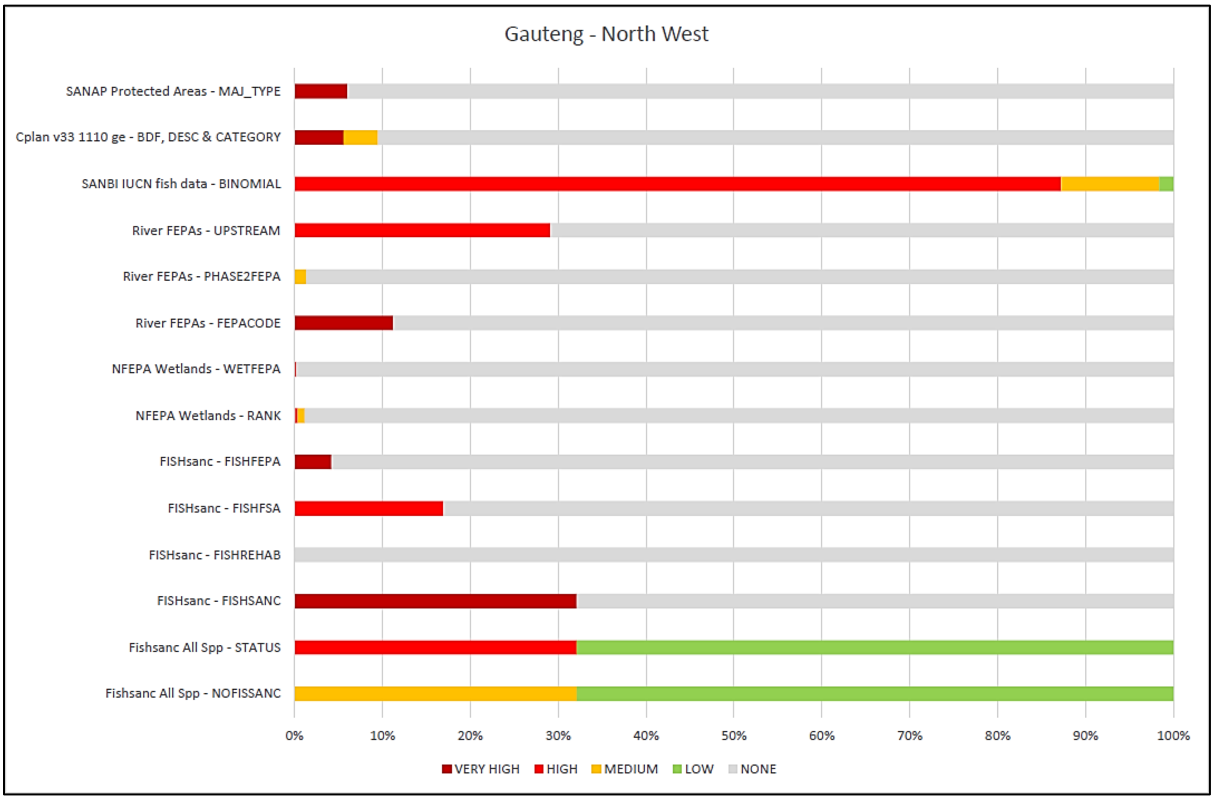



Figure 8. Summary data for the Gauteng – North-West study area, showing sensitivity ratings for each attribute considered in the assignment of overall sensitivity scores, and the geographical extent (% of the whole study area) that each assigned sensitivity class for each attribute occupies.

#### 4.3.7.4 Limpopo (Figure A3.7 - 3.8 and Figure 9)

The sensitivity of this study area is accorded wholly of the study area has been mapped as upstream management areas in the Sand River catchment, protecting the FEPA sub-quaternary downstream of the Sand / Brak River confluence in the northern part of the study area. These areas are rated as being of High sensitivity (Table A2.2). However, Figure 9 also shows that 100% of the study area has High Sensitivity by virtue of the presence of Red List Fish species (http://speciesstatus.sanbi.org/taxa/lineage/538/) in the rivers. There is no confidence rating attached to these data, but for the purposes of this assessment, it must be assumed that, unless shown otherwise, these systems are important for the conservation of one or more species of threatened fish species and this warrant concern.

Relatively small areas of the site have been coded Very High Sensitivity – these ratings are all based on FEPA data.

The only fish sanctuary sub-quaternaries in this area are in the northern section in the Mdodi and Nwanedi (and minor tributary) sub-catchments, supporting the indigenous fish *Clarias theodorae* (NFEPA data), while the FEPA sub-quaternary of the nearby Mutale River supports the indigenous species *Enteromius lineomaculatus* and *Opsaridium peringueyi*.

The Mutale River has also been classified in NFEPA data as a flagship / free flowing river (Figure A3.8) and has Lake Funduzi, one of the only natural lakes in the country. These factors are further supporting its Very High sensitivity status.

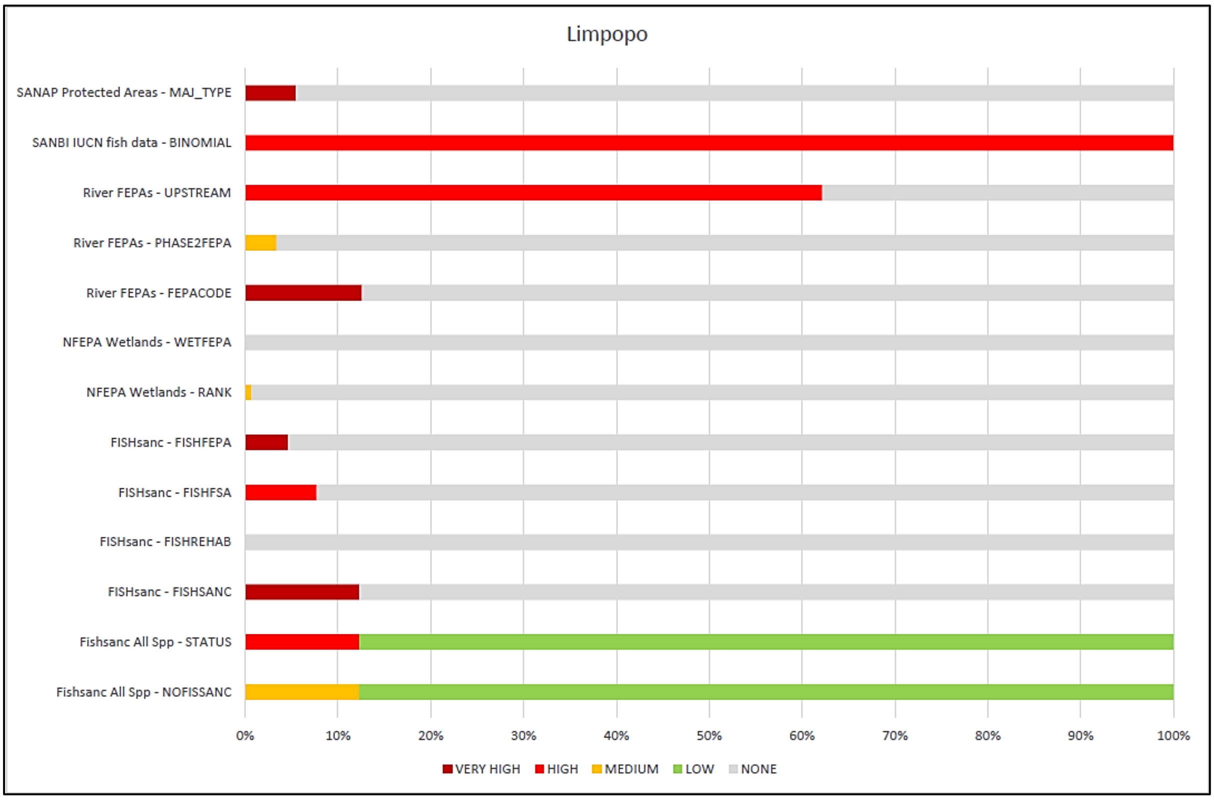



Figure 9. Summary data for the Limpopo study area, showing sensitivity ratings for each attribute considered in the assignment of overall sensitivity scores, and the geographical extent (% of the whole study area) that each assigned sensitivity class for each attribute occupies.

### 4.3.7.5 Mpumalanga (Figure A3.9 - 3.10 and Figure 10)

The whole of this study area has been rated High and Very High sensitivity in Figure A3.9. Figure 10 shows that SANBI Red List Fish species data result in 100% of the area being rated High on account of the mapped presence of 1-2 fish species of concern in all quaternaries. The FEPA sub-quaternaries of the upper Blyde, the Ohrigstad, Spekboom, Alexanderspruit and other similarly rated systems draining into the Steelpoort (and then Olifants) river systems to the north west drive the very high sensitivity ratings of these areas, while in the northern parts of the area, very high sensitivity ratings are contributed to by the FEPA status of sub-catchments of the upper Crocodile (East) and Lunsklip, Klein Komati and Witkloofspruit rivers draining into the Komati River to the east, as well as the fish support sub-quaternary systems also draining into the Komati system.

Fish support areas also contribute to the High and Very High sensitivity ratings, as do the MPTA sub-quaternary data for fish of concern (Very High sensitivity). No flagship rivers occur in the study area, but large areas of the northern (Blyde River) and south eastern parts of the study area are Protected Areas, with Very High sensitivity status.

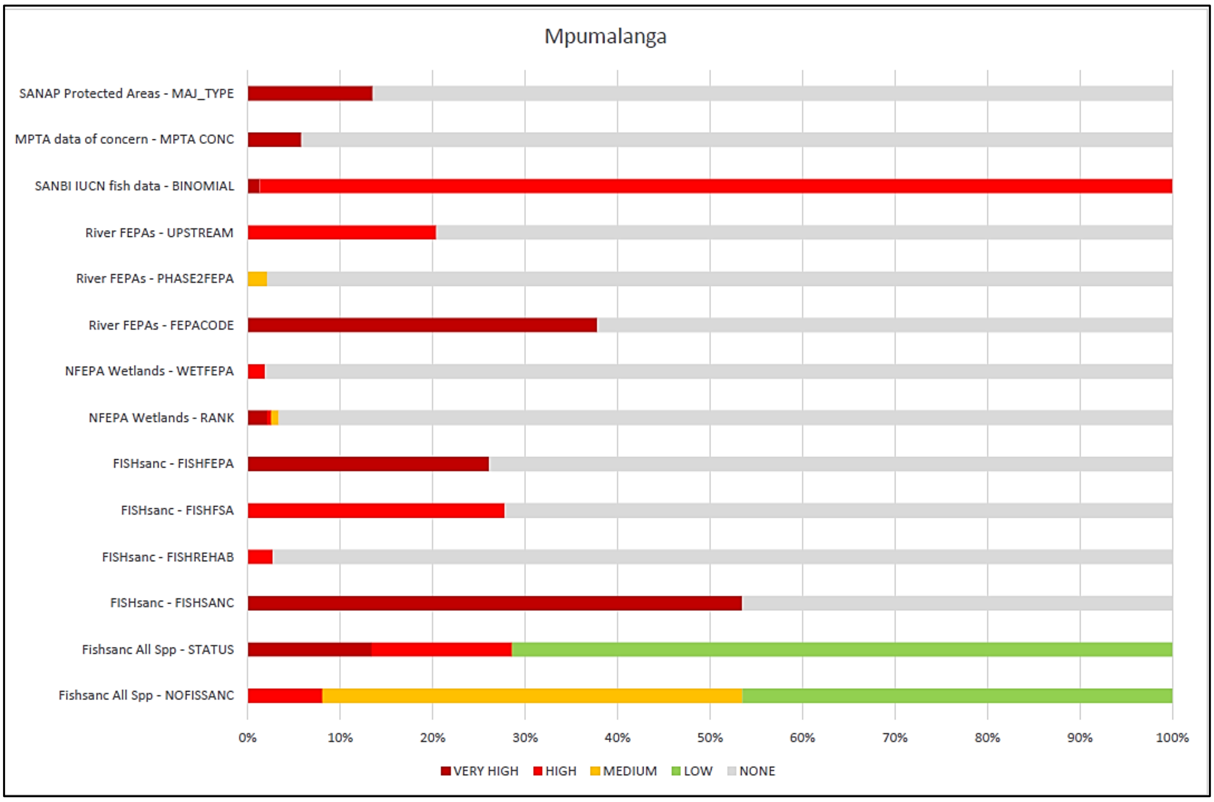



Figure 10. Summary data for the Mpumalanga study area, showing sensitivity ratings for each attribute considered in the assignment of overall sensitivity scores, and the geographical extent (% of the whole study area) that each assigned sensitivity class for each attribute occupies.

#### 4.3.7.6 KwaZulu-Natal – Richards Bay (Figure A3.11 - 3.12 and Figure 11)

Figure A3.11 shows that the whole study area is rated as of High or Very High sensitivity. Summary data presented in Figure 1 show that these ratings are driven primarily by the (updated) SANBI IUCN fish data, which indicate indigenous fish species of conservation importance throughout the study area. Section 4.2.6 notes that these fish species include *Ctenopoma multispine, Enteromius pallidus, Marcusenius caudisquamatus* and *Oreochromis mossambicus*.

No flagship or Protected Areas occur within this study area.

It should be noted that the sensitivity of estuaries and marine areas including and / or abutting onto this study area have not been included in this assessment, but must be considered as part of the overarching assessment (see Section 2 of this report).

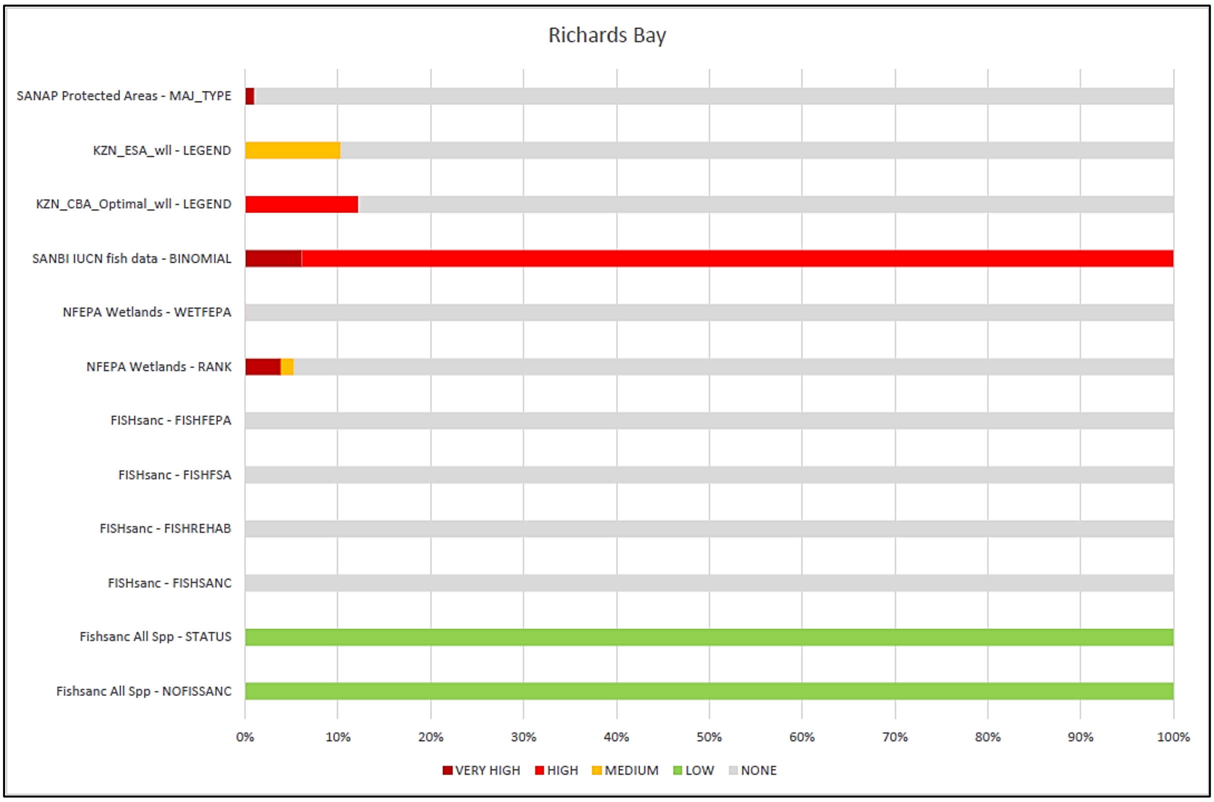



Figure 11. Summary data for the KwaZulu-Natal – Richards Bay study area, showing sensitivity ratings for each attribute considered in the assignment of overall sensitivity scores, and the geographical extent (% of the whole study area) that each assigned sensitivity class for each attribute occupies.

#### 4.3.7.7 Western Cape (Figure A3.13 - 3.14 and Figure 12)

This study area includes portions of the Berg and Breede River catchments, as well as parts of the Eerste and upper Mosselbank rivers.

Most of the areas that have been marked in Figure A3.13 as being of High or Very High sensitivity comprise high-lying areas, much of which also lie in Protected Areas and are thus automatically considered of High sensitivity in this project, and include the upper reaches of the Berg, Eerste, Molenaars (Smalblaar, Krom, Elands) and Wit rivers (Figure A3.15). Many of these sub-quaternaries support endemic fish species, some of which have High IUCN threat status.

Largely urban rivers in the Cape Town metropolitan area such as the Lourens, Sir Lowrys Pass and Steenbras rivers have also been accorded High sensitivities to aquaculture activities – the scale of assessment at sub-quaternary level does not take cognisance of the fact that within the urban areas of Cape Town these particular rivers are unlikely to have above Medium sensitivity to aquaculture activities.

Lower-lying areas within the Upper, Central and Lower Breede Valley, many of which have been exposed to high levels of disturbance associated with agricultural activities as well as alien plant infestations, have largely been rated as of Medium sensitivity – although it is noted that the main stem Breede River is rated as at High sensitivity throughout its reaches.

Figure 12 shows that some 33% of the study area lies within Protected Areas, while just over 50% of the area has been rated as of High sensitivity as a result of SANBI Red List Fish species data attributes.

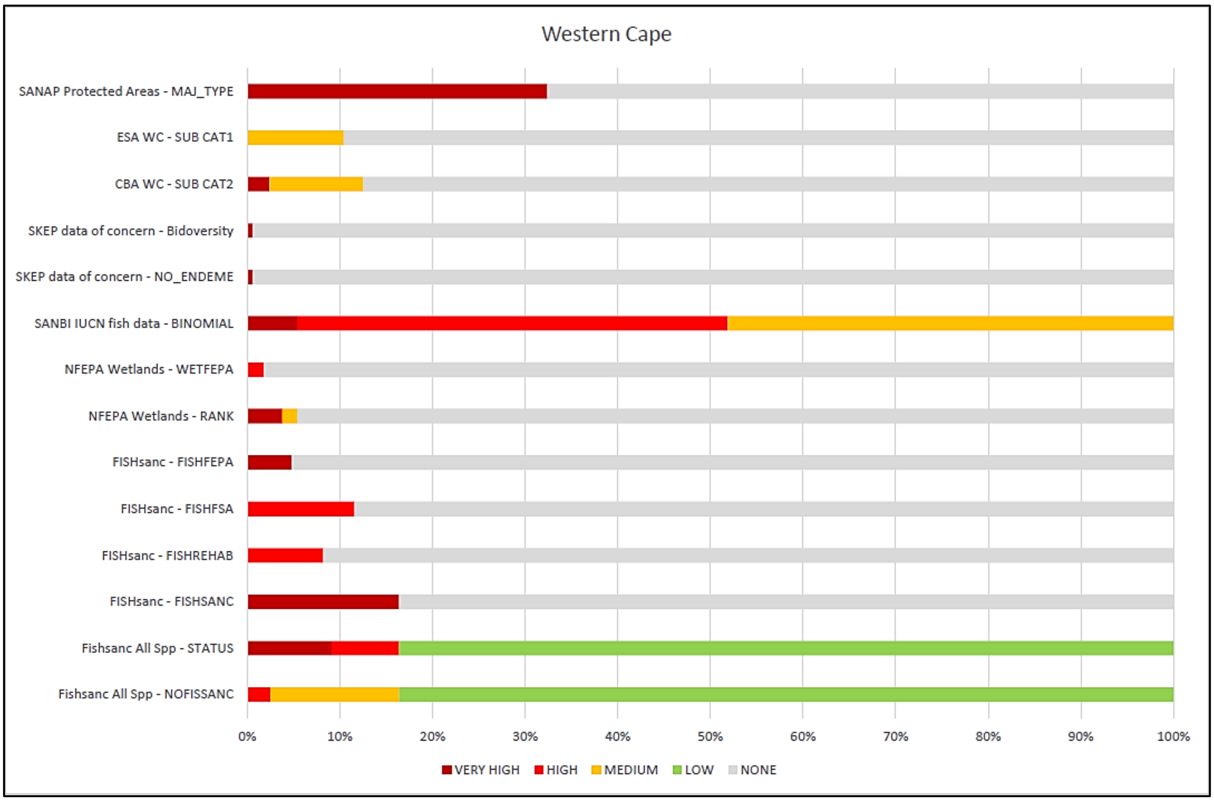



Figure 12. Summary data for the Western Cape study area, showing sensitivity ratings for each attribute considered in the assignment of overall sensitivity scores, and the geographical extent (% of the whole study area) that each assigned sensitivity class for each attribute occupies.

### 4.3.7.8 Vaalharts river systems (Figure A3.15 - 3.16 and Figure 13)

Most of this study area has been rated as of Low sensitivity to aquaculture activities, with the only areas of High and Very High sensitivity being the catchments of the Leeu River (a river FEPA draining into the Vaal River) and the Steenbok, Klein Riet and a number of other unnamed small tributaries of the Vaal River, classified as river FEPAs and mostly accorded a high PES condition rating. All of these tributaries are mapped as seasonal to ephemeral rivers, and the rivers are also considered of High sensitivity to aquaculture activities (and *vice versa*). The sub-quaternaries of the Upper Orange in the southern portion of the study area derive their High sensitivity status from their NFEPA categorisation as fish sanctuary areas.

Figure 13 shows that no fish species of conservation concern have been highlighted in the SANBI Red List Fish species dataset for this study area, indicating that it appears to be one of the more suitable aquaculture focus areas.

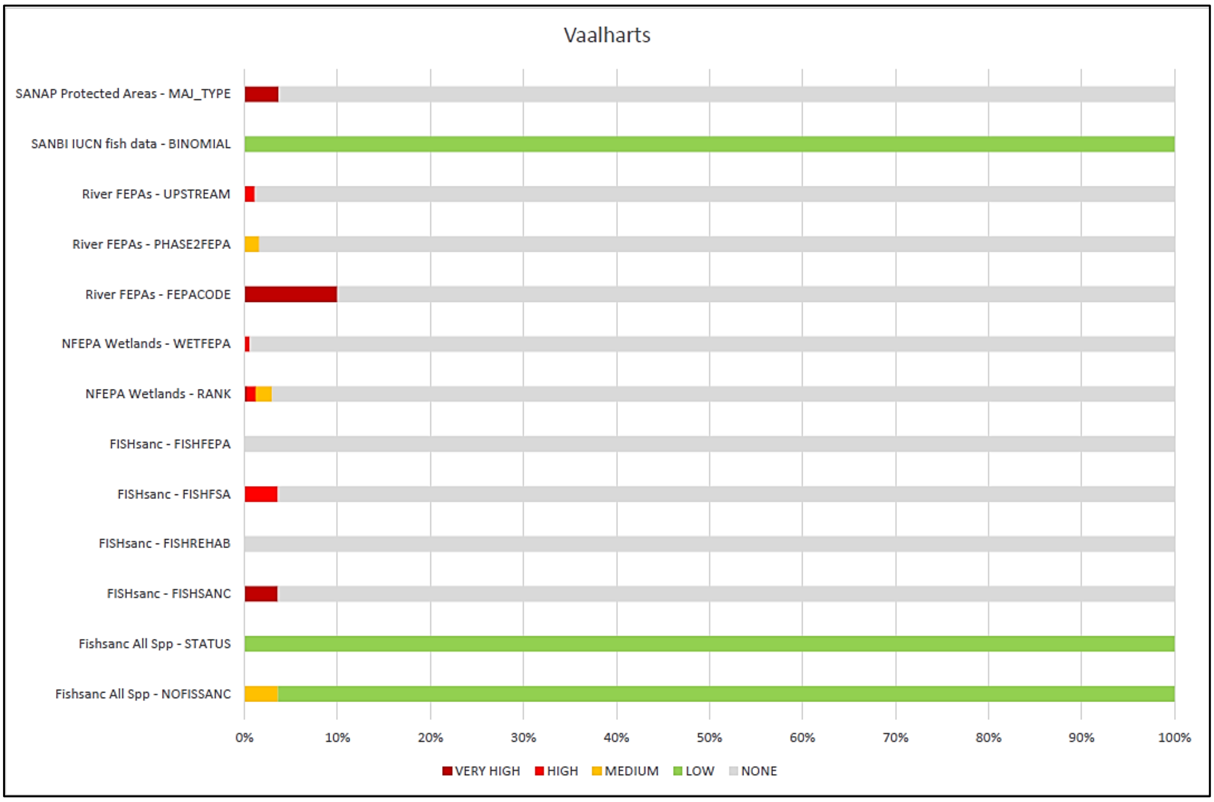



Figure 13. Summary data for the Vaalharts river systems study area, showing sensitivity ratings for each attribute considered in the assignment of overall sensitivity scores to different parts of the study area rated.

#### 4.3.7.9 Vanderkloof-Gariep System (Figure A3.17 - 3.18 and Figure 14)

This study area, which includes a long reach of the Upper Gariep / Orange River, has been mapped with large areas of Low sensitivity to aquaculture activities, although the Gariep / Orange River itself is of High sensitivity. Again, the tributaries entering the Gariep / Orange in this area are all ephemeral to seasonal, and have been accorded High sensitivity ratings on this account. The sub-quaternaries mapped as of High and Very High significance include the Van der Waltsfonteinspruit, Donkerpoortspruit, Gansgatspruit, Palmietspruit and Moddebultspruit systems.

The Gariep Dam is included in an area mapped as High to Very High sensitivity as well. This is driven by the extent of the Oviston and Gariep Nature Reserves (Protected Areas).

Figure 14 shows that SANBI Red List Fish species data for this study area showed that there are no fish species of concern in this study area (Low sensitivity rating), although there are some areas coded Medium sensitivity for data deficient.

Again, the sensitivity layer for this study area indicates that it is, from an aquatic ecosystems perspective, a largely appropriate aquaculture focus area.

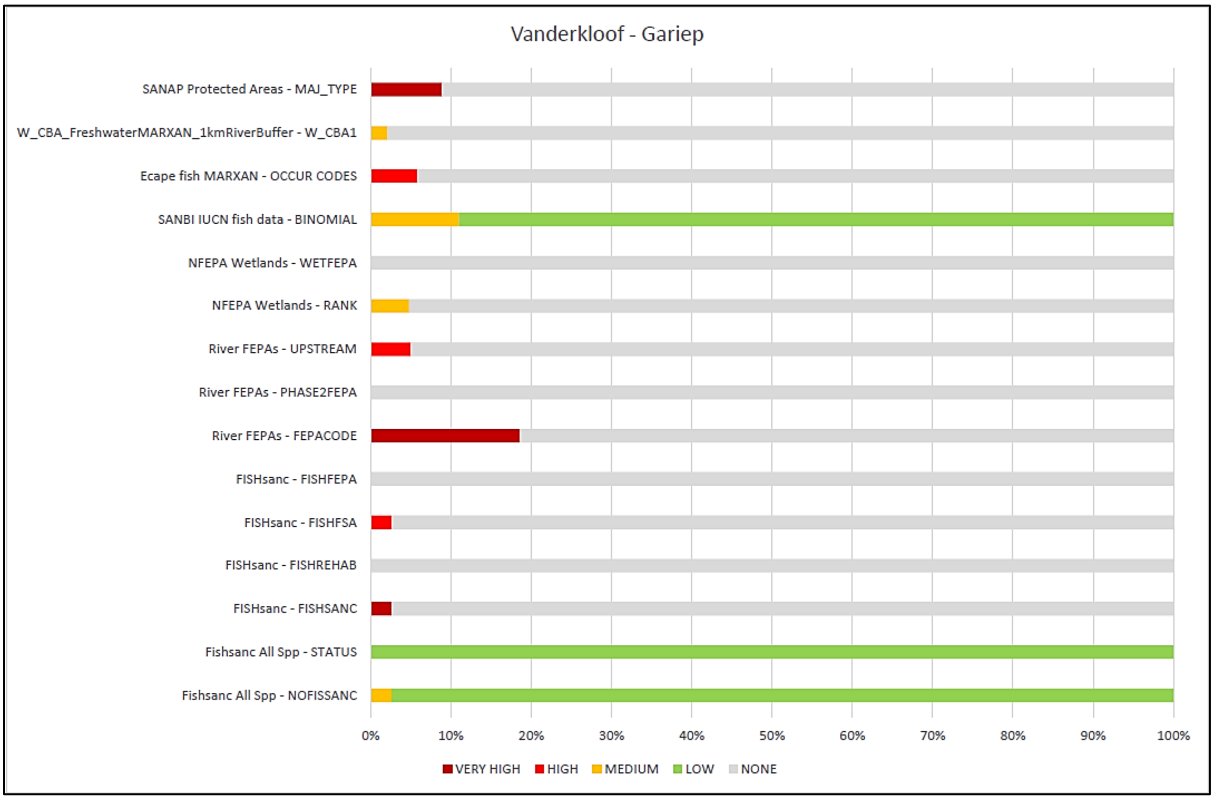



Figure 14. Summary data for the Vanderkloof-Gariep System study area, showing sensitivity ratings for each attribute considered in the assignment of overall sensitivity scores to different parts of the study area rated.

### 4.3.8 Overview

The Sensitivity data presented in Section 4.3.7 show that of the nine study areas:

- Three comprise only High or Very High sensitivity areas (Richards Bay; Mpumalanga and Limpopo);
- Four comprise mainly High and Very High sensitivity, with limited areas of Medium and Low sensitivity (Eastern Cape; Western Cape; Gauteng-North West and Free State – KwaZulu-Natal Highlands);
- Two comprise mainly areas of Low sensitivity, with limited areas of Medium, High and Very High sensitivity (Vaalharts and Vanderkloof-Gariep).

The above data may prove disheartening to the Aquaculture Industry, suggesting substantial environmental impediments to fast-tracking aquaculture development in some areas through this SEA. Past engagement with stakeholders has raised requests that the criteria for Sensitivity Mapping should be revisited, and the stakes lowered. While in some instances the Sensitivity Rating Criteria outlined in Table A2.2 (Appendix 2) have been revised since the previous draft of this report, it is strongly argued that the rating criteria presented in this report are appropriate for a national-scale SEA of this nature. The sensitivity data presented here suggest that Vaalharts and Vanderkloof-Gariep are appropriate focus areas offering high levels of opportunity for aquaculture through an SEA, while Western Cape and Free State-KwaZulu Natal Highlands offer a reduced level of opportunity, but still include substantial areas for consideration. The remaining four areas are, on the basis of best available data, not really appropriate for SEA-level consideration without significant effort to ground-truth and fine-tune available data.

# 5 KEY POTENTIAL IMPACTS

## 5.1 Resource quality and management

Water resource management, including aquaculture management in South Africa should be approached from the perspective of the National Water Act (NWA) (Act 36 of 1998) by considering resource quality characteristics, namely **flow regime, water quality** (physical and chemical), **habitat** and **biota**. One other very important suite of resource quality characteristics that is not explicitly defined in the NWA but rather is implied are the **geomorphological processes** related to the rest of the defined resource quality characteristics. Flowing water inevitably results in movement of sediments / particles and variability in flow results in hydraulic sorting of the particles into areas of stones, cobbles, gravel, sand and mud, typical biotopes for in-stream biota. It is therefore safe to infer that the variable flow of water (flow regime) of a particular water quality (water quality), in sorting particles and sediments hydraulically (geomorphological) act as **Ecosystem Drivers**, and the subsequent response in habitat (habitat) creation / maintenance and colonisation by biota (biota) as **Ecosystem Responses**.

Resource quality characteristics are the foundation blocks on which the NWA was built, and resource quality characteristics are used in the Resource Directed Measures (RDM) and Source Directed Control (SDC) processes of the NWA.

These "ecosystem drivers" and "ecosystem responses", collectively comprising "Ecological Infrastructure", are interdependent and affect each other, and in so doing provide important ecosystem services to society (e.g. water purification, sediment control, biodiversity maintenance, flood attenuation, subsistence resources).

The schematic below (Figure 15) shows the interactions between these resource quality characteristics, and it is clear that both "ecosystem drivers" and "ecosystem responses" can be impact receptors in any type of aquaculture operation. It is therefore critical to determine to what extent the proposed aquaculture project will modify either or both the "ecosystem drivers" and "ecosystem responses", and to what level the modification can be mitigated or reduced. This will enable water use authorisation decisions to ensure that the regulator can still achieve gazetted Resource Quality Objectives (RQOs).

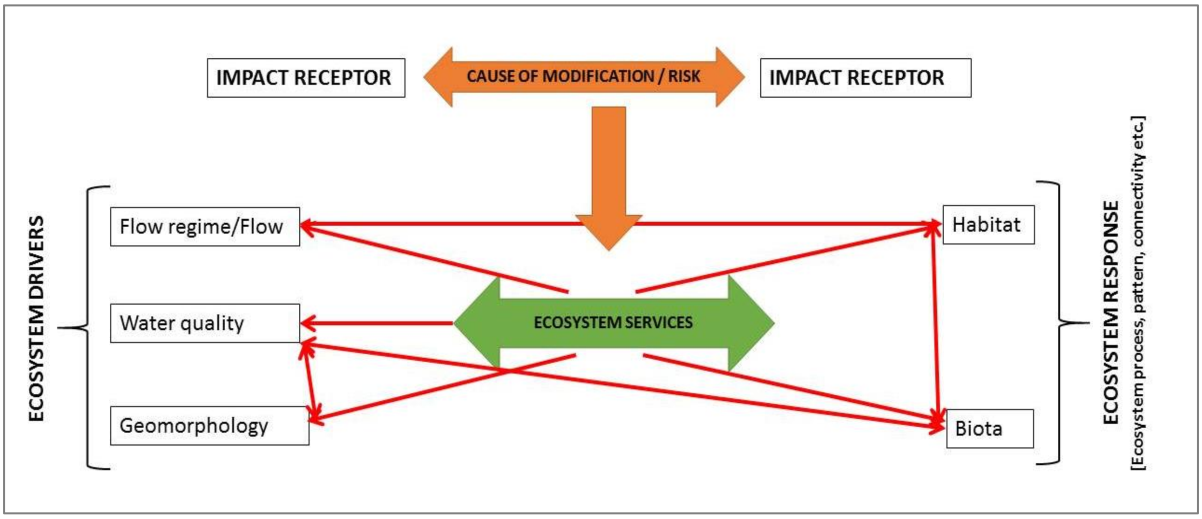



Figure 15. Ecosystem drivers and ecosystem responses are interdependent and affect each other, and in so doing provide important ecosystem services to society.

## 5.2 Impacts of freshwater aquaculture

Aquaculture has been described as a double-edged sword, not only is it the fastest developing food production system in the world with several benefits for society, but the pollutants generated and impacts on the environment, especially water resources can have severe consequences for aquatic ecosystem health and human health (Martinez-Porchas and Martinez-Cordova, 2012).

Resource quality issues of concern, as a result of freshwater aquaculture practices, include land use modifications, change in hydrological patterns, excessive use of freshwater, water pollution, habitat modification and destruction, and negative impacts on biodiversity (Boyd, 2003; Boyd and McNevin, 2015). The magnitude of these changes and impacts are usually catchment or site specific and are largely determined by the farm location, the type and intensity of the aquaculture production system and the operational management thereof (Serpa and Duarte, 2008).

Sustainable aquaculture practices will ensure that no irreparable harm will be caused to aquatic ecosystems by restricting inevitable changes within limits of natural fluctuation (Pillay, 2004). Every effort should be made to integrate aquaculture into local settings in a manner that minimises conflicts over land use and water use and minimises negative environmental impacts and changes in the landscape (Boyd and McNevin, 2015). This will require suitable guidelines and the enforcement of appropriate control and mitigation measures (IFC, 2007).

The main negative impacts on water resources attributed to freshwater aquaculture in general, are described below, while impacts associated with the proposed aquaculture species and production systems as part of this assessment, are summarised in Sub-Section 4.3. Where relevant, mitigation measures to reduce impacts of concern are summarised at the end of this Section.

### 5.2.1 Impact: Altered Water Quality

Water quality includes all physical, chemical and biological factors that influence the beneficial use of water (Jegatheesan *et al*., 2011). When pollutants such as chemicals or other substances are present in concentrations greater than would occur under natural conditions for a particular region, they will cause water quality degradation. Pollutants arising from aquaculture activities due to, for instance, high stocking densities and over-feeding, may require more frequent water exchanges to maintain water quality in certain production systems, and could result in high pollutant loads being discharged. This has negative consequences for the structure and functioning of aquatic ecosystems and subsequently the goods and services provided by these ecosystems (Beardmore *et al*., 1997; Grizzeti, *et al*., 2016). Water quality impacts typically associated with freshwater aquaculture are discussed below.

#### 5.2.1.1 Nutrient enrichment

Aquaculture effluents are generally rich in nutrients and comprise a solid particulate fraction mainly consisting of uneaten and undigested feed and faeces, as well as a dissolved fraction comprising metabolic by-products, mainly ammonia, urea and phosphate (Bergheim and Brinker, 2003).

Inorganic compounds (e.g. ammonia, nitrates, nitrites and phosphates) as a result of organic matter breakdown may have potentially deleterious effects on the surrounding environment (Serpa and Duarte, 2008). The primary source of nitrogen and phosphorus is derived from feed application. This is largely due to the inefficient utilization of aquaculture feeds (whether fertilizers or manufactured feeds) and is regarded as one of the major challenges in sustainable freshwater aquaculture (Boyd, 2003; Shipton and Hecht, 2013). It is estimated that 70 to 80% of nutrients in feed are released as waste (via uneaten food and fish waste products) into the production systems (Tucker and Hargreaveas, 2008).

However, the quality and quantity of the effluent varies and is determined by a number of factors, including the culture species, the type of production system, the nutritional composition of the feed and its rate of application and uptake, as well as on site cleaning and packaging of aquaculture products.

When partially treated or untreated nutrient-loaded effluent is released into surface water bodies, it has a high pollution potential, which often leads to undesirable consequences. High nutrient loads have the potential to cause eutrophication in water resources which can result in a depletion of dissolved oxygen with repercussions for instream biota and human users of water (IFC, 2007).

Eutrophication triggers a significant increase in phytoplankton growth and productivity, e.g. excessive algal blooms (Pillay, 2004). Blue green algae, known as cyanobacteria, are naturally present in dams, lakes and streams in low numbers, but can bloom when large amounts of nutrients are present and could produce toxins that pose health risks and be detrimental to aquatic organisms as well as humans and animals that are exposed to or drink the water (Jegatheesan *et al*., 2011). High nutrient loads also contribute to increased or excessive growth of higher plants such as water hyacinth which has been particularly problematic in dams (e.g. Hartbeespoort Dam).

#### 5.2.1.2 Organic matter enrichment

Particulate organic matter released from aquaculture operations into water resources, results in the stimulation of phytoplankton and bacterial development, which subsequently reduces light penetration into the water column, affecting benthic flora (Serpa and Duarte, 2008). Particles that settle may be incorporated into the sediment and transformed by microbial activity. Changes in the physical and chemical characteristics of sediment can have a significant impact on the structure of benthic communities (Serpa and Duarte, 2008). Organic enrichment of sediments, leads directly to an increased oxygen consumption rate, and when the oxygen demand is more than that which is available, the sediment becomes anoxic. This influences biological and chemical processes in the sediment and changes the ecology of benthic organisms. The same occurs in areas of low turbulence and high organic input where the sediment / water interface can also become anoxic (e.g. below fish cage cultures or near the effluent discharge point). In such oxygen-depleted sediment environments, ammonia, hydrogen sulphide and methane are produced, which may be released into the water column. Ammonia dissolves in the overlying water and adds to the nitrogenous concentration while most of the hydrogen sulphide and all the methane produced are released in gaseous form to the detriment of aquatic organisms (Pillay, 2004).

#### 5.2.1.3 Chemical contamination

Various chemical contaminants are associated with aquaculture practices and can be introduced into water resources as a result of their overuse and misuse (Tucker and Hargreaveas, 2008). The application of these chemicals is mainly dependent on the type of production system, and the indiscriminate use thereof may lead to deteriorating water quality, lethal or sub-lethal effects on non-target organisms, development of resistance by pathogenic organisms, and interference in biochemical processes. These chemicals furthermore can have various fates when released from aquaculture production systems to the environment, so their environmental persistence is often variable. These chemicals include:

- Antibiotics

Antibiotics are chemicals that are produced to kill or inhibit the growth of bacteria and other micro-organisms. There is widespread concern about the discharge of antibiotics into the environment because they pose a diversity of risks to the environment, to both wild and cultivated species as well as humans (Serpa and Duarte, 2008). Antibiotics can be toxic to natural organisms and repeated exposure of bacteria to a particular antibiotic can lead to development of resistance making the antibiotic less effective for its intended purpose. Furthermore, antibiotics used in aquaculture could potentially be endocrine-disrupting chemicals and pose a risk to instream biota and human health (Jegatheesan *et al*., 2011).

- Hormones

Hormones are used to make captive broodstock breed by injecting fish with hormones that stimulate the production of eggs and sperm (RFP, 2010). The use of hormonal-induced sex reversal in fish can be used to produce same-sex fingerlings for stocking thereby avoiding reproduction in culture systems (Pillay, 2004). In most cases hormonally sex-reversed fish may grow faster than normal fish. Neither the common use of hormones in spawning nor the experiments on growth hormones have elicited much environmental or food safety concern; however, the use of 17-methyltestosterone for hormonal-induced sex reversal in fish has been much more controversial (Boyd and McNevin, 2015). Concerns about the use of this hormone relates to the release of pharmaceutically active compounds into the environment via effluents from certain production systems (Boyd and McNevin, 2015).

- Anti-fouling agents

Anti-foulants are chemicals applied to aquaculture equipment, such as cages and ropes, to reduce 'biofouling' — the unwanted growth of plants or organisms on these structures (Science for Environment Policy, 2015). Most of the older anti-foulants use copper as active ingredient, but other metals are now used as well. When copper and metal salts leach into the environment, they can be toxic to non-target organisms. However, the toxicity and bioavailability of these metals to aquatic biota are dependent on their degradation, accumulation and dispersion rates (Serpa and Duarte, 2008). With increasing public awareness and concern for environmental protection, a gradual phasing-out of anti-fouling agents in the aquaculture sector is foreseen and environmentally benign alternatives is increasingly being used (Chen and Qian, 2017).

- Disinfectants and pesticides

Chemical disinfectants and pesticides that are used to eliminate pathogens or control phytoplankton, can have severe negative effects on the environment. Pesticides in particular may be toxic to non-target species and may affect instream biodiversity (Serpa and Duarte, 2008).

#### 5.2.1.4 Salinization

In coastal areas, where over abstraction of groundwater for agriculture and land-based aquaculture may occur, saltwater intrusion from the sea to the groundwater aquifer, may lead to groundwater salinization (Jegatheesan *et al*., 2011). This may affect other water users that rely on groundwater for drinking purposes or agriculture and may also limit the use of water for aquaculture.

### 5.2.2 Impact: Threats to Biodiversity

Loss of biodiversity inevitably leads to ecosystem degradation and subsequent loss of important ecosystem services (Roux *et al*., 2006). Freshwater ecosystems are regarded as the most endangered ecosystems in the world, with declines in biodiversity significantly greater than in the most adversely affected terrestrial ecosystems (Dudgeon *et al.,* 2006). In South Africa, the situation is no different and concerted efforts are being taken to protect the freshwater resources and the services they provide, including water for food production, which humans rely on for their well-being (Driver *et al*., 2005; Roux *et al*., 2006; Nel *et al*., 2011).

The threats that freshwater aquaculture poses to biodiversity are mainly associated with the conversion and destruction of natural habitat, the potential release of alien species and genetically modified organisms, and the development of antibiotic-resistant pathogenic bacterial strains (IFC, 2007), and are briefly discussed in the section below.

While the focus of this section relates mainly to threats posed to fish and macro-invertebrate biodiversity, evidence shows that disturbances caused by the location of aquaculture farms close to the feeding and breeding grounds of aquatic mammals and birds, as well as the anti-predator measures taken by aquaculture farmers, can affect the population size or habitats of these animals as well (Pillay, 2004).

#### 5.2.2.1 Conversion or destruction of instream and riparian habitats

The loss or degradation of habitats is one of the major adverse impacts of aquaculture (Serpa and Duarte, 2008). Riparian and instream habitats as well as wetlands and pans may be irreversibly transformed or impacted to various extents when aquaculture facilities and production systems are being constructed (e.g. channels, dykes and ponds). This has a negative impact on both terrestrial and instream ecosystems.

Aquaculture production systems constructed at inappropriate sites can furthermore lead to habitat conversion and ongoing operational impacts (Jegatheesan *et al*., 2011).

Sediment loads that are discharged during harvesting and post-harvesting when systems are cleaned disrupt benthic communities and may have negative consequences for higher trophic levels which feed on these organisms (Serpa and Duarte, 2008).

Alien and invasive species that establish in nearby water resources can cause habitat fragmentation and this will threaten the existence of indigenous species. The marron crayfish (*Cherax tenuimanus*) for instance, is an omnivore and feeds on both dead and living aquatic plants. Impacts caused when Marron are introduced include destruction of living aquatic macrophytes, which could lead to a small but possible disturbance of bottom-spawning fish (DAFF, 2012c). Rainbow trout can cause a substantial impact on native species due to predation, competition and/or habitat alteration (Cambray, 2003).

#### 5.2.2.2 Introduction of alien and invasive species

Alien and invasive species are recognised globally as direct drivers of biodiversity and ecosystem service loss that pose substantial threats to freshwater ecosystems, especially fragile ecosystems and threatened and endangered species (Ricciardi, 2007). However, invasive and non-invasive alien species have proved to be successful in aquaculture operations.

In South Africa, invasive alien fishes are regarded as a significant threat to native freshwater fishes, as well as other biota such as algal biomass and invertebrate taxa with likely negative consequences for ecosystem structure and functioning (Shelton *et al*., 2015a; Jackson *et al*., 2016; Marr *et al*., 2017). Alien species include species that are not indigenous to the geographic borders of South Africa (e.g. trout, marron, Nile tilapia) while species that are native to South Africa, but have been translocated into areas introduced outside their native ranges, where they do not occur naturally, are referred to as extra-limital species (e.g. African sharptooth catfish and Mozambique tilapia) (Ellender and Weyl, 2014).

These species are introduced via several pathways including stocking for angling, inter-basin transfers, bio-control, ornamental fish trade and aquaculture (Ellender and Weyl, 2014). The introduction of the brown trout, *Salmo trutta*, and the rainbow trout, *Oncorhynchus mykiss*, into natural water bodies for angling purposes and due to aquaculture practices, have been reported to have several negative impacts on native fishes and have caused the disappearance of several of these species (Cambray, 2003; Woodford and Impson, 2004; Shelton *et al*., 2014). The popular aquaculture species Nile tilapia (*Oreochromis niloticus*), is described as highly invasive particularly in areas with suitable habitat and environmental conditions (Weyl, 2008; Zengeya *et al*., 2013). This is as a result of their hybridisation potential with other tilapia species (e.g. *O. mossambicus*). Also, because of their wide environmental tolerances, trophic adaptability and high reproductive rates, they often outcompete other native species for food and habitat, which may have dire consequences for indigenous biota (Canonico *et al*., 2005; Ellender and Weyl, 2014). The African sharptooth catfish (*Clarias gariepinus*) is spreading rapidly through the Eastern and Western Cape, outside its natural range of occurrence, where it threatens native fishes and has had a negative impact on recreational angling in several impoundments (Kimberg *et al*., 2014). Because these species are native to South Africa, they are often difficult to manage.

Escapees from aquaculture facilities, accidental or otherwise, are inevitable and the potential for this to happen be largely determined by the production system used and the preventative measures that are in place (Beveridge, 2004; Boyd and McNevin, 2015). In this regard, cage-cultured fish are particularly susceptible. For example, invasive alien fish eggs can be introduced into the environment even when no fish escape. This has been referred to as "escape by spawning" (Science for Environment Policy, 2015). While some alien species may find the conditions unsuitable for building up a sizeable spawning population, and as a result not become a dominant species, others may, under the same conditions, reduce or eliminate constituents of the local fauna including fish, frogs (tadpoles) and invertebrate communities, through competition or predation (Pillay, 2004; IFC, 2007). The extent, to which escapees compete with native species, depends on their feeding habits and the ecological niches they occupy (Pillay, 2004; Zengeya *et al.,* 2011). Species such as marron and catfish can survive out of water for several days and escapees from aquaculture facilities can travel over land and end up in water resources where they have the potential to establish and reproduce (e.g. Picker and Griffiths, 2011; Weyl *et al*., 2016; Nunes *et al.,* 2017).

#### 5.2.2.3 Introduction of genetically modified species

Selective breeding and genetic manipulation of a domesticated *C. gariepinus* strain (e.g. Dutch catfish) from the Netherlands that is imported for aquaculture farming, has potential negative ecological impacts and poses a threat to native *C. gariepinus* populations (Roodt-Wilding *et al*., 2010). There have therefore been calls to ban aquaculture imports from the Netherlands and to remove existing stocks of these domesticated strains of fish (Cambray and van der Waal, 2006).

Sharptooth catfish as well as artificially hybridized *C. gariepinus* and *Heterobranchus longfilis* escapees pose a threat to native species because this hybrid is known to have viable offspring. It is regarded as a species with a risk of hybridisation or genetic contamination which could ultimately lead to the loss of local genetic adaptions within populations (Roodt-Wilding *et al*., 2010).

#### 5.2.2.4 Hybridisation and alteration of genetic structure of wild native populations

Interbreeding of escapees with wild populations and the subsequent altering of the genetic make-up of wild populations, by introducing genes that are less suited for local conditions, is of great concern and contributes to the loss of genetic biodiversity. In South Africa, the introduction of *O. niloticus* poses severe threats to *O. mossambicus* due to its extensive hybridisation and introgression ability with native *O. mossambicus* (Firmat *et al*., 2013).

Hybridisation poses a primary threat to native *O. mossambicus* and they are consequently listed on the IUCN Red List as “Near-Threatened” (Van der Waal and Bills, 2000).

#### 5.2.2.5 Transmission of diseases and parasites

High-density living conditions, and an increase in animal stress due to overcrowding could lead to outbreaks of disease that would normally not occur in wild populations (Huntington *et al.*, 2006). Disease-causing micro-organisms include bacteria, viruses, fungi and parasites. The parasites and diseases from aquaculture species are mainly disseminated to wild stocks through effluent water, escapees or contaminated aquaculture stock being imported from other countries (Serpa and Duarte, 2008). The effect that parasites from alien fishes may have on indigenous fish populations is often neglected. It is well recorded in South Africa and abroad that the biggest pathological and subsequent mortality of freshwater fishes caused by parasites mainly occurs when they are infected by alien parasites (Kimberg *et al*., 2014).

Besides their environmental risks, diseases and parasites could cause adverse health effects when humans come into contact with them (due to handling and consumption of infected fish) (Avenant-Oldewage, 1993; Jegatheesan *et al*., 2011; Amer, 2014).

### 5.2.3 Impact of target species and production systems

The six target species that are considered in this assessment and the nine study areas of concern are summarised in the study scope (Section 2 of this report). Species such as the African sharptooth catfish and Mozambique tilapia, which are indigenous to Southern Africa, are regarded as alien species when they occur outside their natural distribution range and, where they are invasive, they pose a biodiversity threat to native biota of that area.

The biodiversity threats posed by escapees of the target freshwater species examined in this study are summarised in Table 3. The potential of these escapees to establish in the study areas of concern are summarised in Table 4**Error! Reference source not found.**, based on the compatibility of the species to ocal conditions, which was derived from the draft Biodiversity Risk and Benefit Assessment (BRBA) prepared by Anchor Environmental Consultants for the Department of Agriculture, Forestry and Fisheries (DAFF, 2012a-e). In the BRBAs, the compatibility of the different species to local environmental conditions was evaluated by comparing the ambient annual temperature ranges of the 31, Level 1 terrestrial ecoregions of South Africa (Kleynhans *et al*., 2005b) (Figure 16) with the known environmental tolerance ranges for the respective species (FAO, 2012).

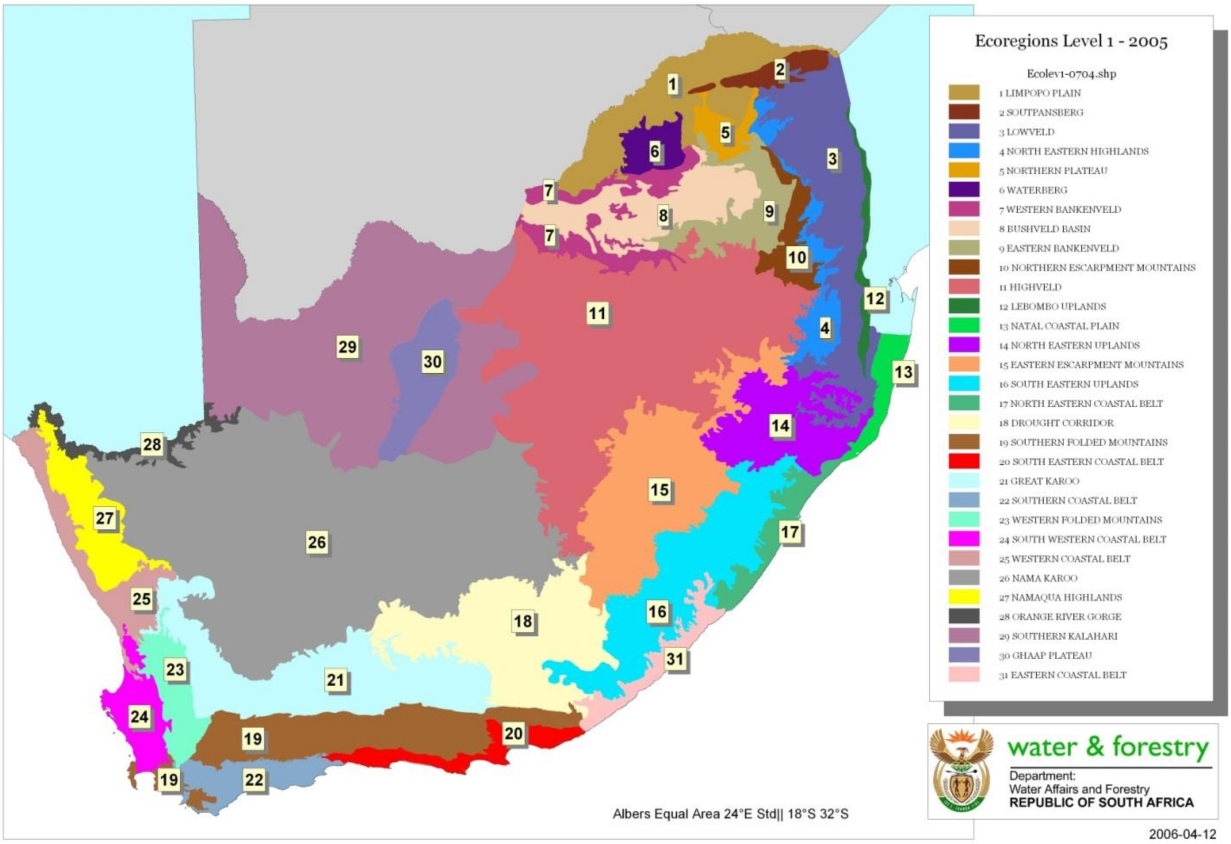



Figure 16. Level 1 Ecoregion map for South Africa (Kleynhans *et al*., 2005b).

Table 3. Summary of the potential biodiversity threat posed by the target freshwater aquaculture species.

| Species | Biodiversity threat | | | | |
|---|---|---|---|---|---|
| | Transmission of diseases and parasites | Introduction of alien species | Introduction of genetically modified species | Conversion / destruction of instream and riparian habitats | Hybridisation and alteration of genetic structure of wild native populations |
| Marron crayfish (*Cherax tenuimanus*) | Freshwater crayfish are carriers of several pathogens which include viruses, bacteria, fungi, and protozoan and metazoan parasites (du Preez and Smit, 2013). Undesirable parasites may pose a health risk and can cause mortality of native aquatic populations (e.g. freshwater crayfish species, macroinvertebrates, crabs, decapods) – especially specimens that are imported (from Australia) for culturing purposes may be infected with the 'crayfish plague' fungus, *Aphanomyces astaci,* and temnocephalan worms. It may cause a long-term detrimental impact on river ecology (Avenant-Oldewage, 1993; DAFF, 2012c; du Preez and Smit, 2013; Tavakol *et al*., 2016). | *C. tenuimanus* could colonise and establish in any previously un-invaded streams across some areas of the country, especially the Highveld, and in the southern and south-western Cape (de Moor 2002). In these areas, introduced crayfish will predate on or compete with indigenous species and will pose a localised ecological impact and risk (albeit small) to the continued survival of native species especially those that are already rare or range restricted (Zengeya *et al*., 2017). The risk can be reduced if bio-secure production systems are used. | Not known. | Destruction of living aquatic macrophytes could lead to possible disturbance of bottom-spawning fish (Nunes *et al.,* 2017). | No hybridisation will occur with indigenous species as there are no native freshwater crayfish species in South Africa (DAFF, 2012c). |
| African sharptooth catfish (*Clarias gariepinus*) | Diseases, pathogens or parasites of escaped organisms likely to be transferred to wild indigenous populations. At least 20 parasite species are associated with *C.gariepinus* of which *Argulus japonicus* is alien to South Africa and has the potential to infect many fish species (DAFF, 2012a). | There may be escapees (fish and eggs) from any established culture facility. *C. gariepinus* that escape will rapidly colonise and establish in any previously un-invaded river catchments across most, if not all, of the country as it is a very hardy species (that can survive outside water) with a very high potential to establish in areas where it does not occur naturally (Cambray, 2003; Weyl *et al*., 2016).. In these areas, introduced catfish will compete with and/or predate on indigenous species and will pose a risk to the continued survival of native fish species especially those that are already rare or range restricted. Can as a | Artificially hybridized *C. gariepinus* and *C. longfilis* escapees pose a threat to native species as this hybrid is known to have viable offspring. It is regarded as a species with a risk of hybridisation or genetic contamination. Selective breeding and genetic manipulation of a domesticated *C. gariepinus* strain from outside of South Africa (e.g. the Netherlands) that is imported for | Can cause habitat fragmentation of native fish species. | Hybridisation will occur with native populations which can have an impact on the genetic fitness of these populations (Roodt-*Wilding et al.,* 2010). |

| Species | Biodiversity threat | | | | |
|---|---|---|---|---|---|
| | Transmission of diseases and parasites | Introduction of alien species | Introduction of genetically modified species | Conversion / destruction of instream and riparian habitats | Hybridisation and alteration of genetic structure of wild native populations |
| | | result disrupt ecosystem functioning. | aquaculture farming, poses a threat to native species and it has been proposed that all imports from the Netherlands be banned and all existing domesticated animals be removed. | | |
| Brown trout (*Salmo trutta*) | Some of the parasites which affect trout may also affect other freshwater finfish. | There will most likely be escapees from any established culture facility. *S. trutta* could potentially colonise and establish in previously un-invaded river catchments where it is introduced and conditions are suitable (ability to spread is high). Introduced trout will compete with and/or predate on indigenous species in the area and may pose a widespread impact and high risk to the continued survival of native fish species especially those that are already rare or range restricted (DAFF, 2012b; Zengeya *et al*., 2017). The invasive potential of *S. trutta* is depicted as an upper medium risk (Marr *et al*., 2017). | Not known. | Can cause habitat fragmentation of native fish species. | No hybridisation will occur with indigenous species as there are no native Salmonidae in South Africa. |
| Rainbow trout (*Oncorhynchus mykiss*) | High stocking densities commonly found in hatcheries can lead to outbreaks of parasites and diseases. Some of the parasites which affect trout may also affect other freshwater finfish. If unknown diseases are introduced, indigenous species may not have an adequate immune system to cope with them, and as a result it can lead to their demise. To date, no diseases have been found in South African salmonids (DAFF, 2012b). | Rainbow trout which escape from aquaculture farms have been found to travel up to 360 km and have a 50% chance of survival, with some individuals surviving up to five years in the wild (DAFF, 2012c). It may pose a widespread ecological impact (Zengeya *et al*., 2017) and the invasive potential of the species is depicted as a high risk (Marr *et al*., 2017). | Not known. | Can cause habitat fragmentation of native fish species. Flow regimes are altered as a result of trout dams, as well as by inundating riverine habitats and wetlands (DAFF, | No hybridisation will occur with indigenous species as there are no native Salmonidae in South Africa. |

| Species | Biodiversity threat | | | | |
|---|---|---|---|---|---|
| | Transmission of diseases and parasites | Introduction of alien species | Introduction of genetically modified species | Conversion / destruction of instream and riparian habitats | Hybridisation and alteration of genetic structure of wild native populations |
| | | Therefore, the impacts of an introduction could potentially spread across an entire river catchment very rapidly if water temperatures are suitable. There is evidence that rainbow trout have an impact on native fish populations. Mean density and biomass of the Breede River redfin (*Pseudobarbus burchelli)*, Cape kurper (*Sandelia capensis)* and Cape galaxias (*Galaxias zebratus)*, was 5-40 times higher in streams without rainbow trout than in streams with rainbow trout (Shelton *et al*., 2015b). Invertebrate species assemblages in streams with trout differed consistently from those in streams without trout. More herbivorous invertebrate species are found where trout is present (Shelton *et al*., 2015a). Impact on environmental processes as a result of algal biomass, which was significantly higher at sites containing trout than at sites without. This was most likely caused by differences in grazing pressure. | | 2012b). | |
| Nile tilapia (*Oreochromis niloticus*) | Diseases or parasites could be transferred to populations of indigenous fish species when Nile tilapia escapes, from aquaculture facilities. | Escapees from any established culture facility could occur. *O. niloticus* could potentially colonise and establish in previously uninvaded river catchments where this species is able to reproduce successfully. In these areas, introduced tilapia will compete with and/or predate on indigenous species and as such may pose a | Not known. | Habitat overlaps, habitat destruction, and habitat fragmentation of native fish species may occur as well as competition for spawning sites | These is a high likelihood that hybridisation will occur with *Oreochromis* species. |

| Species | Biodiversity threat | | | | |
|---|---|---|---|---|---|
| | Transmission of diseases and parasites | Introduction of alien species | Introduction of genetically modified species | Conversion / destruction of instream and riparian habitats | Hybridisation and alteration of genetic structure of wild native populations |
| | | risk to the continued survival of these native fish species especially those that are already rare or range restricted (DAFF, 2012d) | | (Canonico *et al*., 2005). Can cause habitat fragmentation of native fish species. | |
| Mozambique tilapia (*Oreochromis mossambicus*) | Diseases and parasite typically associated with cultured tilapia can be transmitted to native fish species when escapees from aquaculture facilities come into contact with native indigenous species. | When introduced outside its natural range, Mozambique tilapia may be a possible threat to native species through competition for food and nest space. Juveniles have been documented to feed on other fish (de Moor *et al*. 1986); Mozambique tilapia are particularly hardy, resistant to wide varieties of water salinity, oxygen and pollution levels, and can migrate long distances. They occupy a wide range of habitats, and reproduce rapidly and successfully (Canonico *et al.*, 2005). | Strains that have been bred to have very large fillets and a more rounded body form, will unlikely survive outside a farm. All-male populations, developed from hybrids, sex-reversal or genetically male parentage, are less likely to establish a breeding population when they escape. | Can cause habitat fragmentation of native fish species. | Regarded as primary threat to the species (Cambray and Swartz, 2007). Highest hybridisation risk is posed by Nile tilapia. |

Table 4. Ability of escaped (target) species to establish in the respective study areas based on compatibility with local environmental conditions. The study areas (shaded grey blocks) are limited to those listed in the Terms of Reference and ignore other areas where one or more species may now occur after their introduction.

| Study area | African sharptooth catfish | | Nile tilapia | | Marron crayfish | | Mozambique tilapia | | Rainbow and Brown trout | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Occur naturally | Survive in wild | Occur naturally | Survive in wild | Occur naturally | Survive in wild | Occur naturally | Survive in wild | Occur naturally | Survive in wild |
| Limpopo | Y | Y | N | Y | | | Y | Y | | |
| Mpumalanga | | | N | Y | | | Y | Y | N | Y |
| Gauteng – North West | Y | Y | N | Y | | | Y | Y | | |
| Free State – Vaalharts | Y | Y | | | | | | | | |
| Free State – Kwa-Zulu Natal Highlands | | | | | | | | | N | Y |
| Free State – Van derkloof-Gariep | Y | Y | | | | | | | N | N |
| Richards Bay | Y | Y | N | Y | | | Y | Y | | |
| Eastern Cape | | | N | Y | N | Y | Y | Y | N | Y |
| Western Cape | | | | | | | | | N | Y |

**KEY:**

Occur naturally, i.e. Occurring naturally in proposed study area: Y = Yes; N = No

Survive in wild, i.e. Ability of escapees to establish in the wild based on suitability of environmental conditions: Y = Yes; N = No

### 5.2.4 Aquaculture production systems

The aquaculture production systems for consideration in this assessment, as described in Part 1 of the SEA Report, are discussed (Section 4). The practice of freshwater aquaculture varies widely with each method having its own set of benefits, issues and impacts on the environment. Aquaculture can be broadly grouped into three different intensities (Anras *et al.*, 2010; DAFF, 2013):

- **Extensive** – This uses large stagnant or slowly circulating ponds that allow only a low stocking density and rely on natural production to feed the animals (i.e. there is no supplemental feeding). Management and skills input are low.

- **Semi-intensive** – This is much like extensive culture, however there is a greater degree of intervention either through feeding and/or improvement of water quality through aeration and partial water exchange. This allows for an increase in the production of livestock when compared to extensive systems. Management and skills input occur at a medium level.

- **Intensive** – Livestock are maintained at high stocking densities and feeding comes solely from introduced feeds. The culture systems tend to be highly technical and rely on electricity to operate. The space required is relatively small and the system is designed to optimize water use and quality. Management and skills input are high.

One would expect extensive and semi-intensive systems to have a lesser effect over a greater area; while intensive systems tend to have a more severe, but localises effect (Soto *et al.*, 2007). The scale of effect and scale of the impact on aquatic ecosystem drivers and responses are categorised as Low, Medium and High, and are summarised in Table 5.

Table 5. The scale of effects and impacts of the type and intensity of production systems on freshwater ecosystems.

| Production System | Size | Intensity | Scale of effect | | | Scale of impact on drivers and responses | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Consumptive water use | Effluent and waste | Escapee potential | Biodiversity | Habitat | Water quality | Hydrology |
| Dam Cage Culture | Small | Intensive | LOW | MEDIUM #1 | HIGH | HIGH #2 | MEDIUM | MEDIUM | LOW |
| | Large | Intensive | LOW | HIGH | HIGH | HIGH | HIGH | HIGH #3 | LOW |
| Pond Culture | Small | Extensive | LOW | MEDIUM | MEDIUM | LOW | MEDIUM | MEDIUM | LOW |
| | | Semi-intensive | MEDIUM | HIGH | MEDIUM | MEDIUM | MEDIUM | MEDIUM | LOW |
| | | Intensive | MEDIUM | HIGH | MEDIUM | MEDIUM | MEDIUM | MEDIUM | LOW |
| | Large | Extensive | MEDIUM | MEDIUM | MEDIUM | MEDIUM | MEDIUM | MEDIUM | MEDIUM |
| | | Semi-intensive | HIGH | HIGH | MEDIUM | MEDIUM | MEDIUM | MEDIUM | MEDIUM |
| | | Intensive | HIGH | HIGH | MEDIUM | MEDIUM | MEDIUM | MEDIUM | MEDIUM |
| Flow-through | Small | Semi-intensive | MEDIUM | MEDIUM | HIGH | HIGH | MEDIUM | MEDIUM | MEDIUM |
| | | Intensive | HIGH | HIGH | HIGH | HIGH | MEDIUM | MEDIUM | MEDIUM |
| | Large | Semi-intensive | HIGH | HIGH | HIGH | HIGH | HIGH | HIGH | HIGH |
| | | Intensive | HIGH | HIGH | HIGH | HIGH | HIGH | HIGH | HIGH |
| Recirculating Aquaculture System (RAS) | Small | Semi-intensive | LOW | LOW | MEDIUM | MEDIUM | MEDIUM | LOW | LOW |
| | Large | Semi-intensive | LOW | MEDIUM | MEDIUM | MEDIUM | MEDIUM | MEDIUM | MEDIUM |
| | | Intensive | LOW | MEDIUM | MEDIUM | MEDIUM | MEDIUM | MEDIUM | MEDIUM |

#1 This comment applies to small dams; in large and ultra large dams, the impact will be small.

#2 This high rating is normally applicable, but is only medium if the species is already present in the catchment.

#3 This impact depends on the size of dam and fish stocking density. Impacts will be lower in large dams.

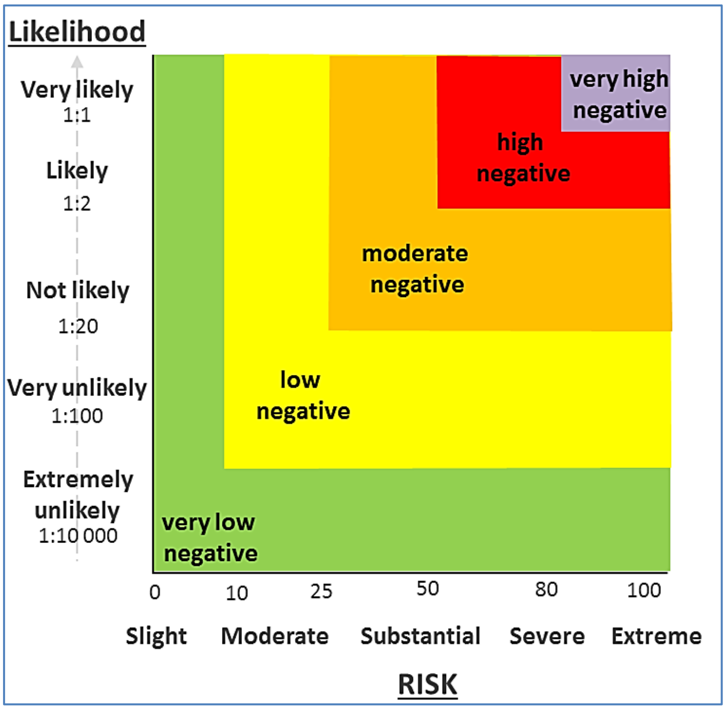
# 6 RISK AND OPPORTUNITY ASSESSMENT

Environmental impacts and risks associated with inland freshwater aquaculture relate primarily to the siting, design and operational management of aquaculture enterprises and their varied interactions with the surrounding environment, particularly water, land and biodiversity (Phillips and Subasinghe, 2008).

> **Risks to human health**
>
> Note that environmental risks may also extend to human communities in downstream reaches, where there is any reliance on the aquatic resource, and it should be stressed that most natural resources used by aquaculture are shared with other water users that rely on the goods and services provided by such ecosystems for their survival and well-being. This may include human food safety as water resource health aspects pertaining to downstream users and communities. These aspects are not assessed in this document.

## 6.1 How risks were determined

A structured Risk Assessment has been carried out which allows Risk to be determined on the basis of a consideration of the likelihood or probability of an impact occurring (see Box below as provided by CSIR), and the consequences for the water resource if it did occur. Consequences have been defined from the perspective of surface freshwater resources and are outlined in the following section.




Box:
Assessment of Risk based on Likelihood and Consequence

**Other potential risks to consider**

Other potential risks that are not addressed or assessed in this document, but that should be taken into account when considering an aquaculture operation, include the following:

- The cost of electricity – especially in remote rural areas where instalment of specific Eskom power lines or renewable energy facilities may be required;
- Whether there is a sustainable market for freshwater fish in the area;
- Distance from a market or off-set area and what the quality and packaging requirements of the product are; and
- Unsuitable quality of onsite water as a result of upstream water users.

### 6.1.1 Determining consequence

Integral to the determination of levels of Risk to surface water resources as a result of different aquaculture activities or aspects (including location) must be an understanding of how these activities and/or aspects affect resource quality characteristics. Impacts on ecosystem drivers and responses and the resultant implications for ecosystem services should all be considered. These effects are considered in Table 6, which provides criteria to define different levels of consequence to the resource, based on different levels of change to ecosystem drivers and responses. Consequences are defined for a number of key potential impacts, which fall broadly into the impact types identified in Section 5.2 (water quality, flow, biodiversity and habitat quality). Determination of consequence in each case takes cognisance of the importance and condition of the affected resource, and the scale (or magnitude) and duration of impacts to both ecosystem drivers and receptors.

In this study, the practical determination of the consequences likely to be associated with different impacts uses a multi-tiered approach, as follows:

- Different production systems are first considered, using the ratings already presented in Section 5.2.3. These are expanded on in Table 7, to include consideration of the degree to which different issues could potentially be mitigated with reasonable technology / operational inputs, with single overall ratings being derived for each system, based on the worst rating for any one criterion.

Note that the implications for biodiversity of escapees of fish species or their associated diseases and parasites are likely to be very different depending on whether the fish species already occurs in the river reaches (either because it is indigenous to the affected system or because it has already been introduced), or whether it would be a new potential invader of these waters. In order to address this issue, consequence levels were determined separately for systems assuming biodiversity impacts associated with escapees into the river system, and excluding such effects. This also allowed differentiation between aquaculture species that are not likely to establish in river systems (e.g. trout into warm rivers) and those that are, using the same production methods.

- The production system ratings are then considered in relation to the sensitivity of receiving areas as shown in Table 8, which is used to derive Consequence levels. The different consequence levels allocated are assumed to represent the conditions defined in Table 6.
- The above consequence ratings were used with consideration of likelihood, to determine the Risk associated with different production systems, regardless of the aquaculture species used in production. Consequences associated with the use of different aquaculture species in different

areas were then determined, using a similar matrix that weighs the invasive capacity of different target species, against the sensitivity of different environments (see Table 9).

The significance level of species establishing in the wild in different areas was rated as follows:

- **Low:** Not likely to establish wild populations in this area – aquatic ecosystems not suitable to support wild populations;
- **Moderate:** Within its natural range and may invade into the wild; and
- **High:** Alien species that has the ability to establish populations in the wild in this area.

The above rating criteria are included in Table 9.

Indirect biodiversity impacts relating to water quality, water quantity and habitat changes are assumed to be included in the ratings outlined in Table 8.

The main reason for separation of consequence levels for impacts associated with production systems (water quality, water quantity, habitat changes and biodiversity impacts in the form of bacteria and pathogens) as opposed to biodiversity changes as a result of escapees, is that the former impacts are largely mitigable with changes in production technology and operational practice. The latter (escapee impacts) are considered unlikely to be practically mitigable in the long-term with any confidence, and mitigation measures revolve around impact avoidance.

Table 6. Criteria for the assignment of different levels of Consequence for surface aquatic ecosystems, as used in the freshwater aquaculture Risk Assessment.

| Impact | Consequence level | | | | |
|---|---|---|---|---|---|
| | Slight | Moderate | Substantial | Severe | Extreme |
| Water Quality | Not impacted beyond allowable limits. | May be impacted; not more than one water quality class. | Will be affected. | Noticeably deterioration in water quality. | Adverse ecosystem-level changes as a result of water quality impacts. |
| Water Quantity: flow regimes and geomorphological processes | Not impacted beyond allowable limits. | Not affected. | May be slightly affected. | Likely to be adversely impacted. | Adverse ecosystem-level changes as a result of water quantity change. |
| Faunal and Floral communities and overall ecosystem structure and function | Floral and faunal communities and overall ecosystem structure and function remain within acceptable limits. | Floral and faunal communities and overall ecosystem structure and function may be impacted, but impacts are reversible once the activity ceases. | Floral and faunal communities and overall ecosystem structure and function may be impacted with probable loss of sensitive biota; impacts are reversible with direct management intervention once the activity ceases;<br>Impacts beyond the adaptive capacity of the users relying on the resource – hence need for active rehabilitation intervention | Floral and faunal communities and overall ecosystem structure and function will be adversely impacted; impacts are only reversible with significant and prolonged management intervention after the activity has ceased, to restore the system to its original state.;<br>Impacts well beyond the adaptive capacity of the users relying on the resource – hence need for active rehabilitation intervention. | Floral and faunal communities and overall ecosystem structure and function are adversely impacted and are likely not to be reversible except with extensive and prolonged management intervention after the activities have ceased.<br>Resource impacts irreversible and remediation likely to be impractical. |
| Red data and/or endemic taxa and/or unique populations, biodiversity sustainability (reflected in CBA impacts) | None | None<br>. | No more than site specific, impacts to relatively small ecosystem components that support known red data and/or endemic taxa and or unique populations. | Sub-quaternary catchment-specific, or affecting more than one river reach, extending beyond ten kilometres. OR<br>Impact is reach-specific and affects ecosystem portions that support known red data and/or endemic taxa or unique populations. OR<br>Impacts located in- or upstream of aquatic CBAs and likely to exert prolonged adverse effects on these | Impacts greater than reach-specific, and more persistent and affecting ecosystems that support known red data and/or endemic taxa and or unique populations OR less than reach-scale but adversely affecting ecosystems that support red data or endemic taxa or unique populations with very limited natural range.<br>Impacts located in- or upstream of aquatic CBAs and likely to exert prolonged adverse effects |

| Impact | Consequence level | | | | |
|---|---|---|---|---|---|
| | Slight | Moderate | Substantial | Severe | Extreme |
| | | | | CBAs or other sensitive or strategic areas | on these CBAs or other sensitive or strategic areas |
| Extent | Limited in extent: Site specific | Possibly affecting up to reach level | Up to reach level, but affect red data species at a site level | Reach-specific | Impacts greater than reach specific |
| Ecostatus | Existing resource ecostatus class would not deteriorate; change readily reversible at any time and/or of short-term duration | Some discernible degradation in resource ecostatus / possible change in class C or worse river, no change in Class A or B watercourse, change is of short duration and reversible. | Marked degradation in resource ecostatus, by at least one category. | Severe degradation in resource ecostatus by between two to three categories in a C or worse class river, or any adverse deterioration in a Class A or B river. | Dramatic and prolonged change to resource ecostatus relative to its baseline condition; change is unlikely to be practically reversible without extensive and prolonged management intervention. |
| Reversibility | Impacts are naturally reversible during the lifetime of the operation | Impacts are naturally reversible once the activity ceases. | Impacts are reversible with direct management intervention once the activity ceases. | Impacts only reversible with significant and prolonged management intervention after the activity has ceased, to restore the system to its original state. | The effects of the adverse impacts can only be reversed with extensive and prolonged management interventions after the activity has ceased, and the aquatic ecosystem is unlikely to be restored to its original state. |
| Affected areas | Impacts on areas of low sensitivity in terms of main drivers | Impacts on areas with Sensitivity ratings not higher than Moderate | Impacts on areas with Sensitivity ratings of moderate to high but biodiversity remains moderate | Impacts on areas with Sensitivity ratings of moderate to high - biodiversity is high | Impacts on areas with Sensitivity ratings that are very high with regard to biodiversity |

Table 7. Adapted from Table 5, to show overarching potential impact intensity and the required mitigation of effects and impacts of the type and intensity of production systems on aquatic ecosystems.

| Production System | Size | Intensity | Escapee potential | Scale of impact on drivers and responses | | | | Overarching impact intensity (including consideration of escapee impacts) | Over-arching impact intensity ignoring escapee impacts | Mitigation potential of impacts (ignoring impacts of escapees) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Biodiversity | Habitat | Water quality | Hydrology | | | |
| Dam Cage Culture | Small | Intensive | HIGH | HIGH | MEDIUM | MEDIUM | LOW | HIGH | MEDIUM | Low potential |
| | Large | Intensive | HIGH | HIGH | HIGH | HIGH | LOW | HIGH | HIGH | Low potential |
| [3]Pond Culture | Small | Extensive | MEDIUM | LOW | MEDIUM | LOW | LOW | MEDIUM | MEDIUM | High potential |
| | | Semi-intensive | MEDIUM | MEDIUM | MEDIUM | MEDIUM | LOW | MEDIUM | MEDIUM | High potential |
| | | Intensive | MEDIUM | MEDIUM | MEDIUM | MEDIUM | LOW | MEDIUM | MEDIUM | High potential |
| | Large | Extensive | MEDIUM | MEDIUM | MEDIUM | MEDIUM | MEDIUM | MEDIUM | MEDIUM | High potential |
| | | Semi-intensive | MEDIUM | MEDIUM | MEDIUM | HIGH | HIGH | HIGH | HIGH | High potential |
| | | Intensive | MEDIUM | MEDIUM | MEDIUM | HIGH | HIGH | HIGH | HIGH | High potential |
| Flow-through | Small | Semi-intensive | HIGH | HIGH | MEDIUM | MEDIUM | MEDIUM | HIGH | MEDIUM | Low potential |
| | | Intensive | HIGH | HIGH | MEDIUM | MEDIUM | MEDIUM | HIGH | MEDIUM | Low potential |
| | Large | Semi-intensive | HIGH | HIGH | HIGH | HIGH | HIGH | HIGH | HIGH | Low potential |
| | | Intensive | HIGH | HIGH | HIGH | HIGH | HIGH | HIGH | HIGH | Low potential |
| Recirculating Aquaculture System (RAS) | Small | Semi-intensive | MEDIUM | MEDIUM | MEDIUM | LOW | LOW | MEDIUM | MEDIUM | High potential |
| | Large | Semi-intensive | MEDIUM | MEDIUM | MEDIUM | MEDIUM | MEDIUM | MEDIUM | MEDIUM | High potential |
| | | Intensive | MEDIUM | MEDIUM | MEDIUM | MEDIUM | MEDIUM | MEDIUM | MEDIUM | High potential |

[3] Note that ratings pertaining to the off-channel productions systems are based on the assumption that these systems are not located in a riparian zone and / or that the necessary precautionary measures are in place to secure the operations during extreme events (e.g. floods) when ponds and other systems may overflow.

The assessment conventions applied to different production systems are defined in Table 8.

Table 8. Assignment of potential consequence levels (as defined in Table 6) to different rated production systems (as rated in Table 7), in areas with different sensitivity ratings with regard to (combined) water quality, hydrology and habitat changes (as mapped and described in Section 4.3.7).

| PRODUCTION SYSTEMS: Potential impact intensity | SENSITIVITY LAYERS: Receiving area sensitivity | POTENTIAL CONSEQUENCE LEVEL |
|---|---|---|
| Low | Low | Slight |
| Low | Medium | Slight |
| Low | High | Moderate |
| Low | Very High | Substantial |
| Medium | Low | Slight |
| Medium | Medium | Moderate |
| Medium | High | Substantial |
| Medium | Very High | Severe |
| High | Low | Moderate |
| High | Medium | Substantial |
| High | High | Severe |
| High | Very High | Extreme |

The assessment conventions applied to the assessment of Consequences associated with aquaculture with different target species in areas of different sensitivity are outlined in Table 9.

Table 9. Assignment of potential biodiversity consequence levels to the use of different target aquaculture species (as rated in Table 4), and where used in areas of different sensitivity ratings with regard to biodiversity (as determined in Section 3). See Table 12 for list of species and areas to which the invasive capacities outlined below apply. Note that assignment of Medium invasive capacity to species that are already present in the river reach requires independent confirmation of the presence of the species of concern within the potentially affected river reaches and those in the upstream quaternary – this is to reduce the potential indirect impact of this SEA in encouraging the establishment of alien fish species in river reaches in order to promote aquaculture.

| SENSITIVITY OF RECEIVING AREA | TARGET SPECIES: Invasive capacity | POTENTIAL CONSEQUENCE: Impacts to biodiversity |
|---|---|---|
| Low | Low | Slight |
| Med | Low | Slight |
| High | Low | Moderate |
| Very High | Low | Moderate |
| Low | Medium (home range or already present) | Slight |
| Med | Medium (home range or already present (confirmed presence in river reach and upstream quaternary) | Moderate |
| High | Medium (home range or already present (confirmed presence in river reach and upstream quaternary) | Substantial |
| Very High | Medium (home range or already present (confirmed presence in river reach and upstream quaternary) | Severe |
| Low | High | Moderate |
| Med | High | Substantial |
| High | High | Severe |
| Very High | High | Extreme |

The consequence ratings outlined in Table 8 and Table 9 were applied to each of the impacts described in Section 5, considered with and without implementation of mitigation / best practice methods. Each of the production systems and each of the five target aquaculture species considered in this assessment were assessed separately, with the assessment taking into account differences between study areas in terms of likelihood of invasion into each (see Table 4), and hence in terms of biodiversity consequence.

## 6.2 Risk Assessment Results

This section presents the results of the Risk Assessments, carried out separately for the production systems (including and excluding escapee biodiversity impacts), and then for target aquaculture species.

Since the sensitivity assessment presents areas of varying sensitivity across all nine study areas, there is no necessity to assess each study area separately. However, different study areas are associated with different degrees of risk of target species escaping into the wild, and this issue is considered in the risk assessments with regard to the different areas.

Note that this study considers the risk of only the most significant activities associated with aquaculture production. Activities such as the construction of facilities and infrastructure could clearly also result in significant impacts. It is assumed that these would be managed through detailed design and planning permissions, on a site-by-site basis.

### 6.2.1 Risk assessment for production methods

Tables 10 and 11 present the risk assessments of different production methods, respectively with and without consideration of the biodiversity impacts associated with the ease of escape from the system. Where species are unlikely to establish populations in the wild, the risk assessment presented in Table 11 would be applicable. Where a species can be shown to have already established populations in the river system and upstream quaternary of a proposed new facility, which have been there 10 years or longer, then Table 11 is also applicable. Note that the reason for the inclusion of a time criterion in this instance in the determination of whether an alien species is deemed established in a system or not is intended to address the otherwise unintended consequence of fish being introduced into areas to facilitate aquaculture expansion.

Table 12 shows which target species and study areas these ratings apply to. The table does not show where some target species may already have established populations in the wild (e.g. brown and/or rainbow trout and tilapia). Although existing data for these species at least are presented in Appendix 1 for each study area, the data are not considered accurate enough for application here. Prospective aquaculturalists would need to show through an independent specialist assessment that the system under consideration met the above criteria, in order to be treated as already within the system and therefore not associated with additional biodiversity risk.

Note that the assessments "with mitigation" assume:

- Complete implementation of all Best Practice and other mitigation measures outlined in Sections 7 and 8;
- Abstraction from rivers to be such that the full ecological reserve is allowed to pass through the river in accordance with the outcomes of a Reserve Determination for the affected system;
- A flexible production system should be devised that allows for (and requires) system closure during drought periods;
- Installation of water level (or similar) telemetry in all inlet systems, to allow auditing of abstraction rates, relative to river flows;
- Monitoring of downstream aquatic ecosystems for river condition (water quality, flow regime, macro-invertebrate community structure and fish assemblages) would be necessary on a regular

(monthly to quarterly) and ongoing basis and any deterioration linked to the aquaculture facilities would be reported to the appropriate authority and acted upon, with the assumption that failure to do so would result in an automatic revoking of licensing for the facility and a requirement to cease activities.

- Note that where production systems are associated with Medium or High Risk, avoidance mitigation in the form of selection of alternative technologies would be required to reduce the assessed risk. In many cases, this Risk is driven by the sensitivity of the receiving environments. The Risk Matrices in Table 10 and Table 11 both show that the fast-tracking of authorisation for aquaculture sought through this SEA would be inappropriate in areas mapped as Very High sensitivity, as well as in areas mapped as having High sensitivity. It has however been acknowledged that there is uncertainty in the sensitivity maps, and that they are thus likely to be conservative. If aquaculture in High Sensitivity areas is requested for authorisation despite its sensitivity status, then the merits and likely ecological impacts of the proposed activities, with their proposed mitigation measures, would need to be considered through the formal Environmental Impact Assessment processes of the National Environmental Management Act (NEMA) and the National Water Act (NWA).

- Fast-tracking of authorisation through the SEA would be appropriate for flow-through systems and in-stream dams only in areas mapped as being of Low sensitivity. In areas of Medium sensitivity; alternative off-channel production systems would be required to reduce levels of Risk to Low.

**Sensitivity adjustments:**

Potential applicants do have an option to query the assigned Sensitivity status of their particular area of concern. Interrogation of the Sensitivity maps at a more detailed scale is enabled through the link outlined in Section 4.3.6. This allows identification of the particular attributes driving assignment of High and Very High sensitivity scores. Where these can be shown through independent specialist input to be invalid in an applicant's study area, adjustment of the Sensitivity score for that area could be considered. It is noted however that this process might not be cheaper or faster than taking the application through the current requirements for authorisation consideration in terms of NEMA and the NWA.

In summary:

- In terms of area and production methods, Low and Very Low Risks (i.e. scenarios that would fall readily into the ambit of the SEA) would be associated with:
    - Areas of Low and Medium Sensitivity in the case of mitigated dam cage culture systems;
    - Areas of Low, Medium or High Sensitivity in the case of mitigated pond culture systems;
    - Areas of Low sensitivity in the case of Flow-through systems
    - Areas of Low, Medium or High Sensitivity in the case of RAS systems.
- Medium Risk would be associated with:
    - Areas of Very High Sensitivity in the case of mitigated small pond and extensive pond culture systems;
    - Areas of Very High Sensitivity in the case of mitigated small pond and extensive large pond culture systems;
    - Areas of Medium Sensitivity in the case of mitigated small and large flow-through systems;
    - Areas of Very High Sensitivity in the case of mitigated RAS systems.

All other production system and sensitivity area combinations have been rated as of High or Very High Risk.

Table 10. Risk Assessment for different production systems – including biodiversity impacts associated with escapees. This table thus represents a worst-case scenario, compared with Table 11, which excludes biodiversity considerations associated with fish species introductions and pathogens. Sensitive areas as mapped in Section 4.3 and Appendix 3. Consequence ratings from Table 7 and 8.

*Note that mitigation measures assumed to include best practice measures outlined in Sections 7 and 8, but assume location sensitivity remains the same.*
*Mitigation measures also do not consider changing production system type – which might reduce potential impact significantly in some cases.*
*Table 7 indicates potential for impacts associated with different production systems to be mitigated.*

| | Size of operation | Intensity of production | [4]Impact intensity | Sensitive areas | Without mitigation | | | With mitigation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | [5]Consequence | Likelihood | Risk | Impact intensity | Consequence | Likelihood | Risk |
| **Impact:** Degradation of instream habitat quality as a result of changes in biodiversity (associated with fish or pathogen escapees) as well as changes in water quality and / or hydrology | | | | | | | | | | | |
| Dam Cage Culture | Small Large | ALL | High | Low | Moderate | Very likely | Low | Medium | Slight | Very likely | Very low |
| | | | High | Medium | Substantial | Very likely | Moderate | Medium | Moderate | Very likely | Low |
| | | | High | High | Severe | Very likely | High | High | Severe | Very likely | High |
| | | | High | Very high | Extreme | Very likely | Very High | Very high | Extreme | Very likely | Very High |
| Pond culture | Small | Any | Medium | Low | Slight | Very likely | Very Low | Low | Slight | Very likely | Very low |
| | | | Medium | Medium | Moderate | Very likely | Low | Low | Slight | Very likely | Very low |
| | | | Medium | High | Substantial | Very likely | High | Low | Moderate | Very likely | Low |
| | | | Medium | Very high | Severe | Very likely | High | Low | Substantial | Very likely | Moderate |
| | Large | Extensive | Medium | Low | Slight | Very likely | Very Low | Low | Slight | Very likely | Very Low |
| | | | Medium | Medium | Moderate | Very likely | Low | Low | Slight | Very likely | Very Low |
| | | | Medium | High | Substantial | Very likely | High | Low | Moderate | Very likely | Low |
| | | | Medium | Very high | Severe | Very likely | High | Low | Substantial | Very likely | Moderate |
| | | Semi intensive and intensive | High | Low | Moderate | Very likely | Low | High | Moderate | Very likely | Low |
| | | | High | Medium | Substantial | Very likely | High | High | Substantial | Very likely | High |
| | | | High | High | Severe | Very likely | High | High | Severe | Very likely | High |
| | | | High | Very high | Severe | Very likely | High | High | Severe | Very likely | High |
| Flow-through | Small | Any | High | Low | Moderate | Very likely | Low | High | Moderate | Very likely | Low |

[4] Derived from Table 7 ("Overarching impact intensity of production systems (including consideration of escapee impacts") set against range of receiving area sensitivities to determine consequence
[5] Derived from Table 8 ("Impact intensity of production systems" set against range of receiving area sensitivities to determine consequence)

| | Size of operation | Intensity of production | [4]Impact intensity | Sensitive areas | Without mitigation | | | With mitigation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | [5]Consequence | Likelihood | Risk | Impact intensity | Consequence | Likelihood | Risk |
| | | | High | Medium | Substantial | Very likely | Moderate | High | Substantial | Very likely | Moderate |
| | | | High | High | Severe | Very likely | High | High | Severe | Very likely | High |
| | | | High | Very high | Extreme | Very likely | Very High | High | Extreme | Very likely | Very high |
| | Large | Any | High | Low | Moderate | Very likely | Low | High | Moderate | Very likely | Low |
| | | | High | Medium | Substantial | Very likely | Moderate | High | Substantial | Very likely | Moderate |
| | | | High | High | Severe | Very likely | High | High | Severe | Very likely | High |
| | | | High | Very high | Extreme | Very likely | Very High | High | Extreme | Very likely | Very high |
| Recirculation aquaculture systems (RAS) | Small and Large | Any | Medium | Low | Slight | Likely | Very Low | Low | Slight | Very likely | Very low |
| | | | Medium | Medium | Moderate | Likely | Low | Low | Slight | Very likely | Very low |
| | | | Medium | High | Substantial | Likely | Moderate | Low | Moderate | Very likely | Low |
| | | | Medium | Very high | Severe | Likely | High | Low | Substantial | Very likely | Moderate |

Table 11. Risk Assessment for different production systems – excluding biodiversity impacts associated with escapees. Sensitive areas as mapped in Section 4.3 and Appendix 3. Consequence ratings from Table 7 and 8. Production system mitigation sensitivity taken from Table 7.

Note that mitigation measures assumed to include best practice measures outlined in Sections 7 and 8, but assume location sensitivity remains the same.

Mitigation measures also do not consider changing production system type – which might reduce potential impact significantly in some cases.

| Impact | Size of operation | Intensity of production | [6]Impact intensity | Sensitive areas | Without mitigation | | | With mitigation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | [7]Consequence | Likelihood | Risk | Impact intensity | Consequence | Likelihood | Risk |
| **Impact:** Degradation of instream habitat quality as a result of changes in water quality and /or hydrology – that is, ignoring biodiversity impacts | | | | | | | | | | | |
| Dam Cage Culture | Small Large | Intensive Extensive | Medium | Low | Slight | Very likely | Very Low | Low | Slight | Very likely | Very low |
| | | | Medium | Medium | Moderate | Very likely | Low | Low | Slight | Very likely | Very low |
| | | | Medium | High | Substantial | Very likely | High | Low | Moderate | Very likely | Low |
| | | | Medium | Very high | Severe | Very likely | High | Low | Substantial | Very likely | Moderate |
| | Large | Intensive | High | Low | Moderate | Very likely | Low | Low | Slight | Very likely | Very low |
| | | | High | Medium | Substantial | Very likely | High | Low | Slight | Very likely | Low |
| | | | High | High | Severe | Very likely | High | Medium | Substantial | Very likely | Moderate |
| | | | High | Very high | Extreme | Very likely | High | High | | Very likely | High |
| Pond culture | Small | Any | Medium | Low | Slight | Very likely | Very Low | Low | Slight | Very likely | Very low |
| | | | Medium | Medium | Moderate | Very likely | Low | Low | Slight | Very likely | Very low |
| | | | Medium | High | Substantial | Very likely | High | Low | Moderate | Very likely | Low |
| | | | Medium | Very high | Severe | Very likely | High | Low | Substantial | Very likely | Moderate |
| | Large | Extensive | Medium | Low | Slight | Very likely | Very Low | Low | Slight | Very likely | Very Low |
| | | | Medium | Medium | Moderate | Very likely | Low | Low | Slight | Very likely | Very Low |
| | | | Medium | High | Substantial | Very likely | High | Low | Moderate | Very likely | Low |
| | | | Medium | Very high | Severe | Very likely | High | Low | Substantial | Very likely | Moderate |
| | | Semi intensive and intensive | High | Low | Moderate | Very likely | Low | High | Moderate | Very likely | Low |
| | | | High | Medium | Substantial | Very likely | High | High | Substantial | Very likely | High |
| | | | High | High | Severe | Very likely | High | High | Severe | Very likely | High |
| | | | High | Very high | Severe | Very likely | High | High | Severe | Very likely | High |
| Flow-through | Small | Any | Medium | Low | Slight | Very likely | Very Low | Low | Slight | Very likely | Very low |

[6] Derived from Table 7 ("Overarching impact intensity of production systems (including consideration of escapee impacts) " set against range of receiving area sensitivities to determine consequence
[7] Derived from Table 8 ("Impact of production systems" set against range of receiving area sensitivities) to determine consequence

| Impact | Size of operation | Intensity of production | [6]Impact intensity | Sensitive areas | Without mitigation | | | With mitigation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | [7]Consequence | Likelihood | Risk | Impact intensity | Consequence | Likelihood | Risk |
| | | | Medium | Medium | Moderate | Very likely | Low | Low | Slight | Very likely | Very low |
| | | | Medium | High | Substantial | Very likely | High | Low | Moderate | Very likely | Low |
| | | | Medium | Very high | Severe | Very likely | High | Low | Substantial | Very likely | Moderate |
| | Large | Any | High | Low | Moderate | Very likely | Low | Medium | Substantial | Very likely | Very low |
| | | | High | Medium | Substantial | Very likely | High | Medium | Moderate | Very likely | Low |
| | | | High | High | Severe | Very likely | High | Medium | Substantial | Very likely | Moderate |
| | | | High | Very high | Severe | Very likely | High | Medium | Severe | Very likely | High |
| Recirculation aquaculture systems (RAS) | Small and Large | Any | Medium | Low | Slight | Likely | Very Low | Low | Slight | Likely | Very low |
| | | | Medium | Medium | Moderate | Likely | Low | Low | Slight | Likely | Very low |
| | | | Medium | High | Substantial | Likely | Moderate | Low | Moderate | Likely | Low |
| | | | Medium | Very high | Severe | Likely | High | Low | Substantial | Likely | Moderate |

### 6.2.2 Risk assessment for aquaculture species

Table 12 (adapted from Table 4) provides a summary of which species are likely to invade into which of the study areas for which they are proposed.

Table 12. Biodiversity threat of aquaculture species by study area – (i) High: Alien species likely to establish populations in the wild; (ii) Medium: Locally indigenous species (to that catchment) likely to establish populations in the wild; OR alien species 8proven to have been established in the affected river reach and upstream quaternary for a period of at least 10 years, and (iii) Low: Unlikely to establish populations in the wild.

| Study area | African sharp-tooth catfish | Nile tilapia | Marron crayfish | Mozambique tilapia | Rainbow and Brown trout |
|---|---|---|---|---|---|
| Limpopo | Medium | High | | Medium | High |
| Mpumalanga | | High | | Medium | High |
| Gauteng - North West | Medium | High | | Medium | |
| Free State – Vaalharts | Medium | | | | |
| Free State – KwaZulu-Natal Highlands | | | | | High |
| Free State – Vanderkloof-Gariep | Medium | | | | Low |
| Richards Bay | Medium | High | | Medium | |
| Eastern Cape | | High | High | Medium | High |
| Western Cape | | | | | High |

Table 13 provides Risk Assessments for the biodiversity impacts of the different aquaculture species, regardless of production methods used. It considers the biodiversity threats outlined in Table 3, which must be interpreted for the species listed above.

Given that the eventual escape of aquaculture species into downstream systems is considered inevitable in all production approaches proposed, this impact is considered largely immitigable, although there are design, operation and technology approaches that will minimise this risk, and are assumed will be incorporated into standard aquaculture design as outlined under Best Practice (Section 8).

Assessments 'with mitigation' assume the following:

- Complete implementation of all Best Practice and other mitigation measures outlined in Sections 7 and 8;
- Monitoring of downstream aquatic ecosystems for river condition (water quality, flow regime, macroinvertebrate community structure and fish assemblages) would take place on a regular (monthly to quarterly) and ongoing basis and deterioration linked to the aquaculture facilities would be reported to the appropriate authority and acted upon, with the assumption that failure to do so would result in an automatic revoking of licensing for the facility and a requirement to cease activities.

[8] Note that assignment of Medium invasive capacity to species that are already present in the river reach requires independent confirmation of the presence of the species of concern within the potentially affected river reaches and those in the upstream quaternary – this is to reduce the potential indirect impact of this SEA in encouraging the establishment of alien fish species in river reaches in order to promote aquaculture.

Table 13. Risk Assessment for production of different aquaculture species – sensitive areas as mapped in Section 4.3 and Appendix 2. Species and study areas as listed in Table 12. Consequence ratings from Tables 8 and 9. Areas wiuth high sensitivity usually driven by the presence of fish species of concern.

| Invasive capacity | Sensitive areas | Without mitigation | | | With mitigation | | |
|---|---|---|---|---|---|---|---|
| | | Consequence | Likelihood | Risk | Consequence | Likelihood | Risk |
| **Impact: Biodiversity loss or change as a result of aquaculture escapees establishing in river systems** | | | | | | | |
| Low | Low | Slight | Not Likely | Very Low | Slight | Very unlikely | Very low |
| | Medium | Moderate | Not Likely | Low | Moderate | Very unlikely | Low |
| | High | Severe | Not Likely | Moderate | Substantial | Very unlikely | Low |
| | Very high | Extreme | Not Likely | Moderate | Severe | Very unlikely | Low |
| Medium | Low | Slight | Very likely | Very Low | Slight | Very likely | Very low |
| | Medium | Moderate | Very likely | Low | Moderate | Very likely | Low |
| | High | Moderate | Very likely | Low | Moderate | Very likely | Low |
| | Very high | Moderate | Very likely | Low | Moderate | Very likely | Low |
| High | Low | Slight | Very likely | Very Low | Slight | Likely | Very Low |
| | Medium | Moderate | Very likely | Low | Moderate | Likely | Low |
| | High | Severe | Very likely | High | Severe | Likely | High |
| | Very high | Extreme | Very likely | Very High | Extreme | Likely | High |

The risk assessment outlined in Table 13 shows that fast-tracking of authorisation through the SEA would be appropriate for:

- Species that are not likely to establish wild populations in areas of Low, Medium and High sensitivity – this in fact applies only to trout in the Free State (Vanderkloof – Gariep) study area. Note that the outcomes of the Production Risk Assessment could also influence the applicability of the SEA for new facilities in areas of High Sensitivity;

- Species that occur naturally in the catchment or that have been shown to have been established there for at least ten years (e.g. trout in certain rivers in Mpumalanga and the Eastern Cape) including in the upstream quaternary could in theory be established in all areas. However, the Production Risk assessments of Tables 10 and 11 pose restrictions in some areas on the basis of the production system utilised;

- Alien species that are likely to establish wild populations in new areas or areas where there is low certainty as to their long-term past presence could only be used in new aquaculture facilities in terms of the fast tracking of authorisation processes intended as an outcome of this SEA, in areas mapped as of Low or Medium sensitivity.

Based on the information provided in the previous sections, assuming full mitigation measures are implemented and drawing on the sensitivity maps of Appendix 3, the following recommendations are proposed based on the Risk Assessment:

- Limpopo

    - African sharptooth catfish and Mozambique tilapia are locally indigenous species likely to invade into catchments and thus would be suitable (in terms of the authorisation dispensations intended by the SEA outcomes) only for areas of Low and Medium sensitivity OR where the nearest watercourses to the operation already have this species naturally occurring, and only local stock is used, to prevent impacts on genetic stock;

    - In all cases, full mitigation and Best Practice measures would be required;

- Mpumalanga

    - Mozambique tilapia are likely to invade into catchments and thus would be suitable (in terms of the SEA) only for areas of Low and Medium sensitivity OR where the nearest watercourses to the operation already have this species naturally occurring, and only local stock is used, to prevent impacts on genetic stock;

    - Nile tilapia and rainbow and brown trout pose a high biodiversity threat in this area and are not locally indigenous. They are suitable (in terms of the SEA) only for areas of Low and Medium sensitivity. Rainbow and brown trout may also be used in verified existing trout presence areas;

    - In all cases, full mitigation and Best Practice measures would be required;

- Gauteng – North West

    - Again, African sharptooth catfish and Mozambique tilapia are locally indigenous species likely to invade into catchments and suitable for areas of Low and Medium sensitivity OR where the nearest watercourses to the operation already have this species naturally occurring, and only local stock is used, to prevent impacts on genetic stock;

- Nile tilapia pose a high biodiversity threat in this area and are suitable only for areas of Low or Medium sensitivity;
- In all cases, full mitigation and Best Practice measures would be required;

- Free State –Vaalharts
  - Again, African sharptooth catfish are locally indigenous species likely to invade into catchments and suitable (in terms of the SEA) for areas of Low and Medium sensitivity OR where the nearest watercourses to the operation already have this species naturally occurring, and only local stock only is used, to prevent impacts on genetic stock – in all cases, full mitigation and Best Practice measures would be required;

- Free State – KwaZulu-Natal Highlands
  - Rainbow and brown trout pose a high biodiversity threat in this area and are not locally indigenous. They are suitable (in terms of the SEA) only for areas of Low and Medium sensitivity with full mitigation and Best Practice measures;

- Free State – Vanderkloof-Gariep
  - Rainbow and brown trout pose a low biodiversity threat in this area and although not locally indigenous, they are unlikely to establish populations in the wild because of high water temperatures. They are suitable (in terms of the SEA) for areas of Low and Medium sensitivity;
  - In all cases, full mitigation and Best Practice measures would be required;

- Richards Bay
  - African sharptooth catfish and Mozambique tilapia are locally indigenous species likely to invade into catchments and are suitable (in terms of the SEA) for areas of Low and Medium sensitivity OR where the nearest watercourses to the operation already have this species naturally occurring, and only local stock is used, to prevent impacts on genetic stock;
  - Nile tilapia pose a high biodiversity threat in this area and are not locally indigenous. They are suitable (in terms of the SEA) only for areas of Low sensitivity, and should be used only with systems (e.g. RAS) that pose low risk of escapees;
  - In all cases, full mitigation and Best Practice measures would be required;

- Eastern Cape
  - Mozambique tilapia is a locally indigenous species likely to invade into catchments and is suitable (in terms of the SEA) for areas of Low and Medium sensitivity;
  - Nile tilapia and brown and rainbow trout pose a high biodiversity threat in this area and are not locally indigenous. They are suitable (in terms of the SEA) only for areas of Low sensitivity;
  - Marron are proposed for this area as well. They too pose a high biodiversity threat in this area should they escape from aquaculture facilities. Therefore, their production is promoted only in areas of Low sensitivity. Given the biodiversity threats posed by this

species, flow-through and dam cage culture production approaches, all associated with bio-security risk, would not be appropriate to their culture in terms of the SEA;

  - In all cases, full mitigation and Best Practice measures would be required;

- Western Cape

  - Brown and rainbow trout pose a high biodiversity threat in this area and are not locally indigenous. They are suitable (in terms of the SEA) only for areas of Low and Medium sensitivity, where any of the production systems could be used or in verified existing trout presence areas. Where these are located in Medium or High sensitivity areas, only RAS is promoted – it is noted that in some verified trout presence areas (e.g. the Molenaars River system), trout pose high biodiversity threats to endemic fish species. Also, while RAS poses low escape risk there is still a possibility of accidental or deliberate release of fish and ideally if trout are not present in a catchment and the catchment is ecologically sensitive, then aquaculture should not be supported in that catchment. The industry should rather aim to intensify their operations in areas that are already ecologically compromised by the presence of trout. In very sensitive catchments where trout are already present, any further development should only be RAS.

**NB: The above recommendations are relevant to sensitivities that have been confirmed at finer scales, and in-field. An area identified that is classified as high sensitivity based on the available spatial data in this assessment may in reality be confirmed as low sensitivity on the ground, and *vice versa*.**

In areas where target species and production systems do not lend themselves for fast tracking, applications would need to be considered on a site by site basis through an EIA.

## 6.3 Summary

This section has outlined an approach to determining Risk, where there are multiple factors to consider. A tiered approach has been used, with aquaculture production types and fish species being considered separately in terms of the Sensitivity of the area in which the facility is proposed. Generally, the fast-tracking of aquaculture authorisation sought through this SEA process would not be applicable to fish species or production systems that are rated as Medium (or higher) Risk.

Where Risk is determined as Low or Very Low, for all aspects, then fast-tracking an application through the SEA would be considered appropriate. Note that in cases where overarching Risk is Moderate, High or Very High, the applicant should consider:

- Checking on the factors driving the assignment of spatial sensitivity to the river / catchment in question – this can be done through the link in Section 4.3.6, and with reference to Table A2.1 in Appendix 2. Where an independent aquatic specialist can show that the factors driving the assignment of Medium or higher sensitivity do not apply to the river reach in question, then motivation for the applicability of the SEA allowances should be possible;

- Checking whether the target species is present already in the river reach and upstream quaternary, and has been there for 10 years or longer, as this could reduce the biodiversity threat rating of the species;

- Checking the aquaculture production process and what additional mitigation measures could be introduced in design to drive down the production risk rating.

It must also be stressed that if a proposed project is associated with a Moderate or higher Risk after mitigation, it does not mean that the project may not proceed. It means rather that the fast-tracking allowed by the SEA is not appropriate for this application, as there are environmental or other complexities which need to be considered more carefully and specifically through an EIA and / or Water Use Licence process, than through the high level generalised approach that this SEA has had to reply on. More particular Mitigation or Design measures might, for example, be required through such a process.

# 7 MITIGATION MEASURES

Sustainable development of freshwater aquaculture is focused on the protection and preservation of natural resources and their ecosystems. With this in mind, the planning and management of facilities have to adopt approaches that aim to safeguard ecosystem integrity and protect human health. The development and implementation of Standard Operating Procedures (SOPs) and mitigation measures serve this purpose.

Freshwater aquaculture farms can vary significantly in terms of their size and type of infrastructure, production intensity, types of input, and level of management. During the construction and operational phase as well as the decommissioning phase, suitable measures therefore have to be taken to mitigate and reduce key impacts and reduce or minimise risks posed to the receiving aquatic environment.

Mitigation measures presented below from IFC (2007) are aimed at reducing impacts on and risks posed to the resource quality of receiving environments during the various phases of aquaculture farming.

## 7.1 Planning and Construction Phase

### 7.1.1 The species

- Biosecurity covers all activities aimed at managing or preventing the introduction of new species to a particular region and mitigating their impacts. Routine application of biosecurity at appropriate levels would minimize new introductions, spread and impacts and should therefore carefully be considered during the planning phase.

### 7.1.2 The site

- When selecting a site, cognisance should be taken of water availability and assurance.

- Impacts may be insignificant when an individual farm is considered, but cumulative impacts of multiple farms that are located in the same area could potentially be highly significant. .

- Before an aquaculture facility is constructed, the biodiversity importance and sensitivity of the area and water resources in close proximity to the proposed facility should be assessed and verified at a local scale.

- Aquaculture facilities and production systems should be sited away from natural water courses, including riparian areas and be above the 1:50 year flood line; all infrastructure should be able to resist the impacts of floods or flood conditions.

### 7.1.3 The aquaculture production system

- Consider production systems where resource consumption (e.g. water) and waste discharge could be minimised / optimised.

- Where possible polyculture should be considered.

- Perform construction during the dry season to reduce sediment-rich runoff that may pollute nearby water resources.

- Install temporary silt fences during construction, to slow down or catch suspended sediments.

- Design facilities in such a way that as much as possible of the natural vegetation habitat is left intact and that conversion and degradation of the natural habitat is minimised.

- Risk of escapes could be decreased if production systems are designed and built with stable walls (free from tree roots and burrowing animals) at a suitable gradient; high biosecurity facilities (e.g. RAS) should be prescribed in certain areas.

#### 7.1.4 The scale / size of the operation

- Considerations regarding the design and type of production systems should be determined by the opportunities and constraints posed by the local environment.

- Avoid / limit pond and canal construction in areas that have a slope of more than 2%, as this will require energy-intensive construction and maintenance.

- Stabilize banks to prevent erosion, if appropriate, with the support of an EMPr.

### 7.2 Operational Phase

#### 7.2.1 Conditions and environmental monitoring

- Careful consideration and adherence with local regulations should be taken with the culture of invasive and alien invasive species, especially in production systems such as cage cultures that pose a high risk for organisms to escape and establish and / or hybridize with native species.

- Where alien species are to be farmed, careful consideration should be given to their compatibility with local conditions.

#### 7.2.2 Biodiversity

- *Clarias gariepinus* is a NEMBA List 3: Category 2 invasive species which needs to be managed by area because it has a high potential negative impact on the environment where it occurs outside its native range. Farming only with the native strain *C. gariepinus* should be allowed and triploids or mono-sex cultures should be encouraged.

- *Tilapia* species are known to reproduce prolifically[9]. *Oreochromis* species excluding *O. mossambicus* and *O. placidus* are NEMBA List 3: Category 2 (for permitted aquaculture facilities). One solution to avoid reproduction of escapees in areas outside their natural range is triploidy, the production of sterile offspring. However, it is important that the sterility of the triploid progeny be confirmed before they are used in an aquaculture operation.

- Control access to aquaculture facilities to prevent intentional removing of live fish is important.

- Biosecurity culture practices, which include preventative measures to reduce escapee risk, should be undertaken where appropriate for brown and rainbow trout in particular due to the threat that they pose to native biodiversity.

- Installation and maintenance of screens with mesh is required to prevent escapees from entering water resources.

- Measures and the necessary structures must be put in place to deal with high rainfall events and extreme flooding events to prevent escape.

[9] Category / Area: a. 3; b. 2 for permitted aquaculture facilities; Scope of exemption from the provisions of Section 71(3) / prohibition in terms of Section 71A(1)

- Regularly inspect production systems such as cages for tears and bio-fouling.

### 7.2.3 Water and waste

- Ensure that saline or brackish water discharges are appropriately treated and disposed of in an environmentally responsible manner.
- During harvesting, contain and disinfect blood-containing water and effluent to reduce the risk of disease spread and to contain effluent matter.
- Slaughter and carcass processing must take place in a contained area.
- Avoid discharging water from ponds while harvesting takes place.
- After harvesting, use partial draining techniques to empty ponds to avoid a nutrient influx into receiving water resources.
- Solid waste matter such as dead stock and dewatered pond sludge should be composted, then either applied to land, or exported off site for a useful purpose, or if these options are not viable, disposed of at a suitable waste landfill site.

### 7.2.4 Animal health and welfare

- Diseases and parasites can largely be avoided if Best Management Practices are adopted, and all individuals are certified as disease free by suitably qualified veterinarians prior to introduction. This is particularly important when importing aquaculture species and their ova from other countries.
- To avoid the introduction of diseases and parasites, ova should be certified as "disease free" by the supplier. Ova should also be disinfected on export or import.

### 7.2.5 Drugs, feeds and fertilizers

- A clear understanding of the impact of feeds (nutrient loading) is essential for sustainable practices.
- Plan the rate and mode of applying fertilizers to maximise utilisation and prevent over-application.
- Avoid the use of fertilizers containing ammonia or ammonium with pH of 8 or above to avoid the formation of toxic unionized ammonia; aim to use environmental friendly feeds that are obtained from reputable suppliers.
- Avoid or limit the use of anti-foulants to treat cages and pens. Rather clean the nets manually with hot water or pressure tools.
- Efforts should be made to reduce or limit the quantities of antibiotics and hormones released, by, for instance, holding water in a waste treatment pond (where applicable), to allow time for natural degradation.

### 7.2.6 Food safety and traceability

- Match food pellet size with the species' life-cycle stage.
- Monitor feed uptake and adjust feeding rates accordingly to prevent over-feeding.
- Use floating feed pellets where possible.

- Stop feeding at a suitable time interval before harvesting.

### 7.3 Decommissioning Phase

Post-operation mitigation measures should include restoration of habitats or offset of losses through the creation of ecologically comparable areas managed for biodiversity.

Avoid the need to abandon and replace improperly designed and built aquaculture facilities by assessing soil properties of the site beforehand to establish whether seepage and possible groundwater contamination would occur (e.g. ponds); and assess the soil for the presence of existing anthropogenic pollutants that may hinder the viability of production systems where applicable. When facilities are abandoned, some of the culture organisms inevitably find their way into local water resources.

# 8 BEST PRACTICE GUIDELINES

In the preceding sections, the potential adverse impacts of aquaculture and the risk posed to aquatic ecosystems, have been discussed. It is clear that the impacts of aquaculture have broad spatial and temporal scales. In order to prevent, reduce, limit or mitigate anticipated impacts of freshwater aquaculture on natural resources, it is important to change or improve the environmental performance of aquaculture practices. Where possible, aquaculture practices should be integrated into other systems (e.g. hydroponics) and effluents reused for other purposes, such as irrigation where appropriate. It is further important that water shortages will become a limiting factor in many areas of South Africa and careful consideration should be given to efficient use of freshwater.

A Best Management Practice (BMP) is considered to be the best available and practical means of preventing a particular environmental impact while still allowing production to be conducted in an economically efficient manner (Boyd, 2003). The BMPs for aquaculture are increasingly regarded as meaningful goals in the overall reduction of on-farm and processing impacts and, by extension, any cumulative impacts that might occur as a result of aquaculture. The adoption and encouragement of aquaculture BMPs are regarded as means to achieve continuous improvement in environmental performance by putting management activities in place that would ensure ongoing minimisation of environmental harm posed by aquaculture activities through cost-effective and continually assessed measures (Hinrichsen, 2007).

Regulators are increasingly interested in finding ways to use BMPs to improve performance and reduce waste and pollution. For many, BMPs are a proxy for achieving regulatory compliance and/or a condition of permitting or licensing (Clay, 2008). However, the mere adoption of BMPs will not always yield an improvement in performance and ensure that impacts on the environment are meaningfully reduced. BMPs should therefore not be seen as being prescriptive, but rather as tools to help producers improve the performance of their aquaculture activities against a baseline and to give them the flexibility to develop their own site-specific ways to improve performance. This will enable them to continuously and proactively respond to environmental concerns and to develop more ecologically responsible production systems (Boyd *et al*., 2008a).

An effective approach to voluntary regulation of an industry is for its members to adopt codes of practice that contain BMPs, which are aimed at reducing and minimising environmental impacts (Boyd *et al*., 2008a). BMPs could also assist in setting standards for specific culture systems and species that could serve as conditions for permits and licenses and references for monitoring compliance (NMFS, 2002). Due to the varied nature of aquaculture practices in terms of sites, species, operational scale, techniques, financial positions, markets and environmental conditions, not all principles and management practices can be applied across the board in the same way. It should be guided by and tailored to the hazards and risks established on a case by case basis and on the basis of the results of an environmental assessment in which site-specific variables, the assimilative capacity and sensitivity of the environment, and other site-specific factors, are taken into account (IFC, 2007). BMPs that improve performance will ultimately reduce some, if not most, of the risks associated with aquaculture.

The importance of BMPs in aquaculture, according to DEA (Hinrichsen, 2007) is from the perspective that:

- Aquaculture must be in compliance with all legal obligations;
- There is a need for resource protection and conservation;
- Resource use must be equitable, responsible and sustainable;
- The aquaculture sector must be recognized as environmentally responsible and sustainable;
- The aquaculture sector needs to provide independent norms and standards by which it can be held accountable; and
- The sector needs to illustrate adequate environmental due diligence.

BMP guidelines must therefore aim to:

- Be relevant to the nature of the aquaculture sector;
- Be practical and easily implementable;
- Provide options for management;
- Be flexible;
- Provide a mechanism for environmental self-regulation;
- Fall within the legal requirements for aquaculture development and operation (although it does not provide any exemption from legislative matters);
- Provide clear standards for performance and monitoring; and
- Be reviewed regularly and updated where relevant.

## 8.1 Development of Best Management Practices

Internationally, there has been much effort towards developing BMPs for various aquaculture species and productions systems (e.g. WWF, 2006; IFC, 2007; Tucker and Hargreaves, 2008; WWF, 2009; FTAD, 2010). This includes developing measurable and performance-based standards for responsible aquaculture and global standards, and certification programmes for accreditation and audit purposes (e.g. by the Food and Agriculture Organization of the United Nations (FAO), the Aquaculture Stewardship Council co-founded by the WWF, and the World Bank Group).

Standards are captured in formal documents that are approved and gazetted (and are therefore legally enforceable) by a recognized organization, authority or entity that provides, for common and repeated use, rules, guidelines or characteristics for products or related processes and production methods. Standards, when adopted, can help reassure buyers, retailers and consumers that the impacts related to aquaculture are minimized. Standards can also provide aquaculture industry stakeholders, as well as consumers, with the confidence that compliance with government and intergovernmental requirements has been achieved.

The credibility and effectiveness of BMPs and standards will increase greatly if stakeholders are involved in the development process (Boyd *et al.*, 2008a). It is therefore important to involve a variety of stakeholders from the start, including producers, scientists, aquaculture experts and representatives of communities situated near aquaculture farms.

In South Africa, commercial aquaculture is increasingly receiving greater emphasis. However, current shortcomings, according to Hinrichsen (2007) include limited awareness and understanding of aquaculture practices, including technologies and methods, and marketing and business principles and impacts (financial, social and environmental). Aquaculture is however viewed as a critical development issue and, as part of the South African government's "Operation Phakisa" initiative, is one of the priority focus areas for implementation. Generic BMPs that are available for freshwater aquaculture in South Africa are limited to the "Generic Environmental Best Management Practice Guideline for Aquaculture Development and Operation in the Western Cape" (Hinrichsen, 2007) while a review document of BMPs for Aquaculture in South Africa is also currently being developed (DAFF, 2017). There are however useful guideline reports (e.g. by the Rural Fisheries Programme at Rhodes University – RFP, 2010) that provide guidelines for freshwater aquaculture in South Africa. The "National Environmental Management Act, 1998 (Act No. 107 of 1998): Draft National Standards for Land-based Abalone Aquaculture" are an example of norms and standards for a marine species that have been developed (and have been gazetted for comment (Government Gazette no: 39971) to regulate the development, expansion and operation of land-based abalone aquaculture facilities at the coast.

Internationally there is a clear trend towards the development and establishment of various types of aquaculture BMPs and related codes of conduct and standards that are monitored and certificated by independent bodies (Bostock *et al*., 2010). These can be adjusted and adopted for use in the South African context (Table 14).

Table 14. International organisations and institutions (with website references) that are involved in the development of guidelines, BMPs and codes of conduct for responsible aquaculture.

| Institution | Website | Key focus |
|---|---|---|
| Aquaculture Stewardship Council (ACS) | https://www.asc-aqua.org/ | Standards for responsible aquaculture farming |
| Food Agriculture organisation of the United Nations (FAO) | www.fao.org/aquaculture | Code of conduct for responsible fisheries |
| Global Good Agriculture Practice (GLOBALG.A.P.) | http://www.globalgap.org/uk_en/for-producers/globalg.a.p./integrated-farm-assurance-ifa/aquaculture/ | Aquaculture certification |
| International Finance Corporation (IFC) | www.ifc.org | Environmental Health and Safety Guidelines for Aquaculture. |
| World Wildlife Fund (WWF) | http://www.worldwildlife.org | Principles and standards for responsible aquaculture, e.g. tilapia and trout. |

### 8.1.1 Key considerations and information required for developing BMPs

BMPs should inform freshwater aquaculture practices from the planning phase, through to rehabilitation as part of the decommissioning phase. In doing so, several categories of possible impacts should be considered.

Information to be considered and obtained in the development of BBPs for the different phases in aquaculture farming are summarised in Table 15 below (adapted from IFC, 2007; Boyd *et al*., 2008a-b).

Table 15. Information to be considered and obtained for the development of BMPs.

**Planning phase**

- General information: species to be farmed, total area in production, total annual production, value of production, size of the operation, employment opportunities, major milestones in terms of marketing and sales, future prospects, and climate information.
- Site specific information for individual farms:
    - Location
    - Significant features, i.e. terrain, soils, elevation, vegetation, proximity of other aquaculture facilities, likelihood of pollution from other land and water users; delineate natural and modified habitats; identify unique and protected areas; presence of red data species and unique populations
    - Aquaculture system (cages, ponds, raceways, RAS, etc.)
    - Area in production (size)
    - Source of water
    - Culture species (sterile or single sex organisms recommended)
    - Annual production volumes
    - Source of power supply for aquaculture operation.

**Construction phase**

- Soil erosion and sedimentation:
    - Extent of earth excavation and moving activities
    - Slope where construction is taking place
    - Bank stabilization measures
    - Construction of structures (e.g. weirs) for diversion / embankment of water
    - Preventative measures for soil erosion and siltation.

**Operational phase**

- Production system:
    - Description of production system
    - Quality of source water
    - Water use rate
    - Water intake and distribution
    - Water release – frequency, volume, quality
    - Retention time
    - Condition of facilities – maintenance of facilities, erosion control, general tidiness.
- Production methodology:
    - Species
    - Source of seed and stocking density
    - Fertilizers and liming materials – types, amounts, application frequency
    - Feed – type and protein, P and N content
    - Feeding – frequency, amount per day, method of application, amount per crop
    - Mechanical aeration – type of aerators, amount of aeration per pond, operating schedule
    - Water exchange – method of application, amount per day, use in response to water quality emergencies, total water use
    - Species health management (including information on the use of antibiotics and hormones)
    - Water quality management (e.g., copper sulphate, zeolite, sodium chloride) —doses, frequencies, methods of application
    - Use of particular approaches (e.g., sand filters) to minimize pollution and transmission of fish ova to receiving streams
    - Monitoring frequency to facilitate early detection of disease and / or other red flags
    - Harvest data—harvest method and harvest statistics.
- Effluents:
    - Annual volume and frequency of discharge
    - Average quality and maximum concentrations of nutrients, suspended solids, biochemical oxygen demand, dissolved oxygen, pH
    - Annual loads of N, P, TSS, and 5-day BOD
    - Treatment of effluent before final discharge
    - Conditions around final discharge point
    - Receiving waters – area, volume, flushing rate, quality, other users, other pollution sources

| |
|---|
| o Licence and permit conditions and monitoring.<br>• Miscellaneous:<br>o Use of pesticides<br>o Predator control method (e.g., nets to prevent piscivorous birds from eating stock)<br>o Storage of materials e.g., feeds, fertilizers, liming materials, fuels<br>o Waste disposal - mortalities, used oil, expired or unwanted chemicals, refuse, sewage<br>o Observations of surrounding environment - evidence of eutrophication or sedimentation in receiving water body, damage caused by improper waste disposal, ecological nuisances |
| **Rehabilitation and post closure** |
| • Design and implement mitigation measures to achieve no net loss of biodiversity where feasible for post operation restoration of habitats.<br>o Offset of losses through the creation of ecologically comparable area(s) managed for biodiversity. |

# 9 MONITORING

To ensure effective environmental management when it comes to aquaculture practices, a sound monitoring programme is required. Without monitoring, very little will be understood about the key environmental issues relevant to a given location or understanding of the effectiveness of any management interventions.

Here, it is important to emphasize that effective monitoring requires resources of many different types: trained personnel, equipment, analytical facilities and money. These requirements would apply both to the aquaculture producer and to the relevant authorities tasked with authorizing and approving the aquaculture operation. In the current situation, the regulatory authorities are hamstrung by lack of resources, so this monitoring requirement would require the authorities to expand their existing monitoring efforts and expertise.

Environmental and water resource monitoring programmes for freshwater aquaculture should therefore be designed and implemented with the aim to address all activities that have been identified to have potentially significant impacts on the receiving environment (IFC, 2007) and which should be aligned with BMPs. The frequency at which monitoring is conducted should be sufficient to provide representative data for the parameters being monitored. Monitoring should be conducted by suitably trained individuals using calibrated and maintained instruments. Data should be analysed frequently and appropriately and compared with the necessary guidelines and standards so that any necessary corrective actions can be taken timeously (Murray *et al*., 2010). Proper record keeping of data and information is equally important.

The type and frequency of monitoring required will be determined by applicable approvals, authorisations and licencing conditions (Hinrichsen, 2007).

## 9.1 Monitoring framework and requirements

The process to develop an appropriate, broad framework for all monitoring in relation to aquaculture activities is hampered by the sheer variety of the possible aquaculture activities, the different organisms intended for culture, the specific issues linked to the intended location of operations, and by the range of sizes of possible aquaculture operations. This matter is particularly problematic when considered at a strategic level – as addressed in this assessment – and the likely outputs in terms of a targeted monitoring system would be far too generic, and therefore ineffectual, to be of practical use to any proposed aquaculture operation.

A far more useful approach would be to specify the types of considerations that need to be borne in mind when considering the need for monitoring of aquaculture operations. In this way, the finer – and more practical – level of detail that would be needed for a monitoring programme could then be defined clearly during the screening and impact assessment phases for a specific proposed aquaculture operation. This approach would allow proper consideration to be given to the scale of the proposed operations, the characteristics of the intended site(s) for the operations, and the specific risks associated with the type(s) of organisms proposed for culture in the given location.

This approach would then also allow decisions to be taken to exempt particular types of aquaculture operations based, for example, on their size, proposed location, and low potential to cause negative impacts. In this way, proposed small-scale aquaculture operations that perhaps have a low to very low potential to cause negative impacts could be 'fast-tracked' for approval. Proposals to undertake larger and more complex aquaculture projects – with a much higher potential to cause negative impacts – could be processed via the routine environmental impact assessment (EIA) route. In both of the types of cases mentioned above, simple guidelines for best practice would inform the project proponents clearly on what activities (including any mandatory monitoring) would need to be undertaken by the proponent.

It is important to note that a sound environmental assessment of a particular project requires good (reliable) data. In order to ensure that good quality data are collected, standardised monitoring protocols and quality control and assurance procedures have to be followed both in the collection and analysis of the samples by trained personnel. These data should include sufficient background data on seasonal variations in water flows and water quality, the existing populations of aquatic biota, potential health threats posed to a proposed aquaculture operation by existing (upstream) water characteristics and uses, and information on other (downstream) water users and their sensitivities to specific water quality issues.

These data would then provide a clear planning framework for the proposed aquaculture operation during the planning, construction, operational and decommissioning phases of the project. In turn, it would allow the project proponent and local, provincial and national authorities to reach agreement as to precisely what parameters should be monitored, how often (frequently) monitoring should be carried out, and how (and by whom) the information will be used. Monitoring undertaken by the project proponent must be verified and aaudited by the relevant authority as required.

In those cases where the available data are judged to be insufficient to guide a firm decision as to whether or not a proposed aquaculture operation should be allowed to proceed, a decision can be taken to proceed with a project under a strict set of conditions that would require reasonably intensive monitoring both upstream and downstream of a facility. Where such monitoring revealed unacceptable levels of impacts caused by the operation, then remedial management actions could be set in place to reduce the negative impacts. Here, subsequent monitoring would provide crucial information as to the efficacy of the management actions. If these management actions yielded a sufficient improvement in the state of the operations, then monitoring could be reduced to a more practical level.

In those cases where a proposed aquaculture operation is considered to be small in area and isolated from other operations, it is likely that the impact of the operation would be localized and low. In contrast to such small operations, two possible scenarios could occur that might increase concerns about negative environmental impacts;

1. The first scenario relates to large-scale commercial aquaculture farms which, because of their large size, could have a greater risk of negative impacts. Despite this, large-scale aquaculture operations have ready access to a range of technologies that could mitigate or eliminate these risks. It is this category of large-scale aquaculture operations that a proper EIA process is needed and should be followed.

2. The second scenario occurs when a number of small-scale aquaculture operations are concentrated in a relatively small geographical area. Individually, each aquaculture operation may have very little impact and pose low to very low environmental risks.

However, in the second scenario, if each of the individual aquaculture operations is successful and profitable, their combined or aggregated impact could be expected to pose greater environmental risks and potentially lead to greater negative impacts than a single operation. In this type of situation, conventional

EIA processes are difficult to implement because each small farm may be judged to be too small to warrant a separate EIA of the operation. Here the EIA process would need to be adapted so that the cumulative or aggregated impacts of the individual aquaculture operations could be properly assessed.

The typical sets of parameters that would need to be considered for inclusion in a monitoring programme designed for a specific aquaculture operation would include:

- Seasonal variations in water flow of the source water to be used in the operation;
- Seasonal variations in the water quality of the source water and the potential risks to humans, the environment and aquaculture product quality posed by particular water quality variables in the source water;
- Volumes of water taken into the aquaculture operation;
- Volumes of effluent (or through-flow water) discharged from the operation;
- The quality of the water discharged from the operation, and the degree to which the quality parameters comply with specific water use and effluent discharge licence conditions;
- The efficacy of any water treatment process used to improve source water for use in the operation, or reduce high concentrations of specific water quality variables in the discharge water;
- The efficacy of all measures put in place to prevent the transfer of cultured organisms or their ova and offspring from the aquaculture operation to the natural environment;
- Water quality parameters within the aquaculture operation that have any positive or adverse impact on the viability and growth of the organisms being cultured; and
- The microbiological quality of the final product(s) produced by the aquaculture operation.

Where smaller operations have been aggregated or located close to one another, the monitoring programme could be adapted to consider the combined characteristics of the inflow water and effluent quality, as well as the quality of the product(s) produced by the grouped operations.

# 10 GAPS IN KNOWLEDGE

- One of the outputs of this project is spatial mapping of sensitive aquatic ecosystems. These maps are used in the Risk Assessment, to determine areas where there is high confidence that impacts to aquatic ecosystems associated with different aquaculture activities would be low. However, the accuracy of the spatial data used is in many cases limited by the scale at which the data are available, namely quaternary and sub-quaternary catchment level data, as well as the generally low levels of ground-truthing that have informed the collation of these data. A major shortcoming of the outputs of this desktop-based assessment is thus the lack of structured, consistent ground-truthing of any of the study areas. This means that sensitivity maps probably over-emphasise the extent of areas of High and Very High sensitivity. This constraint in data and information is an important one and can be addressed only by ground-truthing and the collection and collation of more accurate, verified data.
- NFEPA data are generally provided at the level of sub-quaternary catchments, with main stem rivers mapped at a scale of 1:500 000. However, the dataset is far from perfect, and the mapping and rating of wetland presence, extent and condition in particular, is problematic in many if not most areas. The data also considerably under-represent other watercourse types, such as the ephemeral water courses and their alluvial flood plains in drier areas of the country in particular (e.g. Northern Cape and parts of the Free State). Concerns have also been raised by some specialists in this field as to the accuracy of NFEPA data with regard to fish species distributions and river condition.

- Aquatic CBA data exist for all provinces except the Free State. In the case of Limpopo, North West, Northern Cape and Mpumalanga, the aquatic CBAs are however derived wholly from the NFEPA data, and for this reason, only NFEPA data were used for these provinces. In the Free State, CBAs do not include aquatic ecosystems, other than at the level of FEPA catchments and wetland clusters, with NFEPA data believed to considerably under-represent aquatic ecosystem extent in this area. More accurate aquatic CBAs are currently being finalised in this province but were not available in time for this assessment, and NFEPA data were thus used. Where more detailed provincial CBAs were produced, these data were used.
- Water quality data (especially parameters of importance in aquaculture effluents such as nutrients) would have been a valuable consideration in the sensitivity layers. However, the available data were spatially too sparse to be considered.
- Many of the data accessed in the sensitivity assessment are presented at sub-quaternary or even quaternary catchment level only, and there are some systems for which there are no data at all. Sensitivity rating in this study has taken a deliberately precautionary approach to addressing these issues. Thus some areas may be accorded a higher sensitivity than they actually warrant. A clear way forward is required from the relevant authorities with regards to addressing these existing data gaps.
- Fish data used in the sensitivity ratings comprised only taxa for which the status had been re-assessed during the 2017 IUCN South African Freshwater Fish Workshop. Provincial conservation agencies were approached for additional data regarding fish species distributions and/or other concerns. Of these, only the Mpumalanga Tourism and Parks Agency (MTPA) provided such data, indicating the general paucity of such information nationally.
- The effects of freshwater aquaculture on estuarine and marine ecosystems – changes in water quality as well as potential biodiversity changes as a result of escapee aquaculture species may affect estuarine and potentially even marine ecosystems downstream. Such effects are not considered in this study, but must be raised in the assessment as a whole.
- The potential risk that parasites, bacteria and other waste generated in aquaculture systems (e.g. antibiotics, hormones) pose to human health, especially downstream water users, was not considered in this study and was taken into consideration in the Socio-Economic and Human Health related study.
- This study focused on <u>inland surface water resources</u> and no specific consideration was given to the potential impact on groundwater and groundwater dependent ecosystems, as well as estuaries and marine ecosystems even though it is clear that freshwater aquaculture activities in close proximity to these resources, may have significant impacts and profound ecological implications for these ecosystems.
- Terrestrial ecosystems, the biota and flora of importance in these ecosystems, as well as the sensitivity of these ecosystems in terms of, for instance, soil erosion potential, have not been considered as part of this study. These and several other aspects related to terrestrial ecosystems should be taken into account during site selection and the selection of aquaculture production systems.
- The target aquaculture species (with the exception of the African sharptooth catfish and Mozambique tilapia) are alien invasive species that pose a biosecurity risk should they escape or are introduced into freshwater ecosystems. It is therefore important that native fish and crustacean species are rather considered for aquaculture where possible before introducing non-native species.
- In South Africa, geographic data on invasive and alien species such as the marron crayfish, trout and Nile tilapia refer largely to the distribution of the species and no information is available on their abundance at these locations. This information is important to develop a clear understanding of the extent of their current impact and potential future impact.

- Despite the recognition that high prevalence and abundance of introduced parasites and diseases pose significant threats to native fish communities in South Africa, studies have thus far failed to highlight population-level impacts.

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| | |
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# 12 REFERENCES

Amer, O.S.A. 2014. The impact of fish parasites on human health. A review article. Journal of the Egyptian Society of Parasitology, 44(1): 249-274.

Anras, I., Boglione, c. Cataudella, S. Dinis, M.T., Livi, S., Makridis, P., Mario, G., Ramalho, A. and Yufera, M. 2012. The current status of extensive and semi-intensive aquaculture practices in Southern Europe. *Aquaculture Europe*, 35(**2**): 12-16.

Ashton, P.J. and Haasbroek, B.J.J. 2001. Water demand management and social adaptive capacity: A South African case study. In: A.R. Turton and R. Henwood (eds), *Hydropolitics in the Developing World: A Southern African Perspective*. African Water Issues Research Unit (AWIRU) and International Water Management Institute (IWMI), Pretoria. 21 pages.

Asmal, K. 1998. Water as a metaphor for governance: Issues in the management of water resources in Africa. *Water Policy,* 1: 95-101.

Avenant-Oldewage, A. 1993. Occurrence of *Temnicephala chaeropsis* on *Cherax tenuimanus* imported into South Africa, and notes on its infestation of an indigenous crab. *Suid-Afrikaanse Tydskrif vir Wetenskap*, 89: 427-428.

Beardmore, J.A., Mair, G.C. and Lewis, R.I. 1997. Biodioversity in aquatic systems in relation to aquaculture. *Aquaculture Research*, 28: 829-839.

Beveridge, M. 2004. *Cage Aquaculture*. Third Edition. Blackwell Publishing. 368 pages.

Basson, M.S., van Niekerk, P.H. and van Rooyen, J.A. 1997. *Overview of Water Resources Availability and Utilisation in South Africa*. DWAF Report No. P RSA/00/0197. Department of Water Affairs and Forestry and BKS (Pty) Ltd., Pretoria, South Africa.

Beardmore, J.A., Mair, G.C. and Lewis, R.I. 1997. Biodioversity in aquatic systems in relation to aquaculture. *Aquaculture Research*, 28: 829-839.

Bergheim, A. and Brinker, A. 2003. Effluent treatment for flow through systems and European Environmental Regulations. *Aquacultural Engineering*, 27: 61-77.

Bostock, J., McAndrew, B., Richards, R., Jauncey, K., Telfer, T., Lorenzen, K., Little, D., Ross, L., Handisyde, N., Gatward, I. and Corner, R. 2010. Aquaculture: global status and trends. *Philosophical Transactions of the Royal Society*, 365: 2897-2912.

Boyd, C.E. 2003. Guidelines for aquaculture effluent management at the farm-level. *Aquaculture*, 226: 101-112.

Boyd, C.E. and McNevin, A.A. 2015. *Aquaculture, Resource Use, and the Environment*. John Wiley and Sons, New Jersey. 366 pages.

Boyd, C.E., Lim, C., Queiroz, J., Salie, K., de Wet, L. and McNevin, A. 2008a. *Best Management Practices for Responsible Aquaculture*. In: USAID/Aquaculture Collaborative Research Support Program. Corvallis, Oregon: Oregon State University. 47 pages.

Boyd, C.E., Zajicek, P.W., Hargreaves, J.A. and Jensen, G.L. 2008b. Development, implementation, and verification of better management practices for aquaculture. In: Tucker, C.S. and Hargreaves, J.A. (eds). *Environmental Best Management Practices for Aquaculture*. Blackwell Publishing, Oxford, UK. 595 pages.

Cambray, J.A. 2003. The global impact of alien trout species—a review; with reference to their impact in South Africa., *African Journal of Aquatic Science*, 28:(1) 61-67, DOI: 10.2989/16085914.2003.9626601.

Cambray, J.A. and van der Waal, B.C.W. 2006. Dutch domesticated *Clarias* with mixed genetic background now used in aquaculture in South Africa, with unpredictable consequences for biodiversity*. African Journal of Aquatic Science*, 31(1): 151-153.

Cambray J, Swartz, E. 2007. *Oreochromis mossambicus*. In: IUCN 2012 IUCN Red List of Threatened Species Version .20122. htpp://www.iucnredlist.org. Accessed: 15/01/2018.

Canonico, G.C., Arthington, A., McCrary, J.K. and Thieme, M.L. 2005. The effects of introduced tilapia on native biodiversity. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 15:463-483.

Chakona, A. 2017. *Galaxias sp. nov. 'Riviersonderend'*. Red List of South African Species. South African Biodiversity Institute. http://speciesstatus.sanbi.org/assessment/last-assessment/3623/. Downloaded on 18 August 2019.

Chakona, A. and Jordaan, M. 2017. *Galaxias sp. nov. 'Breede'*. Red List of South African Species. South African Biodiversity Institute. http://speciesstatus.sanbi.org/assessment/last-assessment/3618/. Downloaded on 18 August 2019.

Chakona, A., Jordaan, M., Kadye, W.T. and Van der Walt, R. 2017. *Pseudobarbus skeltoni*. Red List of South African Species. South African Biodiversity Institute. http://speciesstatus.sanbi.org/assessment/last-assessment/3617/. Downloaded on 18 August 2019.

Chakona, A. 2018a. *Enteromius amatolicus*. Red List of South African Species. South African Biodiversity Institute. http://speciesstatus.sanbi.org/assessment/last-assessment/3559/. Downloaded on 18 August 2019.

Chakona, A. 2018b. *Enteromius pallidus*. Red List of South African Species. South African Biodiversity Institute. http://speciesstatus.sanbi.org/assessment/last-assessment/3564/. Downloaded on 18 August 2019.

Chakona, A. 2018c. *Pseudobarbus trevelyani*. Red List of South African Species. South African Biodiversity Institute. http://speciesstatus.sanbi.org/assessment/last-assessment/3532/. Downloaded on 18 August 2019.

Chakona, A. 2018d. *Sandelia capensis*. Red List of South African Species. South African Biodiversity Institute. http://speciesstatus.sanbi.org/assessment/last-assessment/3553/. Downloaded on 19 August 2019.

Chakona, A. and Bills, R. 2018. *Labeo rubromaculatus*. Red List of South African Species. South African Biodiversity Institute. http://speciesstatus.sanbi.org/assessment/last-assessment/3570/. Downloaded on 18 August 2019.

Chakona, A., Sifundza , D. and Kadye, W.T. 2018. *Sandelia bainsii*. Red List of South African Species. South African Biodiversity Institute. http://speciesstatus.sanbi.org/assessment/last-assessment/3552/. Downloaded on 18 August 2019.

Chen, L., Qian, P-Y. 2017. Review on molecular mechanisms of anti-fouling compounds: An update since 2012. *Marine drugs*, 15: 264; doi:10.3390/md15090264. Available online: www.mdpi.com/journal/marinedrugs.

Ciruna, K.A., Meyerson, L.A. and Gutierrez, A. 2004. *The Ecological and Socio-economic Impacts of Invasive Alien Species in Inland Water Ecosystems.* Report to the Convention on Biological Diversity on behalf of the Global Invasive Species Programme, Washington, D.C. pp. 34.

Clay, J.W. 2008. The role of better management practices in environmental management. In: Tucker, C.S. and Hargreaves, J.A. (eds), *Environmental Best Management Practices for Aquaculture*. Blackwell Publishing, Oxford, UK. 595 pages.

Dallas, H.F. and Day, J.A. 2004. *The Effects of Water Quality Variables on Riverine Biotas*. WRC Technical Report No. TT 224/04. Water Research Commission, Pretoria, South Africa.

De Moor, I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science,* 27:2:125-139, DOI: 10.2989/16085914.2002.9626584.

De Moor, F.C., Wolkinson, R.C., and Herbst, H.M. 1986. Food and feeding habits of *Oreochromis mossambiccus* (Peters) in hypertrophic Hartbeespoort Dam, South Africa. *South African Journal of Zoology*, 21(**2**): 170-176.

Department of Agriculture Forestry and Fisheries (DAFF) 2012a. *Draft Biodiversity Risk and Benefit Assessment (BRBA): African sharptooth catfish (Clarias gariepinus)*. Prepared by Anchor Environmental Consultants for DAFF, Pretoria. 25 pages.

Department of Agriculture Forestry and Fisheries (DAFF) 2012b. *Draft Biodiversity Risk and Benefit Assessment (BRBA): Brown trout (Salmo trutta).* Prepared by Anchor Environmental Consultants for DAFF, Pretoria. 23 pages.

Department of Agriculture Forestry and Fisheries (DAFF) 2012c. *Draft Biodiversity Risk and Benefit Assessment (BRBA): Marron crayfish (Cherax tenuimanus)*. Prepared by Anchor Environmental Consultants for DAFF, Pretoria. 22 pages.

Department of Agriculture Forestry and Fisheries (DAFF) 2012d. *Draft Biodiversity Risk and Benefit Assessment (BRBA): Nile tilapia (Oreochromis niloticus)*. Prepared by Anchor Environmental Consultants for DAFF, Pretoria. 24 pages.

Department of Agriculture Forestry and Fisheries (DAFF) 2012e. *Draft Biodiversity Risk and Benefit Assessment (BRBA): Rainbow trout (Oncorhynchus mykiss)*. Prepared by Anchor Environmental Consultants for DAFF, Pretoria. 25 pages.

Department of Agriculture Forestry and Fisheries (DAFF) 2013. *Legal guide for the aquaculture sector in South Africa.* First Edition: September 2013. DAFF, Pretoria.100 pages.

Department of Agriculture Forestry and Fisheries (DAFF) 2016. *Aquaculture Yearbook 2016. South Africa.* Compiled by the Directorate: Aquaculture Technical Services, Fisheries Management Branch, DAFF. ISBN: 978-0-621-46172-5. 116 pages.

Department of Agriculture Forestry and Fisheries (DAFF) 2017. *Feasibility of Aquaculture Species in South Africa: Literature and Best Practices Review (Draft)*. Prepared by Urban-Econ Development Economists. DAFF, Pretoria. 117 pages.

Department of Economic Development, Environmental Affairs and Tourism (DEDEAT). 2017. *Draft Revision of the Eastern Cape Biodiversity Conservation Plan: CBA map criteria layers*.

Department of Environmental Affairs (DEA) 2011. *South Africa's Second National Communication under the United Nations Framework Convention on Climate Change*. Department of Environmental Affairs, Pretoria.

Department of Water Affairs (DWA) 2012. *The Annual National State of Water Resources Report – October 2011 to September 2012*. Department of Water Affairs, Pretoria, South Africa.

Department of Water Affairs and Forestry (DWAF) 1986. *Management of the Water Resources of South Africa*. Department of Water Affairs and Forestry, Pretoria, South Africa.

Department of Water Affairs and Forestry (DWAF) 1996. *South African Water Quality Guidelines. Volume 6: Agricultural Water Use: Aquaculture*. Department of Water Affairs and Forestry, Pretoria. 185 pages.

Department of Water Affairs and Forestry (DWAF) 1997. *White Paper on a National Water Policy for South Africa*. Department of Water Affairs and Forestry, Pretoria. 37 pages.

Department of Water Affairs and Forestry (DWAF) 1998a. *A Strategic Plan for the Department of Water Affairs and Forestry for the Implementation of Catchment Management in South Africa: A discussion paper*. Department of Water Affairs & Forestry, Pretoria. January 1998.

Department of Water Affairs and Forestry (DWAF) 1998b. *A New Approach to Water Pricing in South Africa: Discussion document for public debate*. Department of Water Affairs & Forestry, Pretoria. January 1998.

Department of Water Affairs and Forestry (DWAF) 1998c. *Proposed Strategy for Charges for Raw Water Use in Terms of Section 56(1) of the National Water Act, 1998 (Act No 36 of 1998): Discussion document for public debate*. Government Gazette, December 1998, Pretoria. 24 pages.

Department of Water Affairs and Forestry (DWAF) 1999a. *The Water Conservation and Demand Management National Strategy Framework*. Department of Water Affairs & Forestry, Pretoria. 36 pages.

Department of Water Affairs and Forestry (DWAF) 1999b. *Map of Proposed Water Management Areas in South Africa* (1:1 500 000 map). Department of Water Affairs & Forestry, Pretoria.

Department of Water and Sanitation (DWS) 2014. *A Desktop Assessment assessment of the Present Ecological State, Ecological Importance and Ecological Sensitivity per sub-Quaternary Reaches for Secondary Catchments in South Africa. Secondary: [W5] (example).* Compiled by RQIS-RDM: https://www.dwa.gov.za/iwqs/rhp/eco/peseismodel.aspx Accessed on 9 February 2016.

Driver, A., Desmet, P., Rouget, M., Cowling, R. and Maze, C. 2003. *Succulent Karoo Ecosystem Plan Biodiversity Component*. Technical Report. Cape Conservation Unit, Report No CCU 1/03. Botanical Society of South Africa.

Driver, A., Maze, K., Rouget, M., Lombard, A.T., Nel, J.L., Turpie, J.K., Cowling, R.M., Desmet, P., Goodman, P., Harris, J., Jonas, Z., Reyers, B., Sink, K. and Strauss, T. 2005. National spatial biodiversity assessment 2004: Priorities for biodiversity conservation in South Africa. *Strelitzia*, 17, 1–45.

Driver, A., Sink, K.J., Nel, J.N., Holness, S., Van Niekerk, L., Daniels, F., Jonas, Z., Majiedt, P.A., Harris, L. and Maze, K. 2011. *National Biodiversity Assessment. 2011: An assessment of South Africa's biodiversity and ecosystems. Synthesis report.* South African National Biodiversity Institute and Department of Environmental Affairs, Pretoria. 200 pages.

Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z-I., Knowler, D.J., Lévêque, C., Naiman, R.J., Prieur-Richard, A-H., Soto, D., Stiassny, M.L.J. and Sullivan, C.A. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Review*, 81: 163-182.

Du Preez, L. and Smit, N. 2013. Double blow: Alien crayfish infected with invasive temnocephalan in South African waters. *African Journal of Science,* 109(9/10):1-4.

Ellender, B.R., Chakona, A. and Weyl, O. 2017. *Pseudobarbus sp. nov. 'keiskamma'*. Red List of South African Species. South African Biodiversity Institute. http://speciesstatus.sanbi.org/assessment/last-assessment/3641/. Downloaded on 18 August 2019.

Ellender, B.R., Wasserman, R.j., Chakona, A., Skelton, P.H. and Weyl, O.L.F. 2017. A review of the biology and status of Cape Fold Ecoregion freshwater fishes. *Aquatic Conservation, Marine and Freshwater Ecosystems*, 27(**4**): 867-879.

Ellender, B.R., Woodford, D.J. and Weyl, O.L.F. 2015. The invasibility of small headwater streams by an emerging invader, *Clarias gariepinus*. *Biological Invasions*, 17(1): 57-61.

Ellender, B.R. and Weyl, O.L.F. 2014. A review of current knowledge, risk and ecological impacts associated with non-native freshwater fish introductions in South Africa. *Aquatic Invasions*, 9(**2**): 117-132.

FAO 2005-2012. *Cultured Aquatic Species Information Programme*. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 18 February 2005.

Firmat, C., Alibert, P., Losseau, M., Baroiller, J.-F and Schliewen, U.K. 2013. Successive invasion-mediated interspecific hybridizations and population structure in the endangered cichlid *Oreochromis mossambicus*. *Plos One* 8: 1-1. http://dx.doi.org/10.1371/journal.pone.0063880.

Freshwater Trout Aquaculture Dialogue (FTAD) 2010. *Draft Standards for Environmentally and Socially Responsible Trout Farming*. World Wildlife Fund (WWF) Inc.

Garrow, C. and Marr, S. 2012. *Swimming on the Edge of extinction. The perilous state of the indigenous freshwater fish of the Western Cape*. NISC, Cape Town. 94 pages.

GDARD 2014. *Technical Report for the Gauteng Conservation Plan (Gauteng C-Plan v3.3)*. Gauteng Department of Agriculture and Rural Development: Nature Conservation Directorate. 60 pages.

Grizzetti, B., Lanzanova, D., Liquete, C. Reynaud, A. and Cardoso, A.C. 2016. Assessing water ecosystem services for water resource management. *Environmental Science and Policy*, 61: 194-203.

Harris, J. and Haasbroek, B.J.J. 1999. *Water Demand Management: South Africa case study*. Contract report to the IUCN Regional Office for Southern Africa (IUCN-ROSA), Harare. Division of Water, Environment & Forestry Technology, Pretoria, CSIR. 104 pages.

Hinrichsen, E. 2007. *Generic Environmental Best Practice Guideline for Aquaculture Development and Operation in the Western Cape: Edition 1*. Division of Aquaculture, Stellenbosch University Report. Republic of South Africa, Provincial Government of the Western Cape, Department of Environmental Affairs and Development Planning, Cape Town. 65 pages.

Huntington, T.C., Roberts, H., Cousins, N., Pitta, V., Marchesi, N., Sanmamed, A., Hunter-Rowe, T., Fernandes, TF., Tett, P., McCue, J. and Brockie, N. 2006. *Some Aspects of the Environmental Impact of Aquaculture in Sensitive Areas*. Report to the DG Fish and Maritime Affairs of the European Commission. Report no.: 221-EC/R/02/B. Hampshire, United Kingdom. 305 pages.

Impson, D., Jordaan, M. and Van der Walt, R. 2017. *Pseudobarbus capensis*. Red List of South African Species. South African Biodiversity Institute. http://speciesstatus.sanbi.org/assessment/last-assessment/3526/. Downloaded on 18 August 2019.

International Finance Corporation (IFC) 2007. *Environmental, Health, and Safety Guidelines: Aquaculture*. World Bank Group, New York.

Jackson, M.C., Woodford, D.J., Bellingan, T.A., Weyl. O.L.F., Potgieter, M.J., Rivers-Moore, N.A., Ellender, B.R., Fourie, H.E. and Chimimba, C.T. 2016. Trophic overlap between fish and riparian spiders: potential impacts of an invasive fish on terrestrial consumers. *Ecology and Evolution*, 6(6): 1745-1752.

Jegatheesan, V., Shu, L. and Visvanathan, C. 2011. Aquaculture Effluent: Impacts and remedies for protecting the environment and human health. In: Nriagu, J. (ed). *Encyclopedia of Environmental Health*. Elsevier Science, Burlington, Vt., pp.123-135.

Job, N., Snaddon, C.D., Nel, J., Smith-Adao, L and Day, E. 2008. C.A.P.E. fine-scale planning project: Aquatic ecosystems of the Saldanha - Sandveld planning domain. Report submitted to Cape Nature, November 2008, 52 pp + appendices. Cape Town, South Africa.

Jordaan, M., Van der Walt, R., Swartz, E.R. and Impson, D. 2017. *Pseudobarbus burgi.* Red List of South African Species. South African Biodiversity Institute. http://speciesstatus.sanbi.org/assessment/last-assessment/3634/. Downloaded on 18 August 2019.

Jordaan, M. and Chakona, A. 2018. *Pseudobarbus sp.nov.'breede'*. Red List of South African Species. South African Biodiversity Institute. http://speciesstatus.sanbi.org/assessment/last-assessment/561/. Downloaded on 18 August 2019.

Kellerman, L. 2017. *Project Description. Strategic Environmental Assessment for Aquaculture Development in South Africa.* Department of Environmental Affairs, Department of Agriculture, Forestry and Fisheries and Operation Phakisa. 36 pages.

Kimberg, P.K., Woodford, D.J., Weyl, O.L.F., Hui, C., Richardson, D.M., Msezane, T.P., van der Walt, K.A., Swartz, E.R., Chimimba, C.T. Zengeya, T. and Ellender, B.R. 2014. *Understanding the Unintended Spread and Impact of Alien Invasive Fish Species – Development of Management Guidelines for South African Inland Waters*. WRC Report No.: 2039/1/14. Water Research Commission, Pretoria. 130 pages.

Kleynhans, C.J., Louw, M.D., Thirion, C., Rossouw, N.J., and Rowntree, K. 2005a. *River EcoClassification: Manual for EcoStatus determination (Version 1).* Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. KV 168/05.

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

Le Maitre, D.C., Versfeld, D.B. and Chapman, R.A. 2000. The impact of invading alien plants on surface water resources in South Africa: A preliminary assessment. *Water SA*, 26(3): 397-408.

Maake, P. 2017. *Marcusenius caudisquamatus*. Red List of South African Species. South African Biodiversity Institute. http://speciesstatus.sanbi.org/assessment/last-assessment/3628/. Downloaded on 18 August 2019.

Marr, S., Hoffman, A. and Bills, R. 2018. *Labeo ruddi*. Red List of South African Species. South African Biodiversity Institute. http://speciesstatus.sanbi.org/assessment/last-assessment/3571/. Downloaded on 18 August 2019.

Marr, S.M., Ellender, B.R., Woodford, D.J., Alexander, M.E., Wasserman R.J., Ivey, P., Zengeya, T. and Weyl, O.L.F. 2017. Evaluating invasion risk for freshwater fishes in South Africa. Bothalia – *African Biodiversity and Conservation,* 47(2), a2177. https://doi.org/10.4102/abc.v47i2.2177.

Martinez-Porchas, M. and Martinez-Cordova, L.R. 2012. World Aquaculture: Environmental impacts and troubleshooting alternatives. *The Scientific World Journal*, Article ID 389623: 1-9.

Midgley, D.C., Pitman, W.V. and Middleton, B.J. 1994. *The Surface Water Resources of South Africa 1990 (WR90)*. Water Research Commission, Pretoria, South Africa.

Murray, K., Dabrowski, J., Hill, L., du Preez, M., Kadiaka, M. and Strydom, W. 2010. *Water Quality Data and Information: A communicator's manual*. Water Research Commission (WRC) Report No.: TT 394/10. WRC, Pretoria. 98 pages.

National Marine Fisheries Service (NMFS) 2002. *A Code of Conduct for Responsible Aquaculture Development in the U.S. Exclusive Economic Zone*. United States of America. 44 pages.

Nel, J.L, Murray, K.M., Maherry, A.M., Petersen, C.P., Roux, D.J., Driver, A., Hill, L., van Deventer, H., Funke, N., Swartz, E.R., Smith-Adao, L.B., Mbona, N., Downsborough, L. and Nienaber, S. 2011. *Technical Report for the National Freshwater Ecosystem Priority Areas Project*. WRC Report No. 1801/2/11. Water Research Commission, Pretoria. 150 pages.

Nunes, A.L., Douthwaite, R.J, Tyser, B., Measey, G.J. and Weyl, O.L.F. 2016. Invasive crayfish threaten Okavango Delta. *Frontiers in Ecology and the Environment*, 14:237–238.

Nunes, A.L., Zengeya, T.A., Measy, G.J. and Weyl, O.L.F. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science*, 42(4): 309-323.

O,Brien, G., Kubheka, S., Craigie, J. and Evans, S.W. 2017. *Ctenopoma multipine*. Red List of South African Species. South African Biodiversity Institute. http://speciesstatus.sanbi.org/assessment/last-assessment/576/. Downloaded on 18 August 2019.

Ollis, D.J., Snaddon, C.D., Job, N.M. and Mbona, N. 2013. Classification System for Wetlands and other Aquatic Ecosystems in South Africa. User Manual: Inland Systems. *SANBI Biodiversity Series* 22. South African National Biodiversity Institute, Pretoria.

Otter, L., Olago, D.A. and Niang, I. (eds) 2007. *Global Change Processes and Impacts in Africa: A Synthesis*. East African Publishers Limited.

Peeler, E. and Feist, S. 2011. Human intervention in freshwater ecosystems drives disease emergence. *Freshwater Biology,* 56: 705–71.

Phillips, M.J. and Subasinghe, R.P. 2008. Application of risk analysis to environmental issues in aquaculture, pp. 101–119. In: M.G. Bondad-Reantaso, J.R. Arthur and R.P. Subasinghe (eds). *Understanding and Applying Risk Analysis in Aquaculture*. FAO. Fisheries and Aquaculture Technical Paper No. 519. FAO, Rome.

Picker, M.D. and Griffiths, C.L. 2011. *Alien and Invasive Animals – A South African Perspective*. Randomhouse/Struik, Cape Town, South Africa. 240 pages.

Pillay, T.V.R. 2004. *Aquaculture and the Environment*. Blackwell Publishing, United Kingdom. 206 pages.

Pitman, W.V. 2011. Overview of water resource assessment in South Africa: Current state and future challenges. *Water SA*, 37(5): 659-664.

Pool-Stanvliet, R., Duffell-Canham, A., Pence, G. and Smart, R. 2017. *The Western Cape Biodiversity Spatial Plan Handbook.* Cape Nature, Stellenbosch.

Rana, K.J. 2010. *Critical Review and Analysis of the Current Aquaculture Regulatory Framework in the Republic of South Africa in Relation to International Benchmarks*. Department of Economic Development and Tourism, Western Cape Government. 105pp.

Reizenberg, J-L., Bloy, L.E., Weyl, O.L.F., Shelton, J.M. and Dallas, H.F. 2018. Variation in thermal tolerances of native freshwater fishes in South Africa's Cape Fold Ecorgion: examining the east-west gradient in species' sensitivity to climate warming. *Journal of Fish Biology*, 94:103-112.

Republic of South Africa 1998. *The National Water Act (Act 36 of 1998)*. Government Printers, Pretoria. 75 pp.

Resh, V.H., Brown, A.V., Covich, A.P., Gurtz, M.E., Li, H.W., Minshal, G.W., Reice, S.R., Sheldon, A.L., Wallace, B.J. and Wissmar, R.C. 1988. The role of disturbance in stream ecology. *Journal of the North American Benthological Society,* 7(4): 433-455.

Ricciardi, A. 2007. Are modern biological invasions an unprecedented form of global change? *Conservation Biology,* 21: 329-336.

Roodt-Wilding, R., Swart, B.L. and Impson, N.D. 2010. Genetically distinct Dutch-domesticated *Clarias gariepinus* used in aquaculture in southern Africa. *African Journal of Aquatic Science,* 35(3): 241-249.

Roux, D.J., Nel, J.L., MacKay, H.M. and Ashton, P.J. 2006. *Discussion Paper on Cross-sector Policy Objectives for Conserving South Africa's Inland Water Biodiversity*. WRC Report No. 1801/2/11. Water Research Commission, Pretoria.

Roux, F. and Hoffman, A. 2017a. *Chetia brevis*. Red List of South African Species. South African Biodiversity Institute. http://speciesstatus.sanbi.org/assessment/last-assessment/3536/. Downloaded on 18 August 2019.

Roux, F. and Hoffman, A. 2017b. *Enteromius treurensis*. Red List of South African Species. South African Biodiversity Institute. http://speciesstatus.sanbi.org/assessment/last-assessment/3531/. Downloaded on 18 August 2019.

Roux, F. and Hoffman, A. 2017c. *Kneria sp. nov. 'South Africa'*. Red List of South African Species. South African Biodiversity Institute. http://speciesstatus.sanbi.org/assessment/last-assessment/3599/. Downloaded on 18 August 2019.

Roux, F. and Hoffman, A. 2018. *Chiloglanis emarginatus*. Red List of South African Species. South African Biodiversity Institute. http://speciesstatus.sanbi.org/assessment/last-assessment/3592/. Downloaded on 18 August 2019.

Rowlston, W. 2011. Water law in South Africa: From 1652 to 1998 and beyond. In: King, J.M. and Pienaar, H. (eds). *Sustainable Use of South Africa's Inland Waters.* WRC Report No TT 491/11, Water Research Commission, Pretoria.

Rural Fisheries Programme (RFP) 2010. *A Manual for Rural Freshwater Aquaculture*. Rural Fisheries Programme, Department of Ichthyology and Fisheries Science, Rhodes University. Water Research Commission Report No.: TT 463/P/10. 93 pages.

Schulze, R.E. 2011. Climate proofing the South African water sector 2: An initial study on practical suggestions for adaptation to climate change. In: Schulze, R.E. 2011. *A 2011 Perspective on Climate Change and the South African Water Sector*. WRC Report 1843/2/12, Z, Chapter 9.3, 309-364. Water Research Commission, Pretoria, South Africa.

Science for Environment Policy 2015. *Sustainable Aquaculture*. Future Brief 11. Brief produced for the European Commission DG Environment by the Science Communication Unit, UWE, Bristol. Available at: http://ec.europa.eu/science-environment-policy.

Serpa, D. and Duarte, P. 2008. Impacts of aquaculture and mitigation measures. *Dynamic Biochemistry, Process Biotechnology and Molecular Biology*, 2 (special issues 1): 1-20.

Shelton, J.M., Samways, M.J. and Day, J.A. 2014. Predatory impact of non-native rainbow trout on endemic fish populations in headwater streams in the Cape floristic region in South Africa. *Biological Invasions*, 17:365-379, DOI 10.1007/s10530-014-0735-9.

Shelton, J.M., Samways, M.J. and Day, J.A. 2015a. Non-native rainbow trout change the structure of benthic communities in headwater streams of the Cape Floristic Region, South Africa. *Hydrobiologia*, 745: 1-15.

Shelton, J.M., Samways, M.J. and Day, J.A. 2015b. Predatory impact of non-native rainbow trout on endemic fish populations in headwater streams in the Cape Floristic Region of South Africa. *Biological Invasions*, 17: 365-379.

Shipton, T.A. and Hecht, T. 2013. Economic, regulatory and legal review of feed management practices. In: Hasan, M.R. and New, M.B. (eds), *On-farm Feeding and Feed Management in Aquaculture*. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. pp. 565–585.

Smakhtin, V., Ashton, P.J., Batchelor, A., Meyer, R., Maree, J.P., Murray, R., Barta, B., Bauer, N., Terblanche, D. and Olivier, J. 2001. Unconventional water supply options in South Africa: Possible solutions or intractable problems? *Water International*, 26(3): 314-334.

Snyman-van der Walt, L. 2017. *Phase 2 Output Report: Identification of Strategic Aquaculture Areas. Strategic Environmental Assessment for Aquaculture in South Africa*. Department of Environmental Affairs, Department of Agriculture, Forestry and Fisheries and Operation Phakisa. 27 pages.

Soto, D., Aguilar-Manjarrez, J. and Hishamunda, N. (eds.). 2007. *FAO Fisheries and aquaculture proceedings. Building an ecosystem approach to aquaculture*. FAO/Universitat de les Illes Balears Expert Workshop. 7-11 May 2007. Palma de Mallorca, Spain.

StatsSA 2017. Mortality and Causes of Death in South Africa 2015: Findings from death notification P0309 3 Pretoria.

Stuart-Hill, S., Schulze, R.E. and Colvin, J. 2012. *Handbook on Adaptive Management Strategies and Options for the Water Sector in South Africa Under Climate Change.* WRC Report No. 1843/2/12. Water Research Commission, Pretoria.

Tavakol, S., Luus-Powell, W.J., Smit, W.J., Baker, C., Hoffman, A. and Halajian, A. 2016. First introduction of two Australian Temnocephalan species into Africa with an alien host: Double trouble. *Journal of Parasitology*, 102(6), 653-658.

Tucker, C.S. and Hargreaves, J.A. (eds). (2008) *Environmental Best Management Practices for Aquaculture*. Blackwell Publishing, Oxford, UK. 595 pages.

Tweddle, D., Bills, R., Swartz, E., Coetzer, W., Da Costa, L., Engelbrecht, J., Cambray, J., Marshall, B., Impson, D., Skelton, P.H*, et al*. 2009: *The status and distribution of freshwater fishes*. *In*: *The Status and Distribution of Freshwater Biodiversity in Southern Africa.* Edited by Darwall, W.R.T., Smith, K.G., Tweddle. D. and Skelton, P,H. IUCN and South African Institute for Aquatic Biodiversity; 2009:21-37.

Van der Waal, B.C.W. and Bills, R. 2000. *Oreochromis niloticus* (Teleostei: Cichlidae) now in the Limpopo River systems. *South African Journal of Science*, 96: 47-48.

Weyl, O.L.F. 2008. Rapid invasion of a sub-tropical lake fishery in central Mozambique by Nile tilapia, *Oreochromis niloticus* (Pisces: Cichlidae). *Aquatic Conservation: Marine and Freshwater Ecosystems*, 18: 839-851.

Weyl, O.L.F., Daga, V.s., Elender, B.R. and Vitule, J.R.S. 2016. A review of *Clarias gariepinus* invasions in Brazil and South Africa. *Journal of Fish Biology*, 89(1): 386-402.

Woodford, D.J. and Impson, N.D. 2004. A preliminary assessment of the impact of alien rainbow trout (*Oncorhynchus mykiss*) on indigenous fishes of the upper Berg River, Western Cape Province, South Africa. *African Journal of Aquatic Science*, 29(1): 107-111.

World Wildlife Fund (WWF). 2006. *Principles for responsible tilapia aquaculture*. http://www.worldwildlife.org.

World Wildlife Fund (WWF). 2009. International Standards for responsible tilapia aquaculture. http://www.worldwildlife.org.

World Wildlife Fund (WWF). 2016. *Water: Facts and Futures. Re-thinking South Africa's Water Future*. WWF, Cape Town. 100 pages.

Zengeya, T.A., Booth, A.J., Bastos, A.D.S. and Chimimba, C.T. 2011.Trophic interrelationships between exotic Nile tilapia, *Oreochromis niloticus* and indigenous tilapiine cichlids in a subtropical African river system (Limpopo River, South Africa). *Environmental Biology of Fishes*, 92:479-489.

Zengeya, T.A., Robertson, M.P., Booth, A.J. and Chimimba, C.T. 2013. A qualitative ecological risk assessment of the invasive Nile tilapia, *Oreochromis niloticus* in a sub-tropical African river system (Limpopo River, South Africa). *Aquatic Conservation: Marine and Freshwater Ecosystems*, 23: 51-64. *Environmental Biology of Fishes*, 92: 479-489.

Zengeya, T., Ivey, P., Woodford, D.J., Weyl, O., Novoa, a., Schackleton, R., Richardson and van Wilgen, B. 2017. Managing conflict-generating invasive species in South Africa: Challenges and trade-offs. *Bothalia*, 47(2): a2160. https://doi.org/10.4102/abc.v47i2.2160.

# APPENDIX 1: BASELINE MAPS

# APPENDIX 1

## BASELINE MAPS

**Figure A1.1A: Eastern Cape Baseline information**
**River condition / Present Ecological State (PES)**

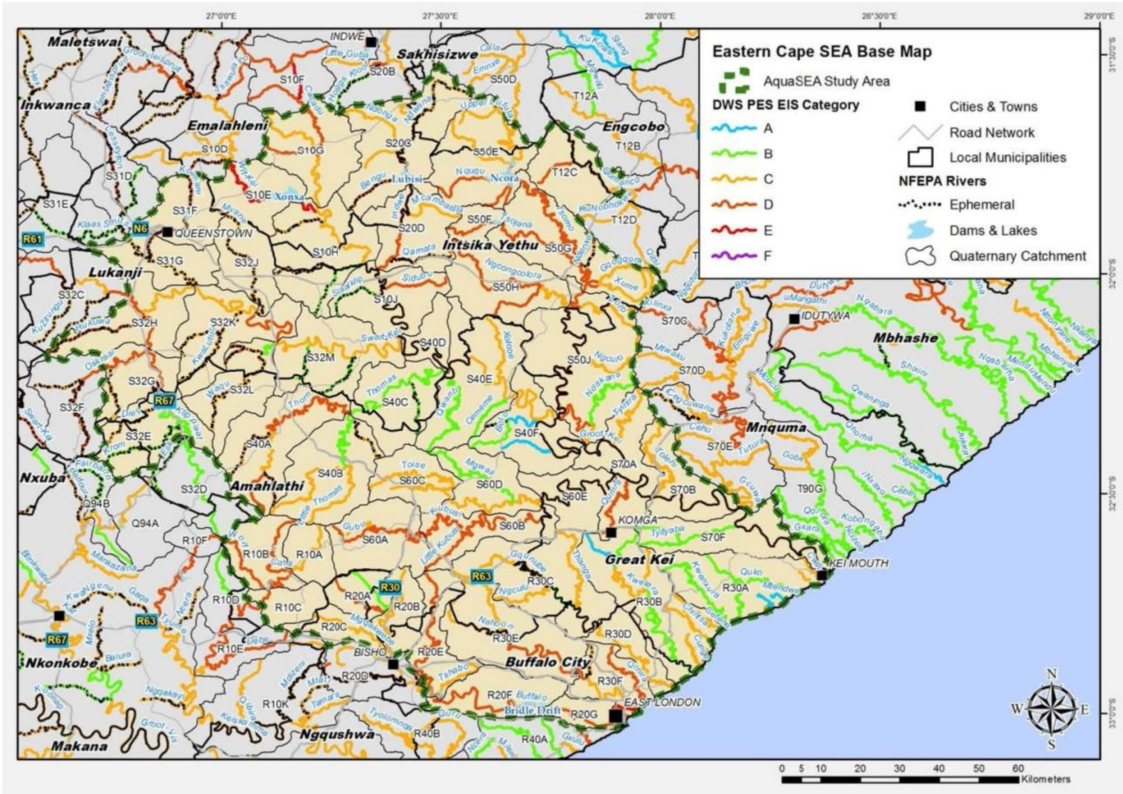

**Figure A1.1B: Eastern Cape**
**Habitat modification layer (SANBI 2017)**

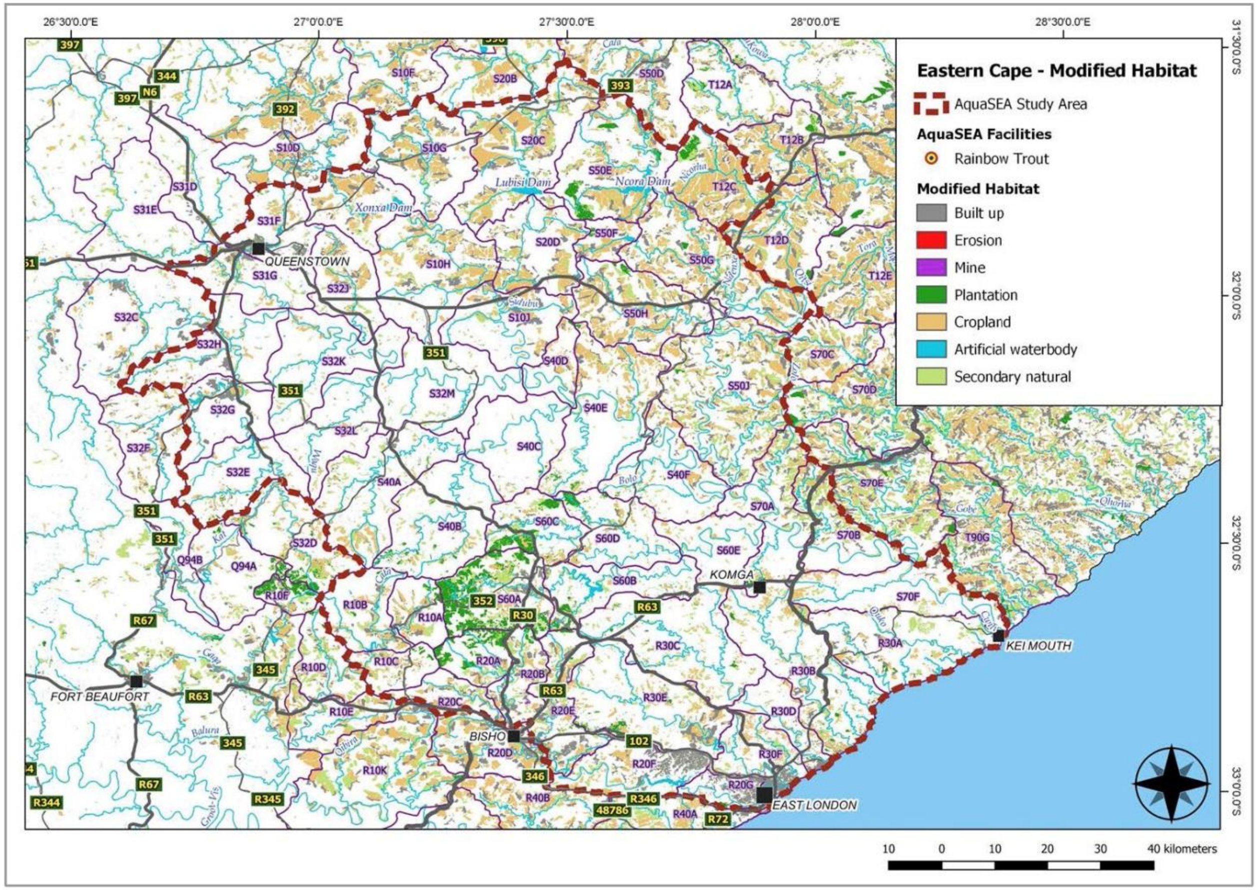

**Figure A1.1C: Eastern Cape Baseline information**
**Known trout presence (SANBI 2016) with aquaculture facilities overlay (CSIR 2017) showing all mapped facilities**

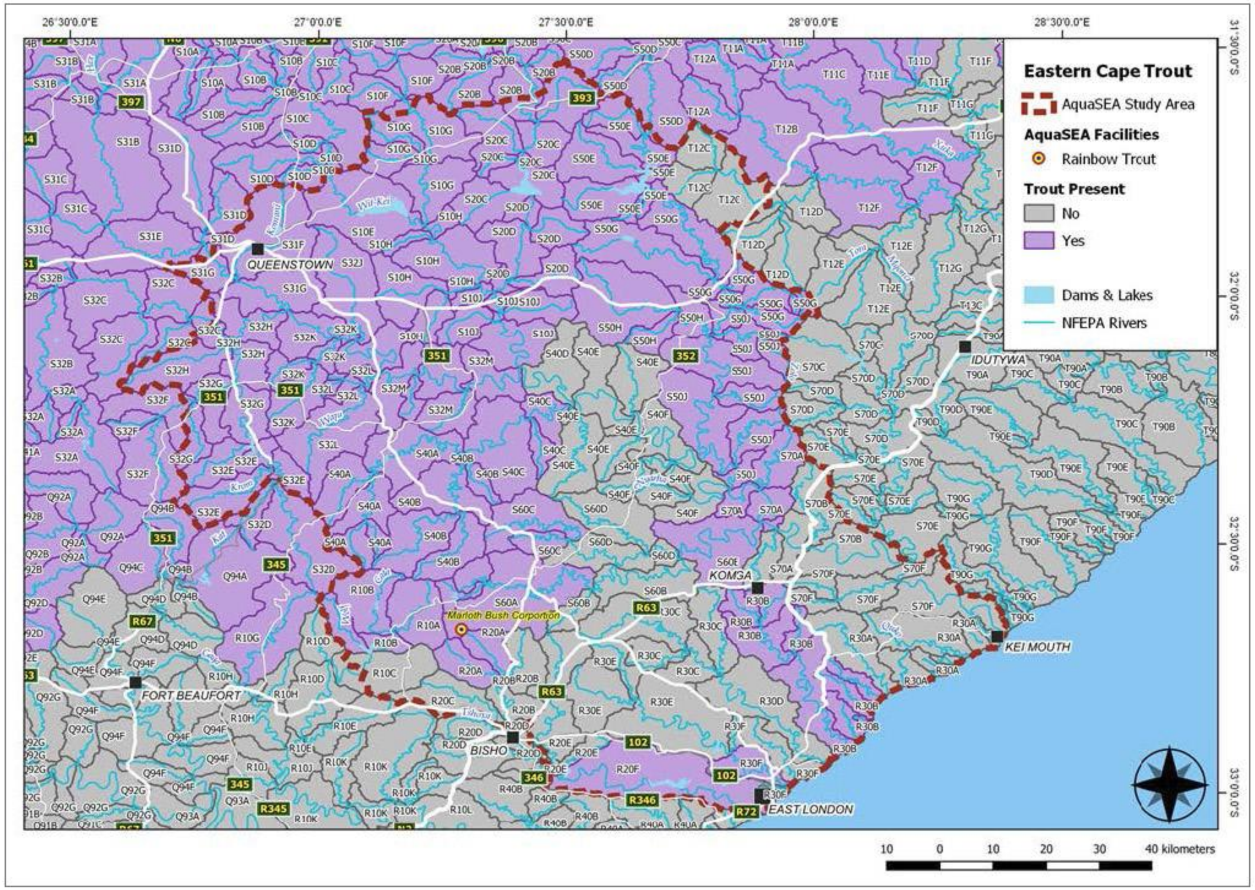

**Figure A1.1D: Eastern Cape Baseline information**
**Known tilapia presence (SANBI 2018) with aquaculture facilities overlay (CSIR 2017) showing all mapped facilities**

No data for this study area - assumed too cold to support tilapia in the wild

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**Figure A1.2A: Free State – KwaZulu-Natal Highlands Baseline information**
**River condition / Present Ecological State (PES)**

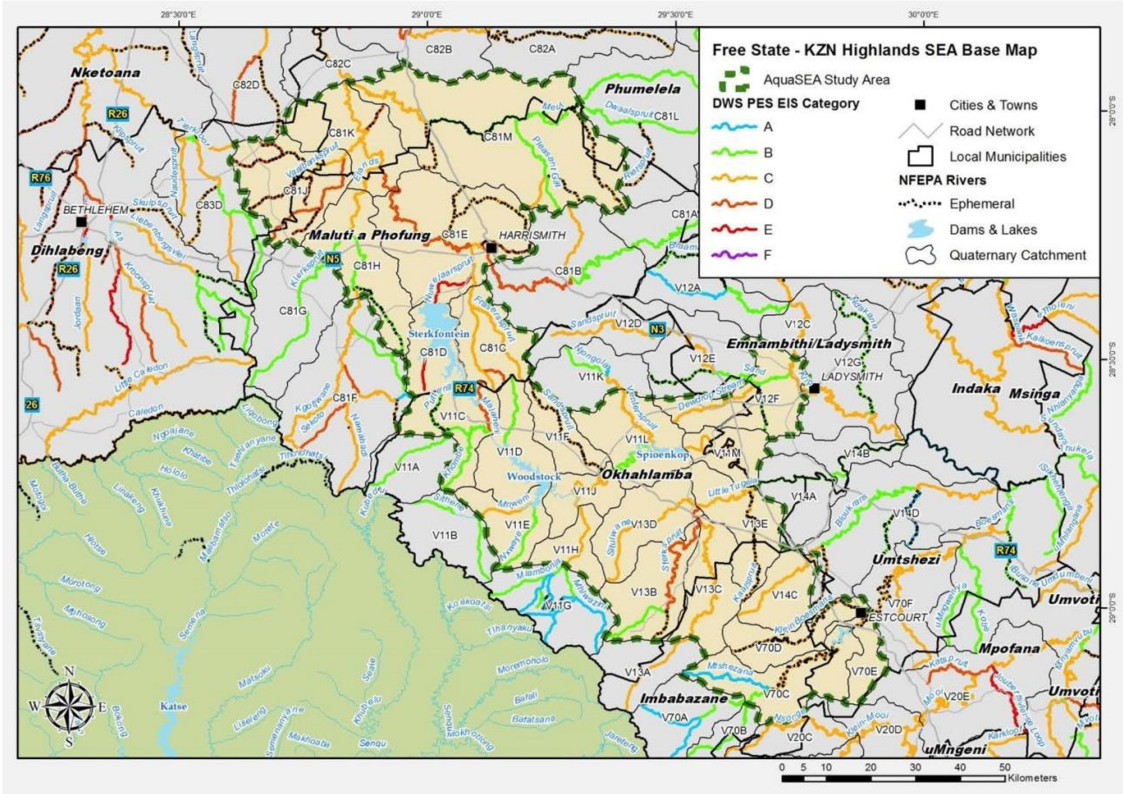

**Figure A1.2B: Free State – KwaZulu-Natal Highlands Baseline**
**Habitat modification layer (SANBI 2017)**

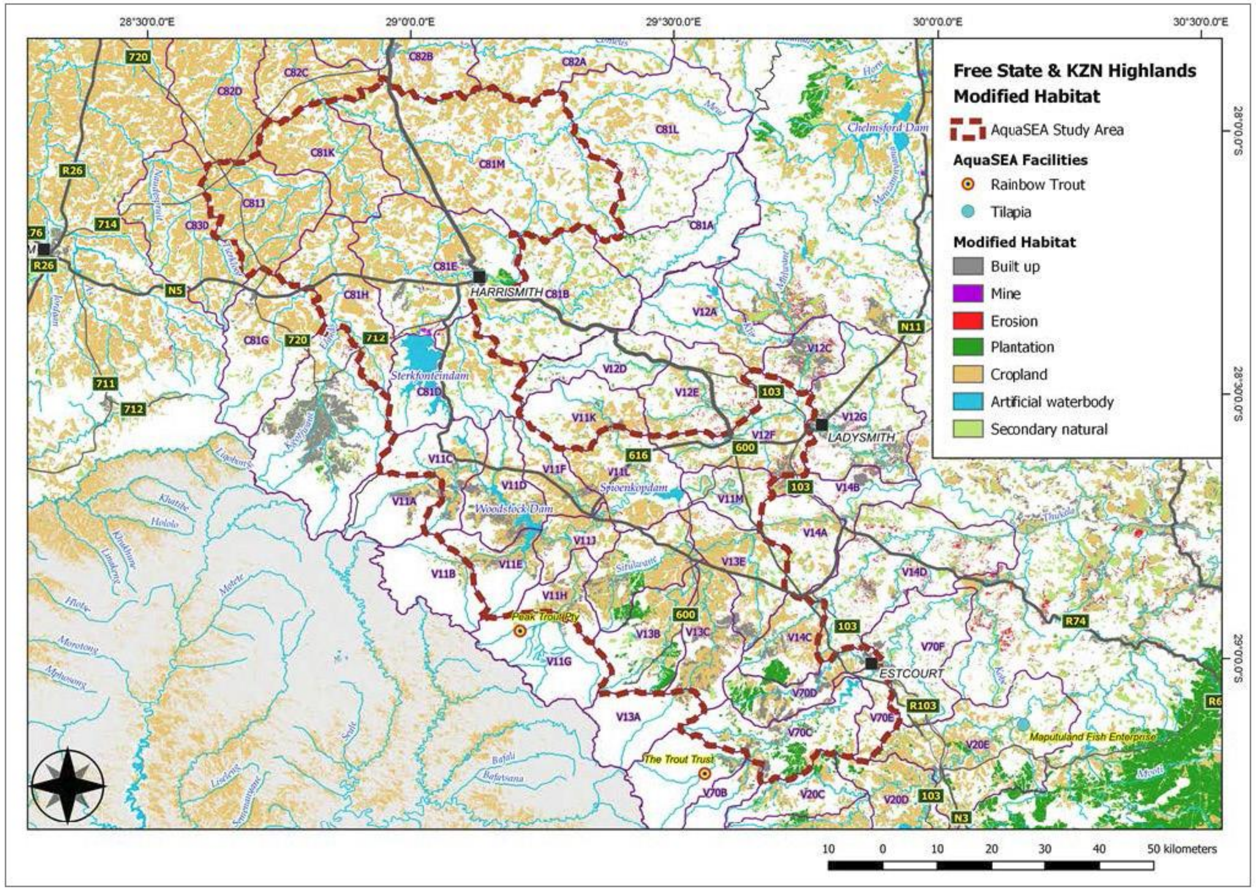

**Figure A1.1C: Free State – KwaZulu-Natal Highlands Baseline information**
**Known trout presence (SANBI 2016) with aquaculture facilities overlay (CSIR 2018) showing all mapped facilities**

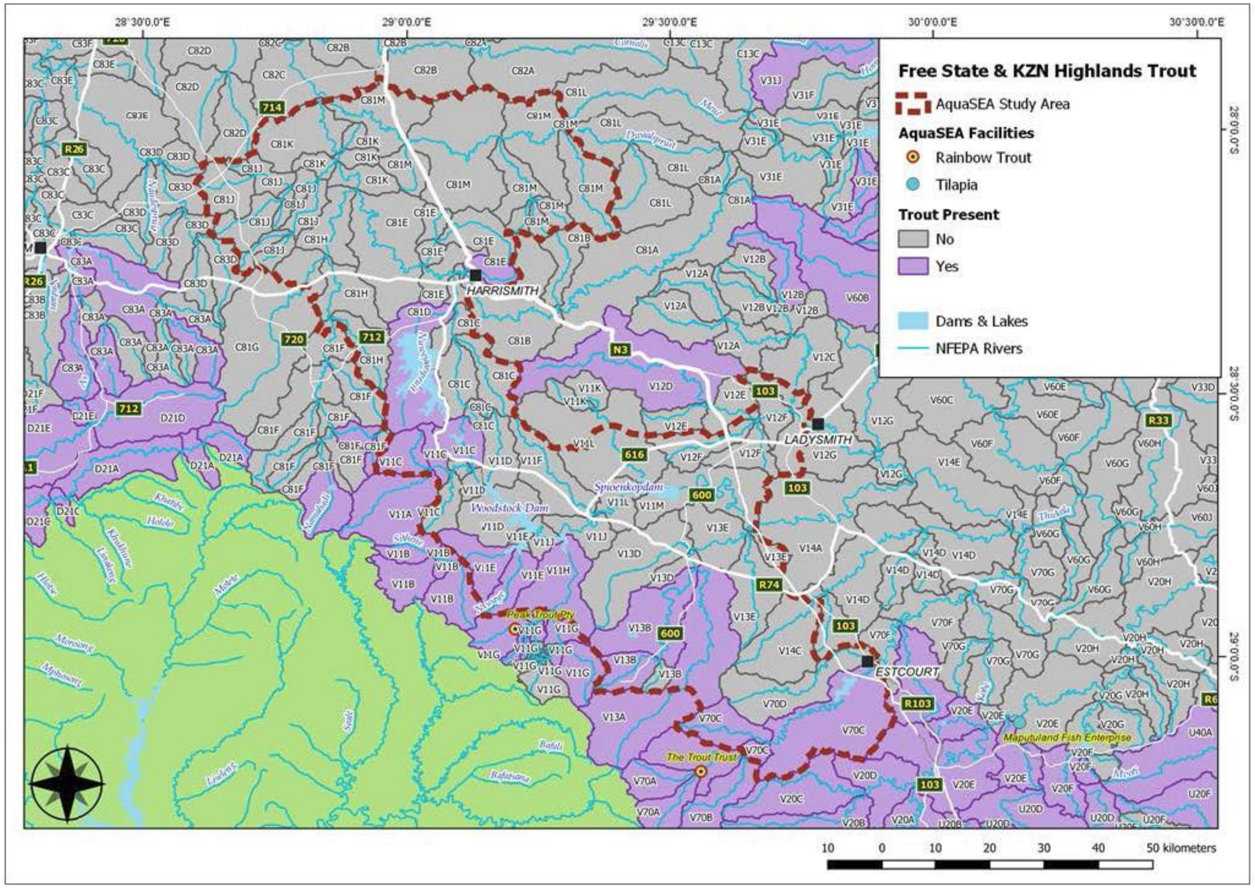

**Figure A1.1D: Free State – KwaZulu-Natal Baseline information**
**Known tilapia presence (SANBI 2018) with aquaculture facilities overlay (CSIR 2017) showing all mapped facilities**

No data for this study area - assumed too cold to support tilapia in the wild

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**Figure A1.3: Gauteng – North-West Baseline information**
**River condition / Present Ecological State (PES)**

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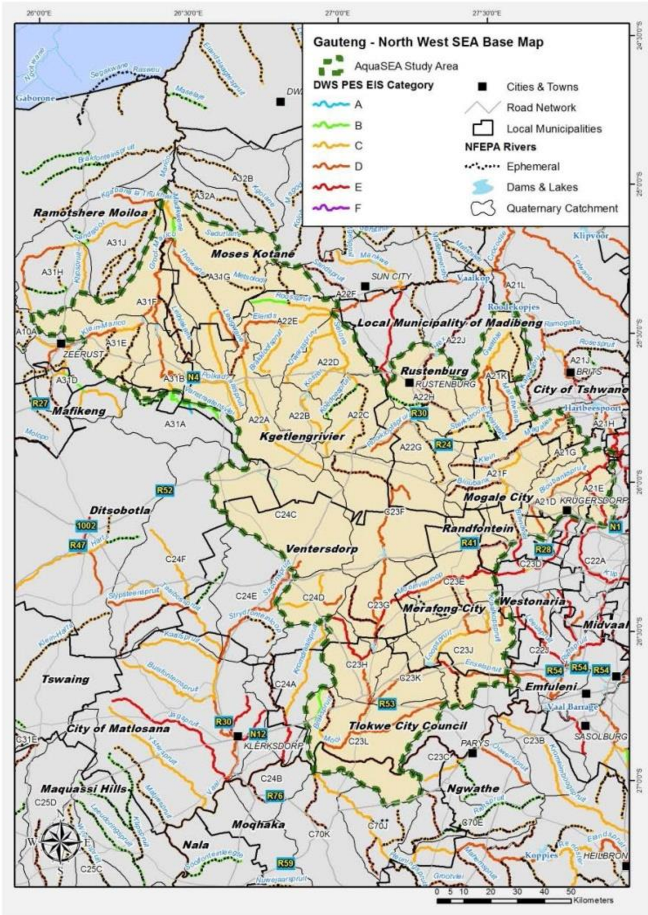

**Figure A1.3B: Gauteng North West Baseline information**
**Habitat modification layer (SANBI 2017)**

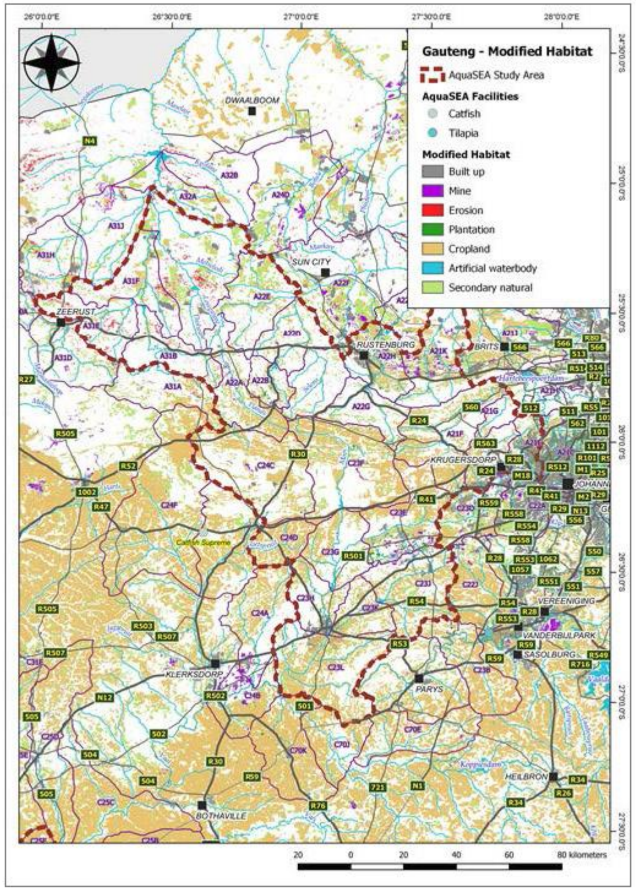

**Figure A1.3C: Gauteng North West Baseline information**
**Known trout presence (SANBI 2016) with aquaculture facilities overlay (CSIR 2017) showing all mapped facilities**

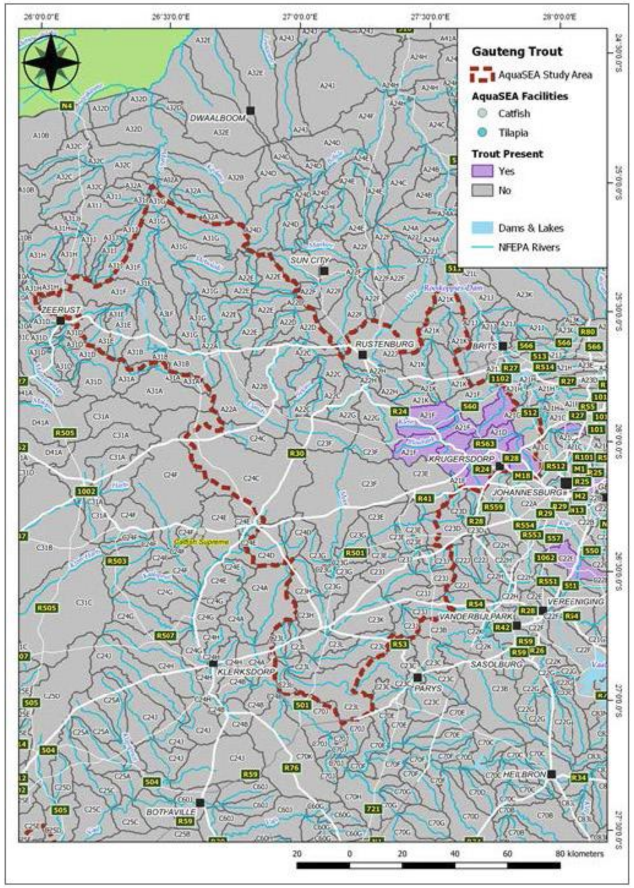

**Figure A1.3D: Gauteng North West Baseline information**
**Known tilapia presence (SANBI 2018) with aquaculture facilities overlay (CSIR 2017) showing all mapped facilities**

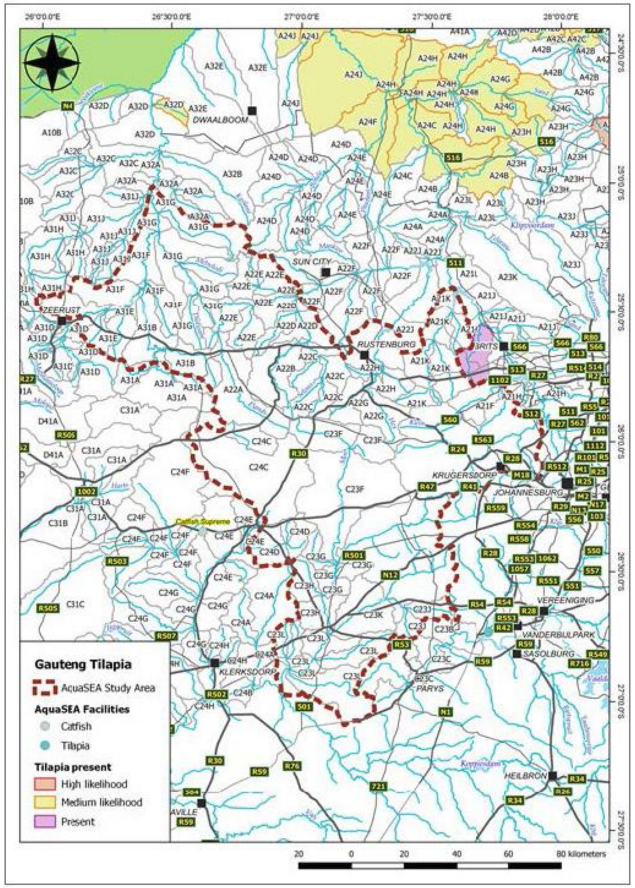

**Figure A1.4A: Limpopo Baseline information**
**River condition / Present Ecological State (PES)**

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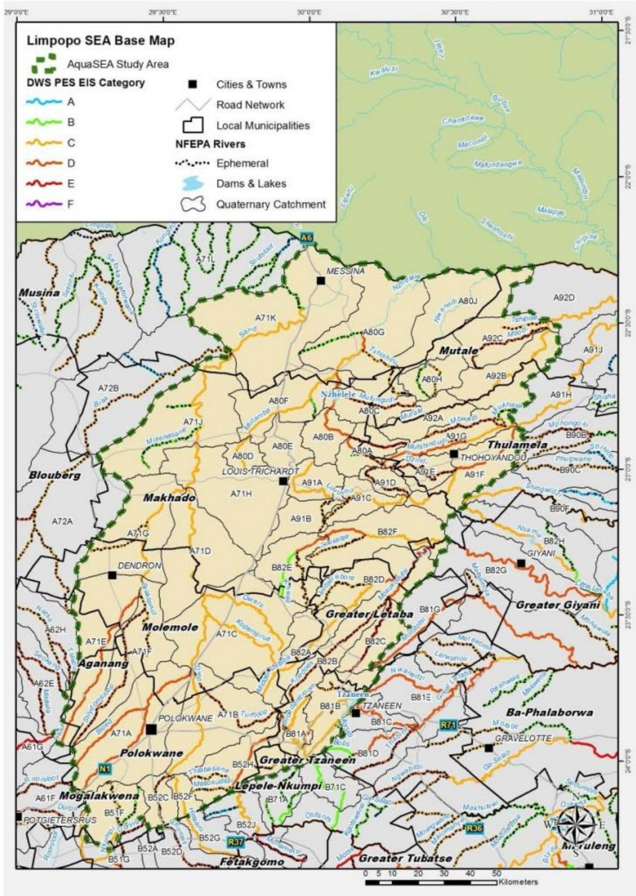

**Figure A1.4B: Limpopo**
**Habitat modification layer (SANBI 2017)**

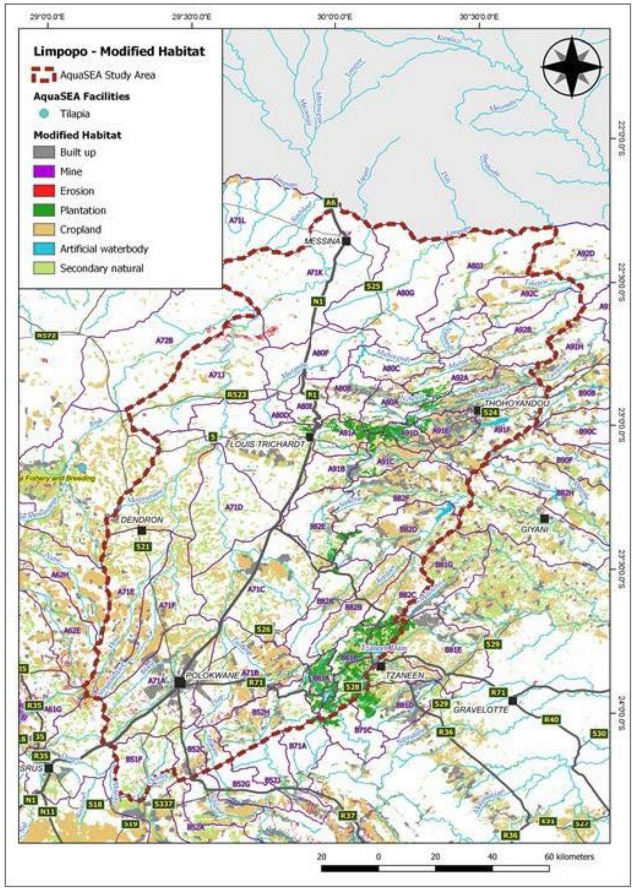

**Figure A1.4C: : Limpopo**
**Known trout presence (SANBI 2016) with aquaculture facilities overlay (CSIR 2017) showing all mapped facilities**

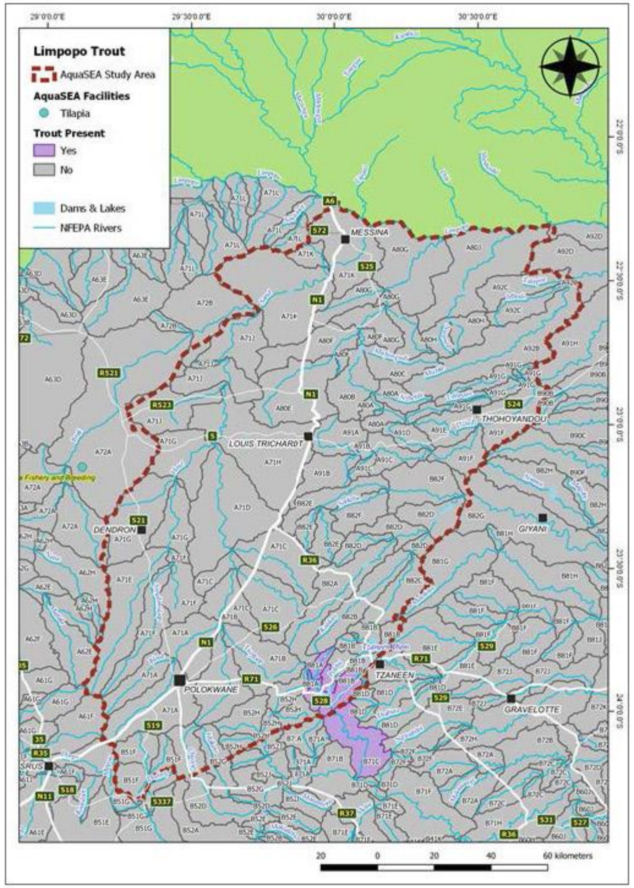

**Figure A1.4D: : Limpopo**
**Known tilapia presence (SANBI 2018) with aquaculture facilities overlay (CSIR 2017) showing all mapped facilities**

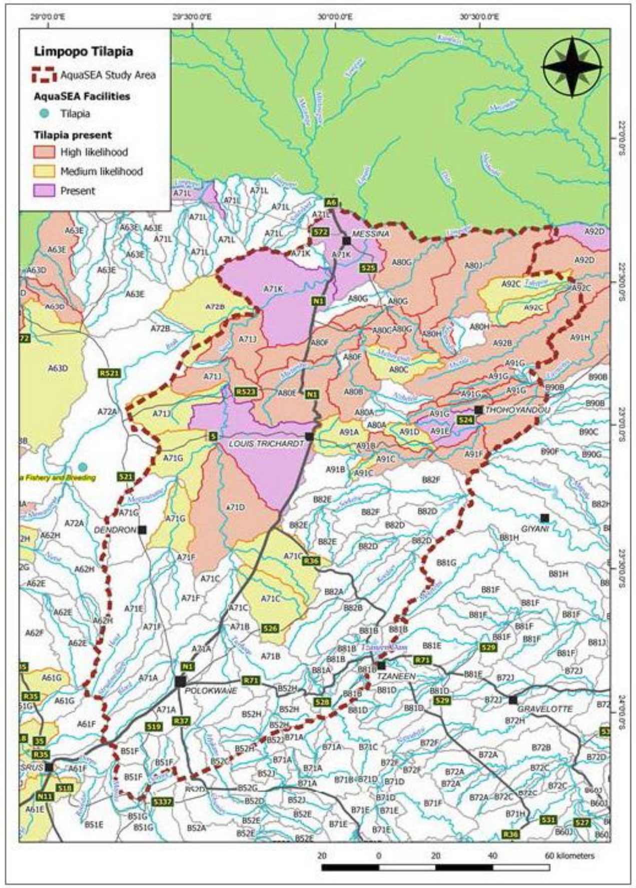

**Figure A1.5A: Mpumalanga Baseline information River condition / Present Ecological State (PES)**

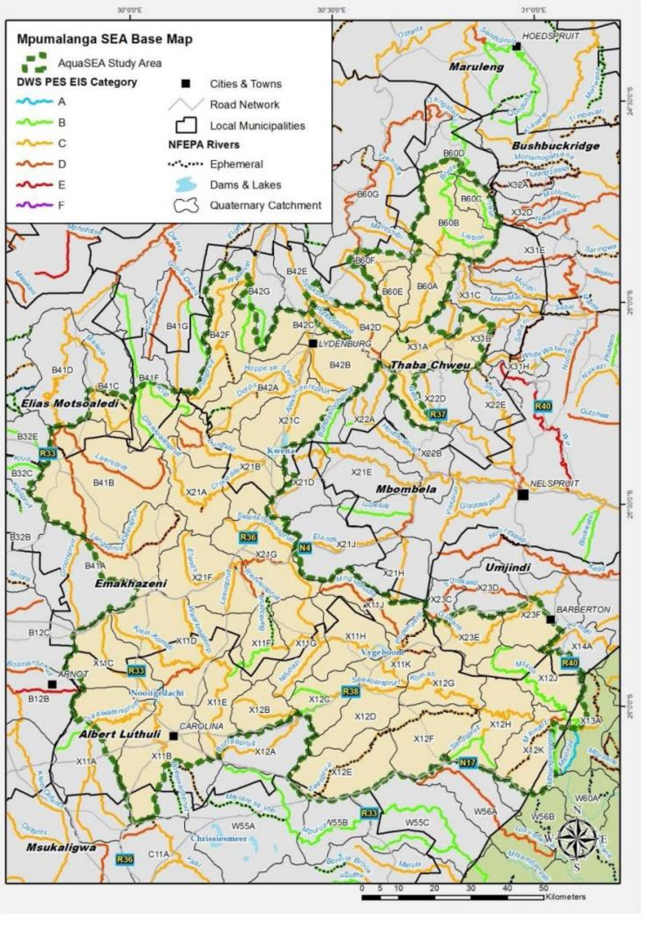

**Figure A1.5B: Mpumalanga**
**Habitat modification layer (SANBI 2017)**

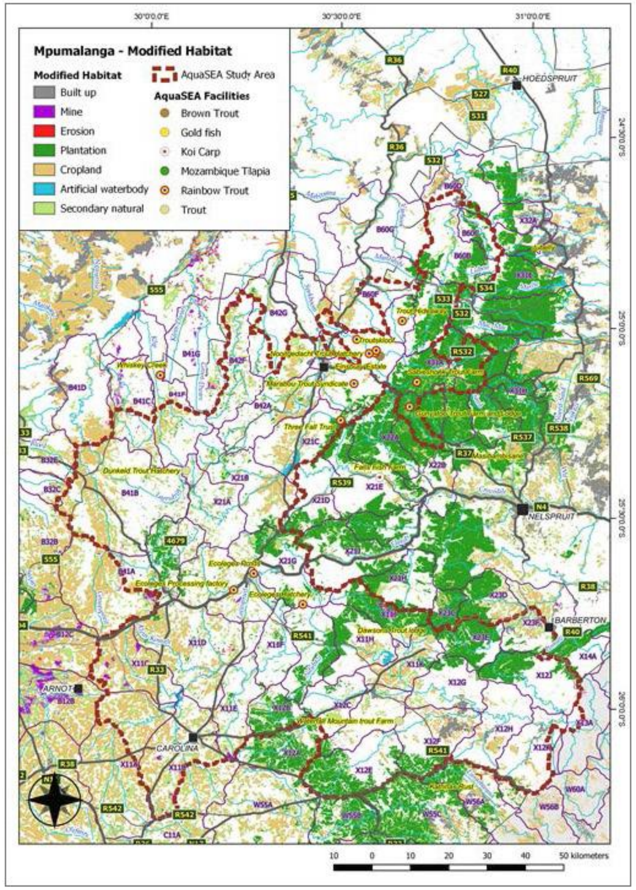

**Figure A1.5C: Mpumalanga Baseline information**
**Known trout presence (SANBI 2016) with aquaculture facilities overlay (CSIR 2017) showing all mapped facilities**

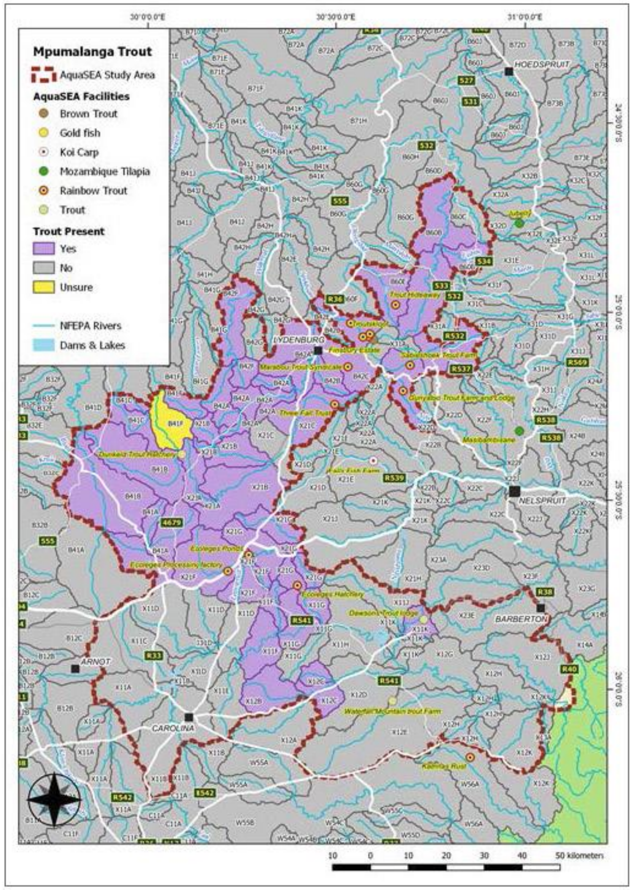

**Figure A1.5D: Mpumalanga Baseline information**
**Known tilapia presence (SANBI 2018) with aquaculture facilities overlay (CSIR 2017) showing all mapped facilities**

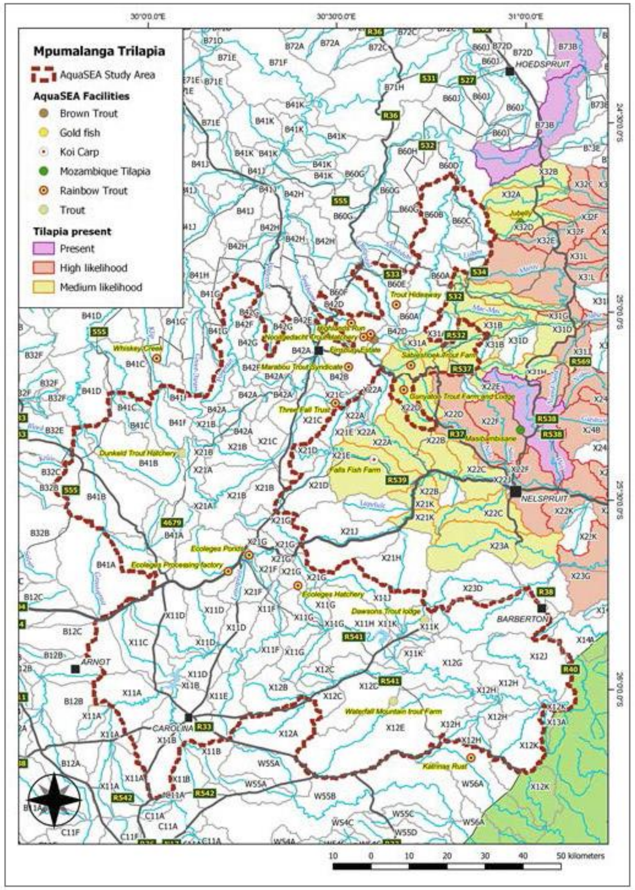

**Figure A1.6A: Richards Bay Baseline information**
**River condition / Present Ecological State (PES)**

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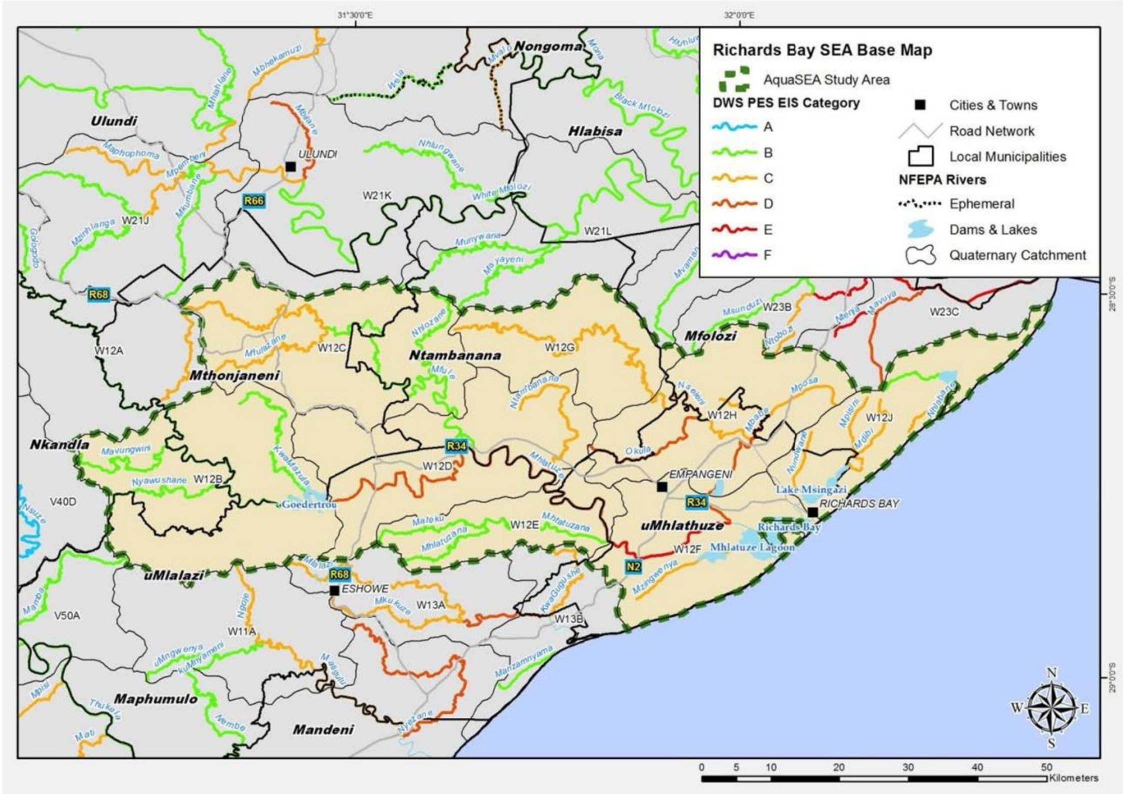

**Figure A1.6B: Richards Bay**
**Habitat modification layer (SANBI 2017)**

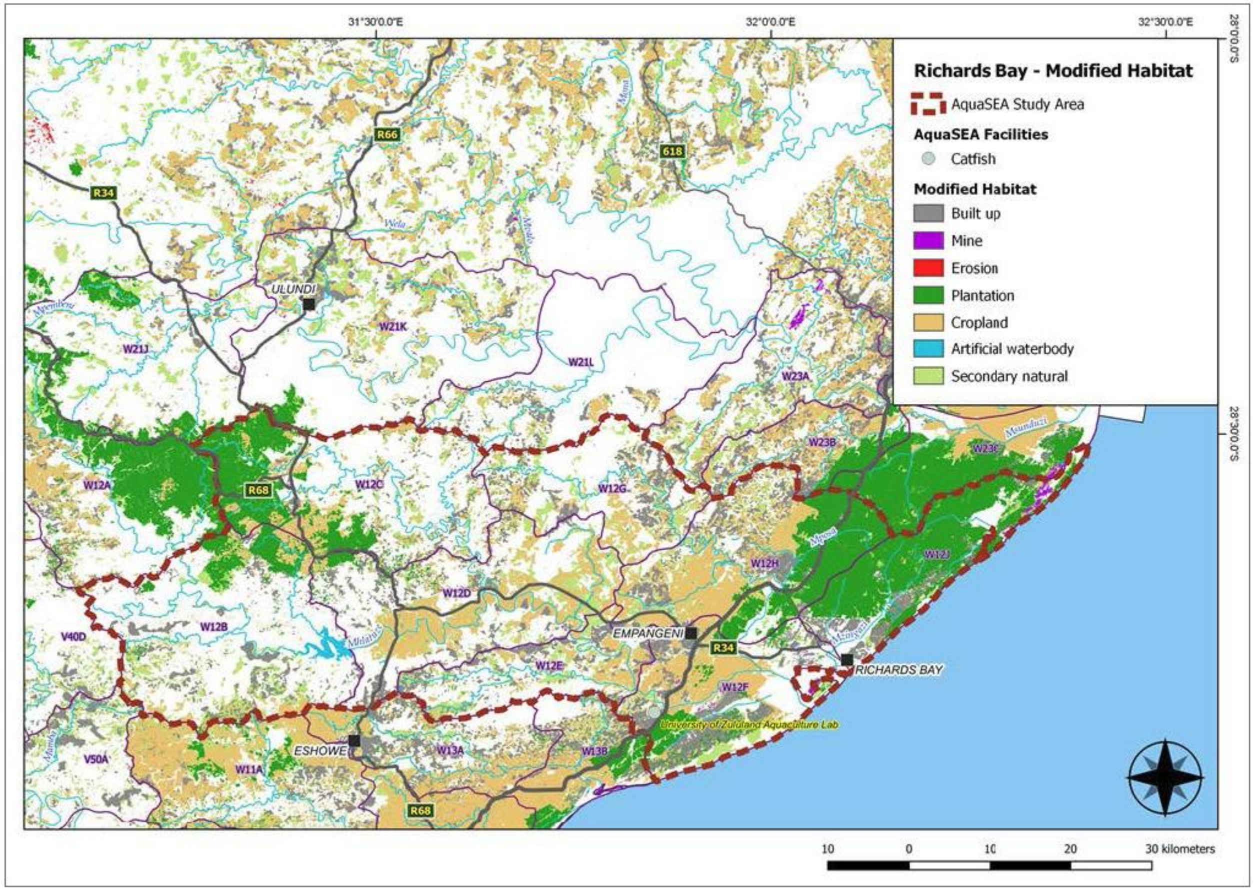

**Figure A1.6C: Richards Bay**
**Known trout presence (SANBI 2016) with aquaculture facilities overlay (CSIR 2017) showing all mapped facilities**

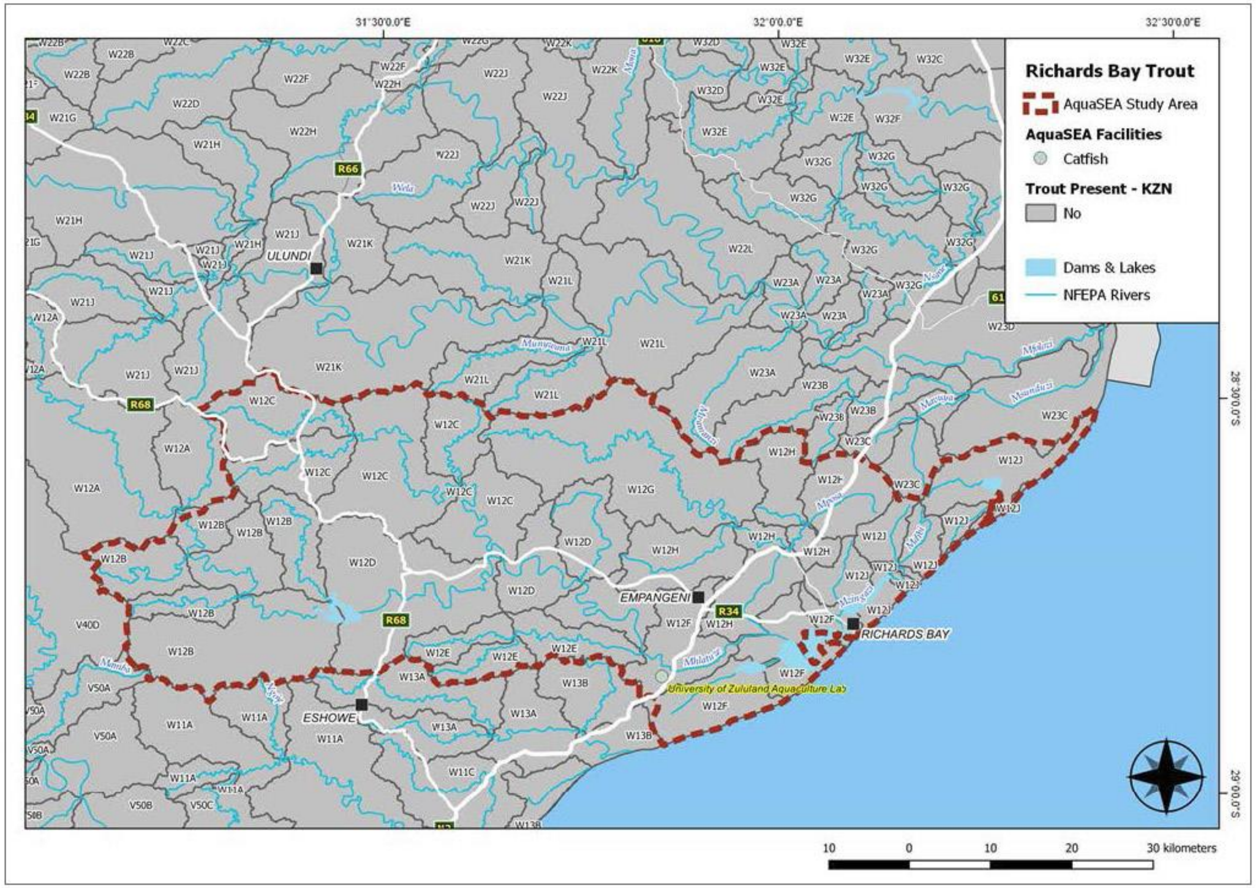

**Figure A1.6D: Richards Bay Baseline information**
**Known tilapia presence (SANBI 2018) with aquaculture facilities overlay (CSIR 2017) showing all mapped facilities**

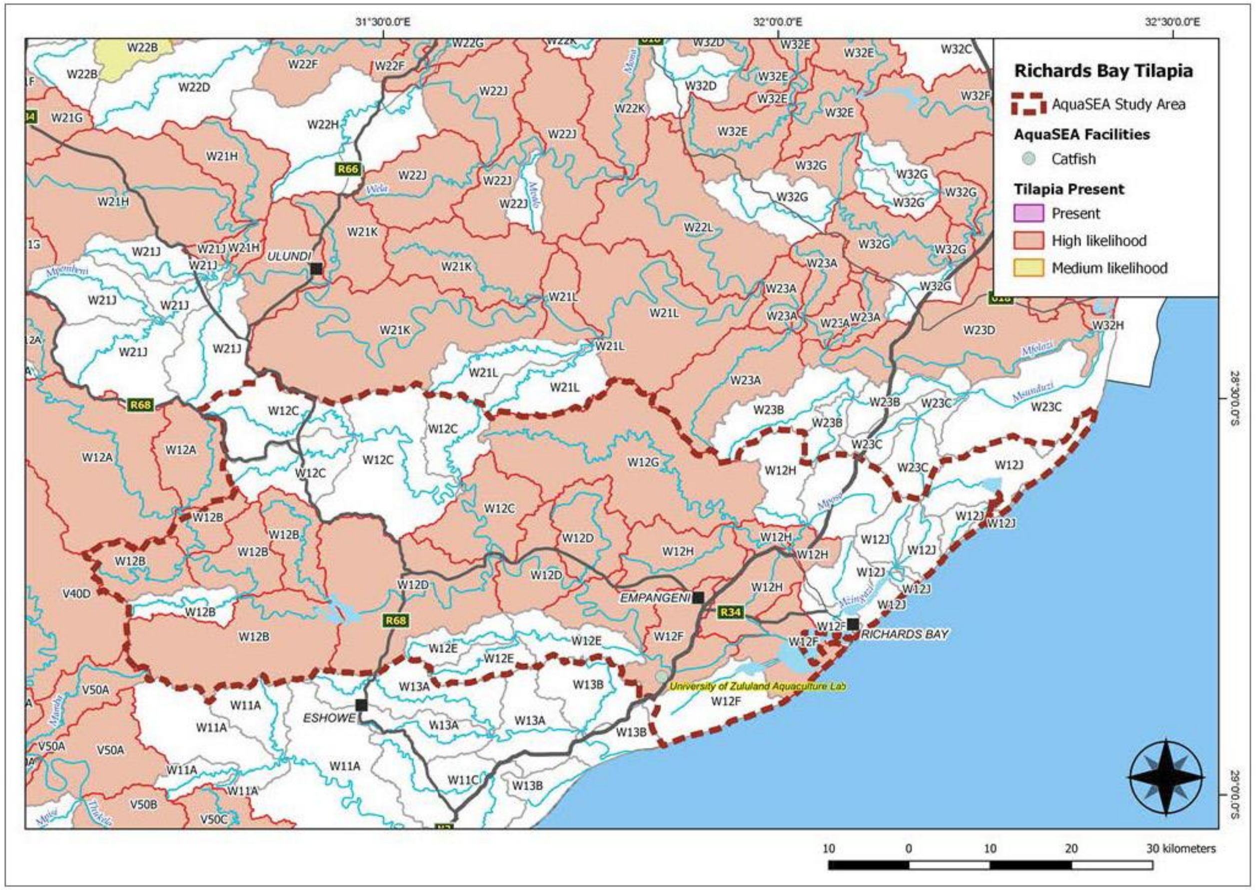

**Figure A1.7A: Western Cape Baseline information**
**River condition / Present Ecological State (PES)**

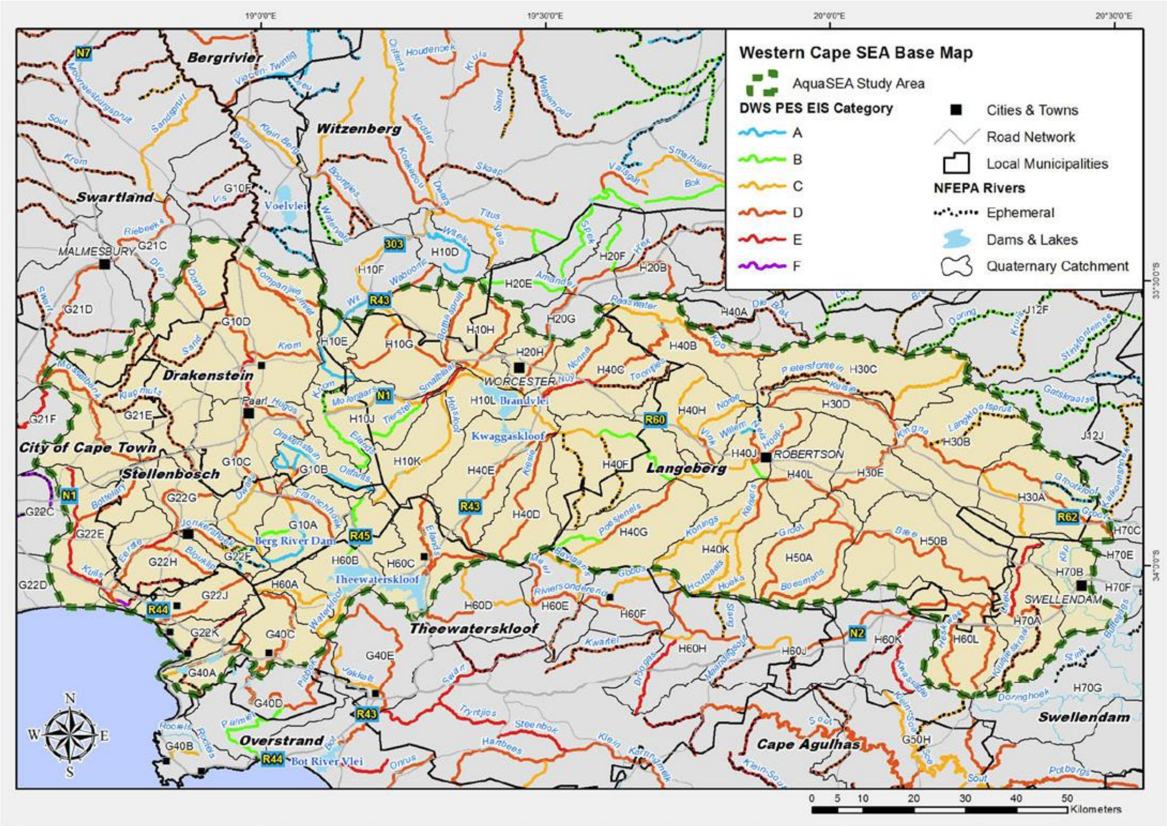

**Figure A1.7 B: Western Cape**
**Habitat modification layer (SANBI 2017)**

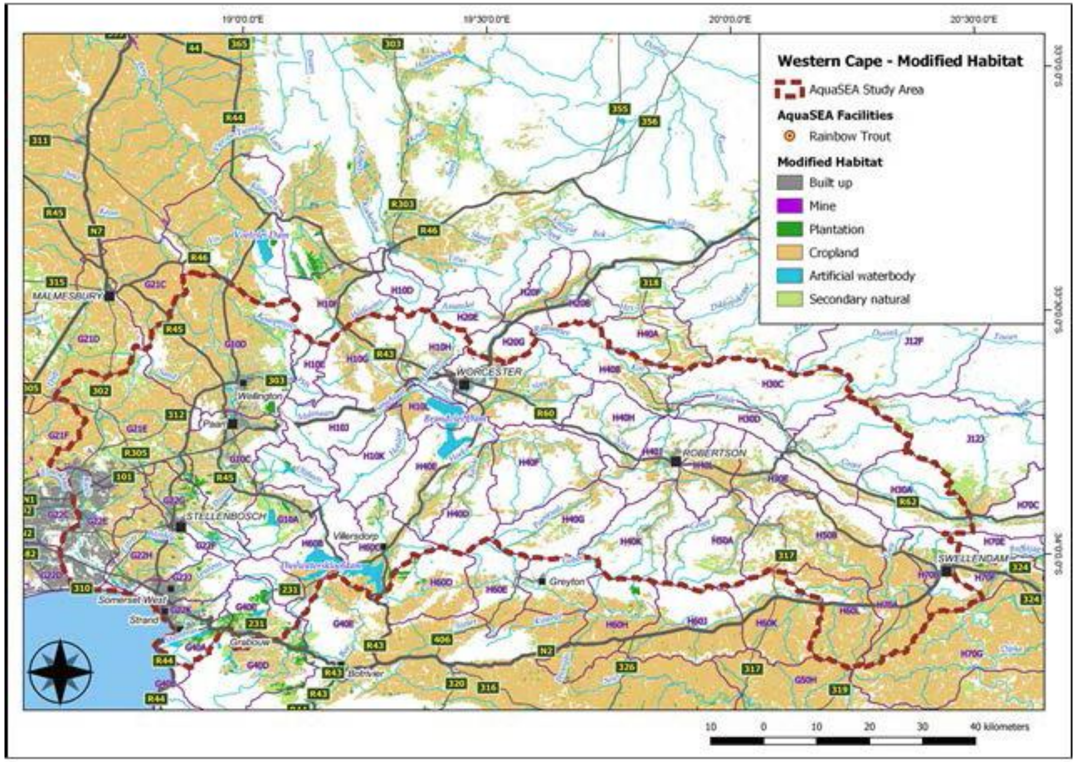

**Figure A1.7C: Western Cape Baseline information**
**Known trout presence (SANBI 2016) with aquaculture facilities overlay (CSIR 2017) showing all mapped facilities**

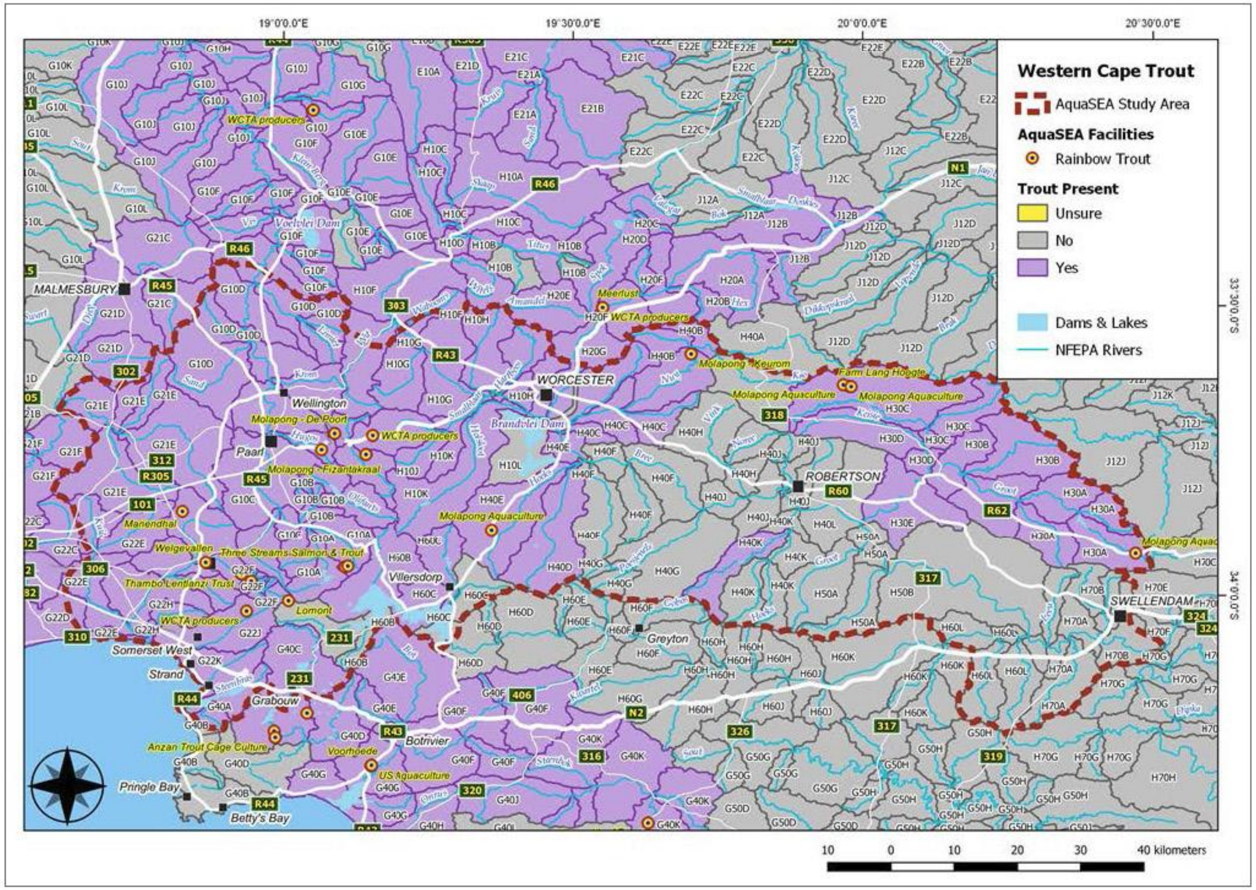

**Figure A1.7D: Western Cape Baseline information**
**Known tilapia presence (SANBI 2018) with aquaculture facilities overlay (CSIR 2017) showing all mapped facilities**

No data for this study area - assumed too cold to support tilapia in the wild

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**Figure A1.8A: Vaalharts Baseline information**
**River condition / Present Ecological State (PES)**

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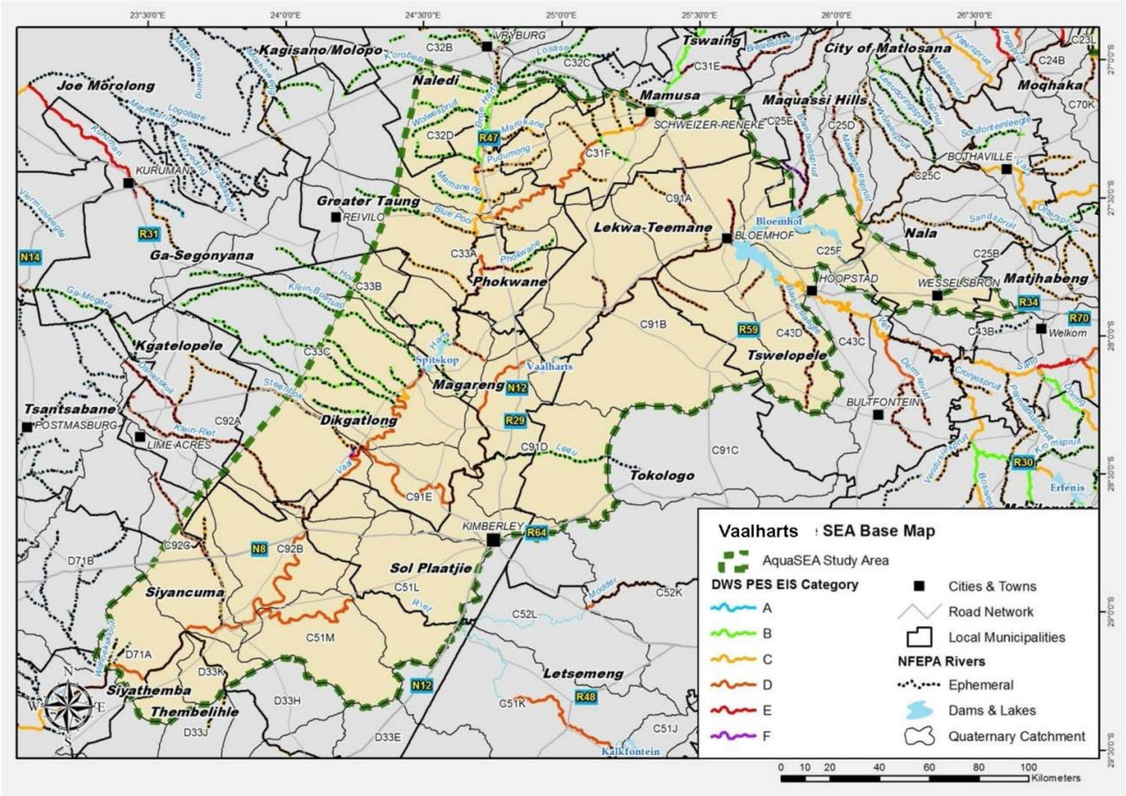

**Figure A1.8B: Vaalharts Habitat modification layer (SANBI 2017)**

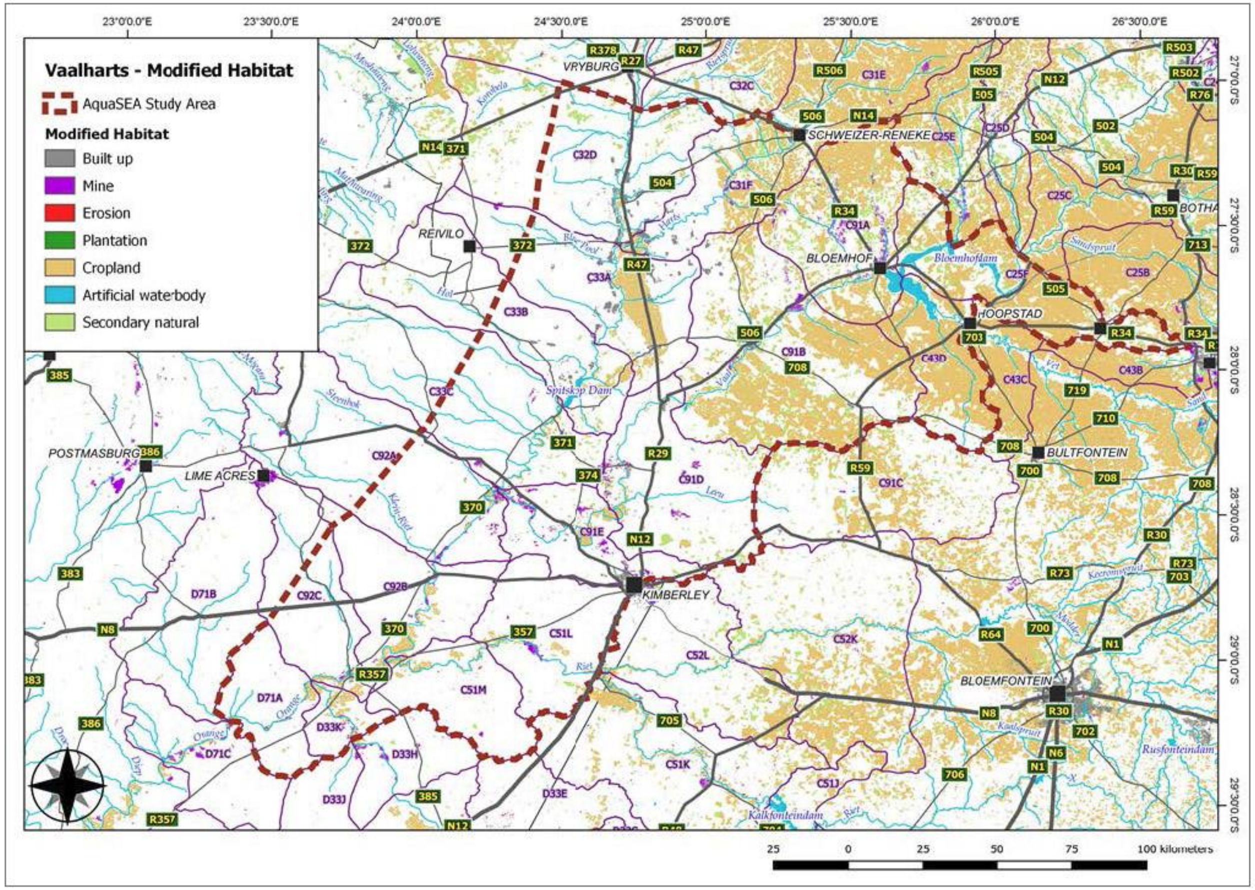

**Figure A1.8C: Vaalharts Baseline information**
**Known trout presence (SANBI 2016) with aquaculture facilities overlay (CSIR 2017) showing all mapped facilities**

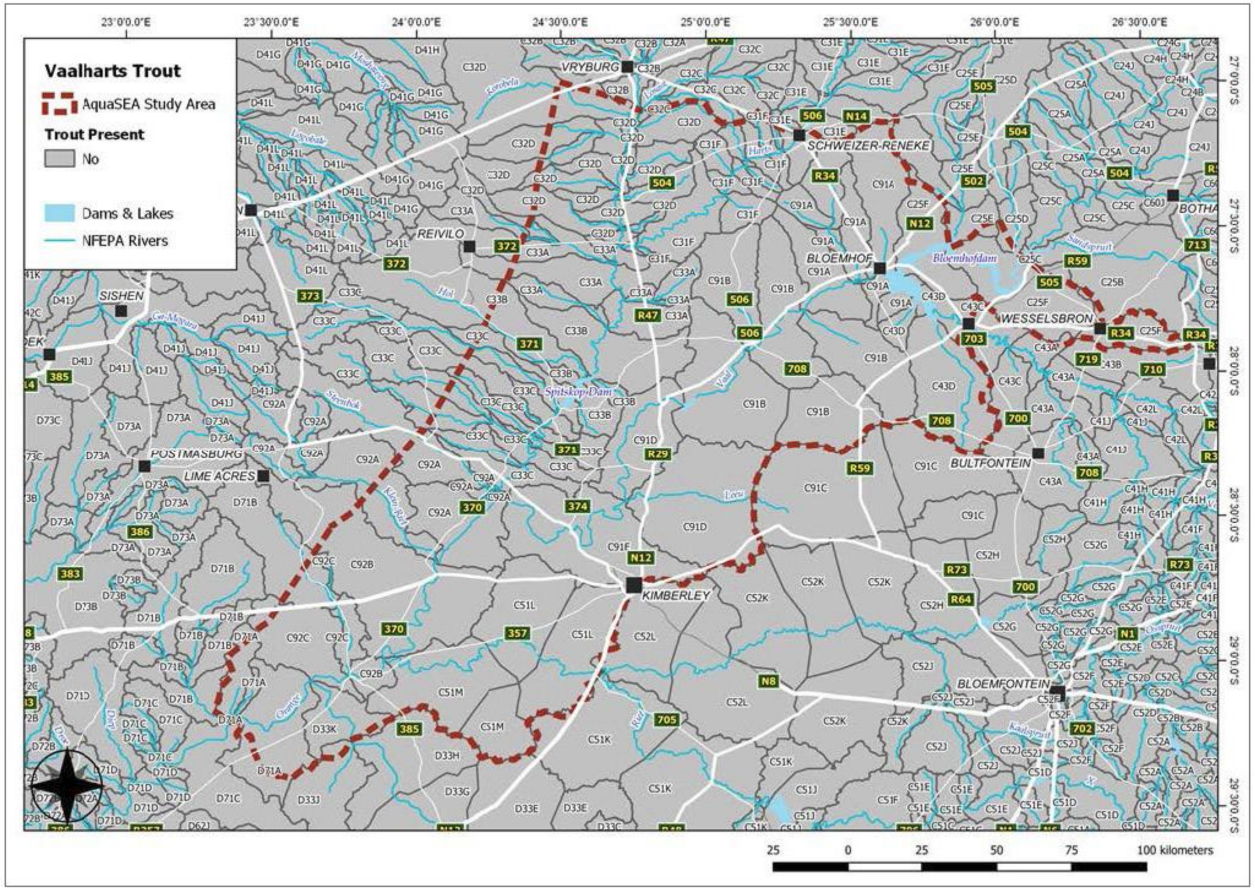

**Figure A1.8D: Vaalharts Baseline information**
**Known tilapia presence (SANBI 2018) with aquaculture facilities overlay (CSIR 2018) showing all mapped facilities**

. No data for this study area - assumed too cold to support tilapia in the wild

**Figure A1.9A: Vanderkloof-Gariep Baseline information**
**River condition / Present Ecological State (PES)**

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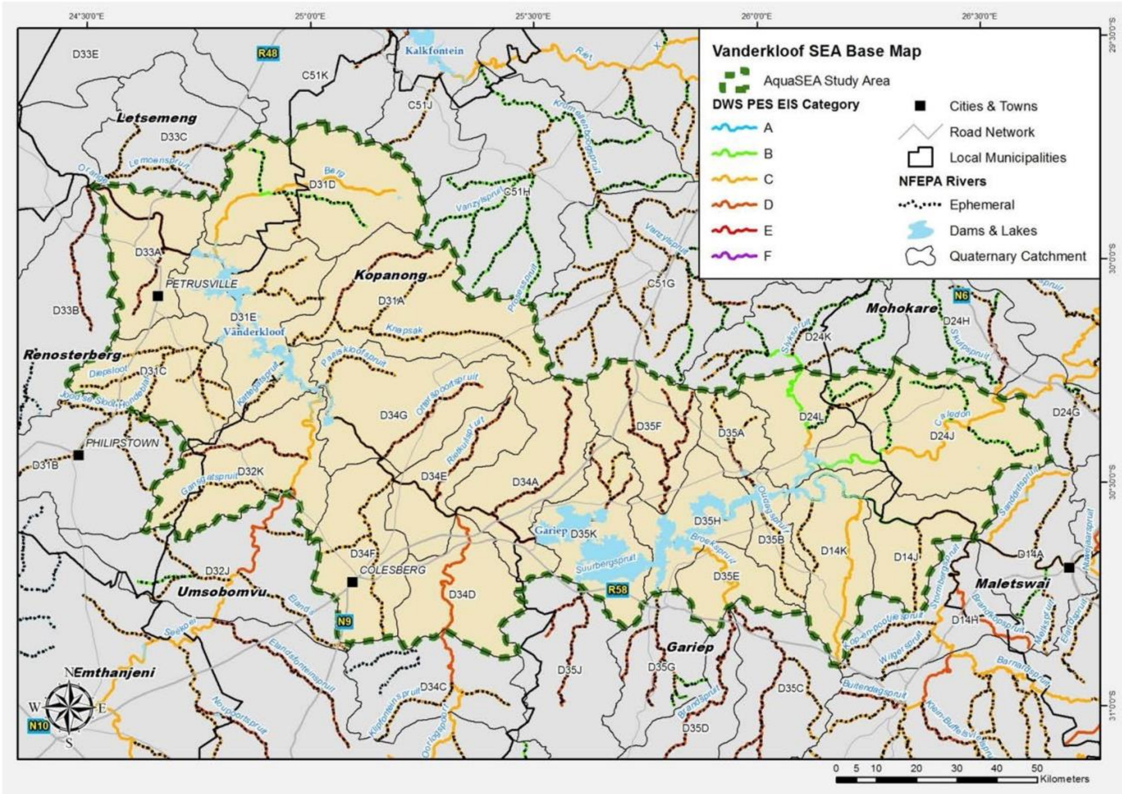

**Figure A1.9B: Vanderkloof-Gariep Baseline information**
**Habitat modification layer (SANBI 2017)**

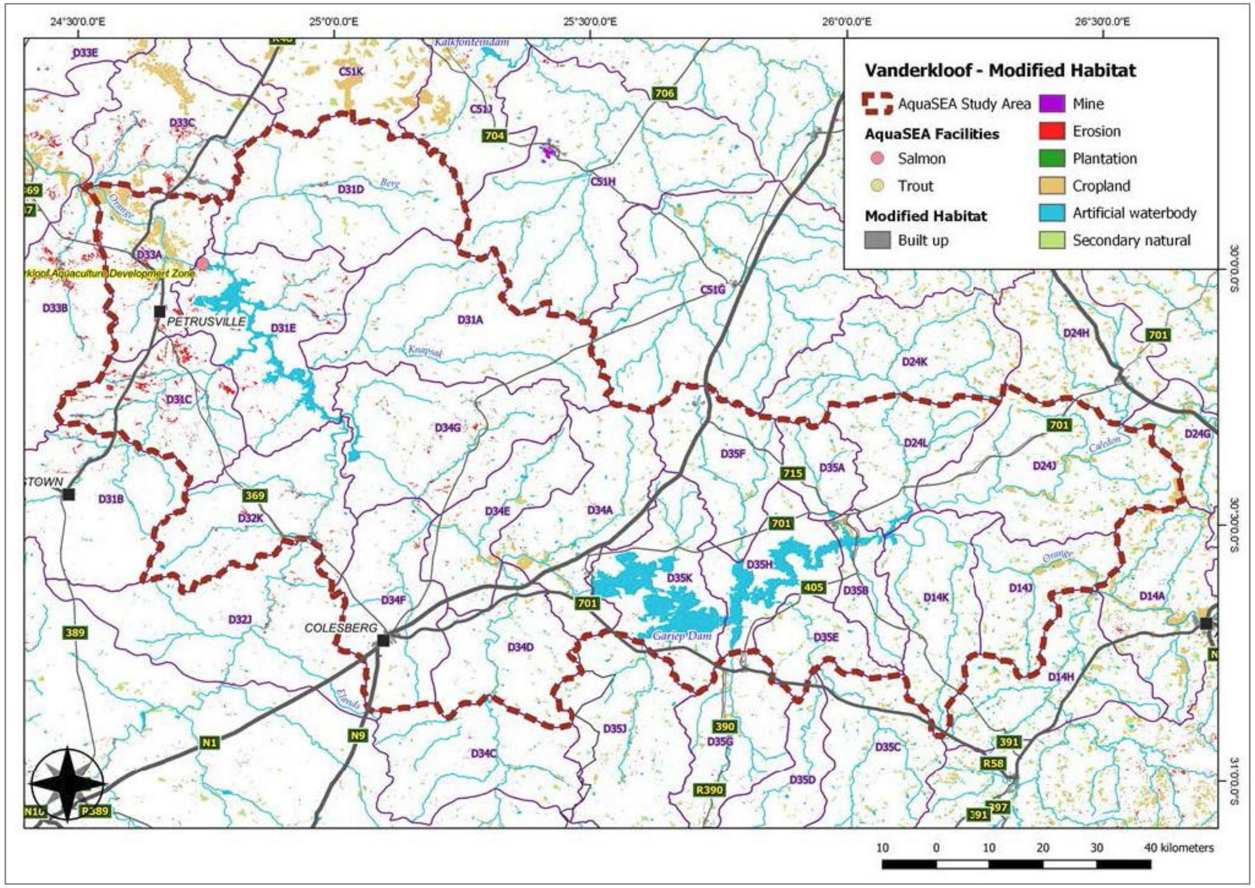

**Figure A1.9C: Vanderkloof-Gariep Baseline information**
**Known trout presence (SANBI 2016) with aquaculture facilities overlay (CSIR 2017) showing all mapped facilities**

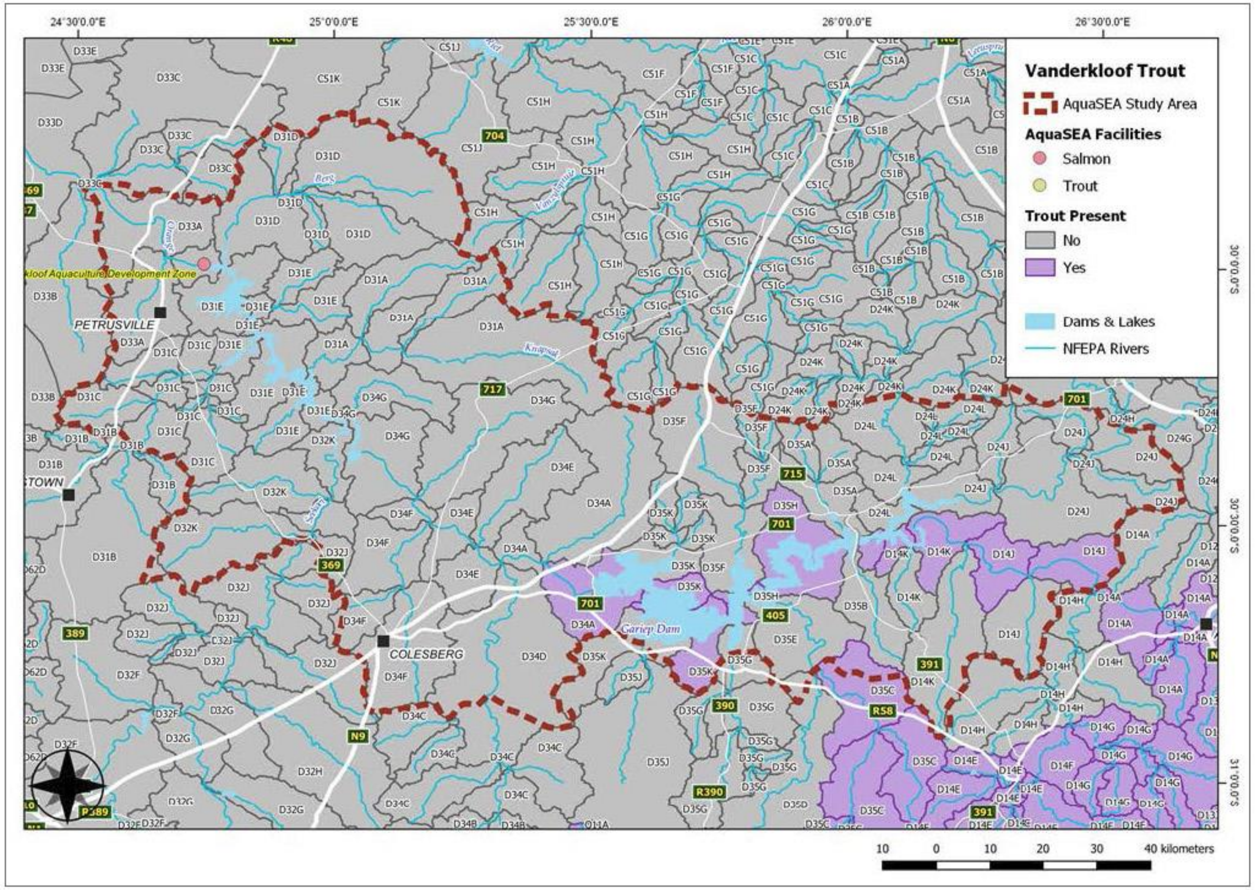

**Figure A1.9D: Vanderkloof-Gariep Baseline information**
**Known tilapia presence (SANBI 2018) with aquaculture facilities overlay (CSIR 2017) showing all mapped facilities**

No data for this study area - assumed too cold to support tilapia in the wild

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# APPENDIX 2: DATA AND RATING SCALES USED IN SENSITIVITY MAPPING

**Table A2.1** Data used in sensitivity mapping – last four columns show which sensitivity layer each contributes to. Table A2.2 outlines the rating criteria for each of these datasets. Note that sensitivity rating types provide guidance as to where to focus appropriate mitigation, to reduce Risk ratings in different areas. That is, if Sensitivity Type is water quality, then Mitigation measures should focus on addressing threats to water quality

| DATASET | DATA | ATTRIBUTE | CONTRIBUTION TO SENSITIVITY RATING TYPE | | | | WEBSITE LINKS |
|---|---|---|---|---|---|---|---|
| | | | Water quality | Biodiveristy | Hydrological | Habitat quality | |
| **NFEPA DATA** | | | | | | | |
| NFEPA | NFEPA Rivers | Mainstem | | | | | http://bgis.sanbi.org/SpatialDataset/Detail/397 |
| | | FLOW | X | | X | X | |
| | | FFRFLAGSHP | | | X | | |
| | River FEPAs [NOT used for WC, KZN, EC] | FEPACODE | X | X | X | X | http://bgis.sanbi.org/SpatialDataset/Detail/398 |
| | | PHASE2FEPA | X | X | X | X | |
| | | UPSTREAM | X | X | | | |
| | NFEPA wetlands | RANK | X | X | | X | http://bgis.sanbi.org/SpatialDataset/Detail/395 |
| | | WETFEPA | X | X | X | X | |
| | FISHsanc | FISHSANC | | X | | | http://bgis.sanbi.org/SpatialDataset/Detail/399 |
| | | FISHREHAB | | X | | | |
| | | FISHFEPA | | X | | | |
| | | FISHFSA | | X | | | |
| | Fishsanc All Spp | NOFISSANC | | X | | | |
| | | STATUS | | X | | | http://bgis.sanbi.org/SpatialDataset/Detail/400 |
| **SUPPLEMENTARY FISH DATA** | | | | | | | |
| SANBI IUCN fish data | SANBI supplementary fish species: Threatened taxa | BINOMIAL (species name) | | X | | | http://speciesstatus.sanbi.org/taxa/lineage/538/ |
| MPTA | MPTA data of concern (FISH) (MTPA_concerns_aquaSEA) | MTPA CONC | | X | | | |
| SKEP | SKEP data of concern | NO_ENDEME | | X | | X | |
| | | Biodiversity | | x | | X | |
| ECape Fish – MARXAN | Excel spreadsheet with sites and SQHASH links | OCCUR CODES | | X | | | |

| DATASET | DATA | ATTRIBUTE | CONTRIBUTION TO SENSITIVITY RATING TYPE | | | | WEBSITE LINKS |
|---|---|---|---|---|---|---|---|
| | | | Water quality | Biodiveristy | Hydrological | Habitat quality | |
| **CONDITION DATA: PES / EI AND ES AND LANDUSE** | | | | | | | |
| DWS (2014) desktop PESEIS | PESEIES | PES CATEGO | X | X | X | X | https://www.dwa.gov.za/iwqs/rhp/eco/peseismodel.aspx |
| | | MEAN EI CL | X | X | X | X | |
| | | MEAN ES CL | X | X | X | X | |
| **AQUATIC CBA DATA** | | | | | | | |
| WESTERN CAPE CBA (2017) | CBA-WC | SUB CAT2 | X | X | X | X | |
| | ESA-WC | SUBCAT1 | X | X | X | X | |
| EASTERN CAPE: AA_CBA_MAP_DRAFT2 (2017) | W_CBA1_EC_FreshwaterMARXAN_River_BUFFER1km_v1 | W_CBA1 | | X | | X | https://egis.environment.gov.za/ECBCP-2017 |
| | W_CBA1_EC_FreshwaterMARXAN_Rivers_20170619_v1 | F_CBA1 | | X | | X | |
| | W_CBA4_StrategicWaterAreas_v1 | F_CBA4 | X | | X | | |
| | W_CBA7_EC_Integrated Wetlands_v1 | F_CBA7 | | X | | X | |
| | lc_int2014 Image file | LC5_CLASS | X | X | X | X | |
| KZN 2016 | KZN_CBA_Optimal_wll_03032016 | LEGEND | | X | | X | |
| | KZN_ESA_wll_01022016 | | | X | | X | |
| Gauteng: C-Plan (GDARD 2014) | Gauteng: C-Plan v33 1110 ge | BDF DESC and CATEGORY | X | X | X | X | |
| **PROTECTED AREA DATA** | | | | | | | |
| SAPAD | | MAJ_TYPE | X | X | X | X | http://www.sasdi.net/sresults.aspx?text=Protected+Area |

**Table A2.2.** Assignment of Sensitivity Levels to each rated attribute. The highest sensitivity level for each sub-quaternary is applied by sensitivity type (see Appendix 3: Figure A3.1 - 3.19)

| DATASET | DATA | ATTRIBUTE | SCALE | CONTRIBUTION TO SENSITIVITY RATING TYPE | | | | ATTRIBUTE RATING ASSOCIATED WITH EACH SENSITIVITY LEVEL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Water quality | Biodiversity | Hydrological | Habitat quality | Low | Medium | High | Very High |
| **NFEPA DATA** | | | | | | | | | | | |
| NFEPA | NFEPA Rivers | Mainstem | Illustrative | | | | | n/a | | | |
| | | FLOW | Rated Linear | X | | X | X | | P (Perennial} | E [Ephemeral] | |
| | | FFRFLAGSHP | Rated Linear | | | X | | 0 [not free flowing flagship] | | 1 [free flowing flagship] | |
| | River FEPAs [NOT used for WC, KZN, EC] | FEPACODE | Rated SQ | X | X | X | X | | | | 1 [FEPA River] |
| | | PHASE2FEPA | Rated SQ | X | X | X | X | | 1 [Phase 2 FEPA] | | |
| | | UPSTREAM | Rated SQ | X | X | | | | | 1 [Upstream management catchment] | |
| | FEPA wetlands | RANK | Rated buffered polygons | X | X | | X | | 5, 6 [wetlands in sub-quaternary with Working for Wetland wetlands; other wetlands excluding dams] | 3, 4 [Wetlands in sub-quaternaries with wetlands of (unstated) biodiversity importance; Wetlands in Category A, B or C condition associated with 3 or more wetlands] | 1, 2 [Wetlands within 500 m of an IUCN threatened frog, threatened waterbird point locality / quaternary with Crane sightings/breeding areas /intact wetlands] |
| | | WETFEPA | Rated buffered polygons | X | X | X | X | | | 1 [final selected wetland FEPAs] | |
| | FISHsanc | FISHSANC | Rated SQ | | X | | | | | | 1 [fish sanctuary |

| DATASET | DATA | ATTRIBUTE | SCALE | CONTRIBUTION TO SENSITIVITY RATING TYPE | | | | ATTRIBUTE RATING ASSOCIATED WITH EACH SENSITIVITY LEVEL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Water quality | Biodiversity | Hydrological | Habitat quality | Low | Medium | High | Very High |
| | | | | | | | | | | | areas identified for threatened fish species] |
| | | FISHREHAB | Rated SQ | | X | | | | | 1 [sub-quaternaries identified as necessary for rehabilitation for threatened fish species] | |
| | | FISHFEPA | Rated SQ | | X | | | | | | 1 [Fish sanctuary, translocation, relocation zones in AB condition for threatened fish species] |
| | | FISHFSA | Rated SQ | | X | | | | | 1 [Fish sanctuary, translocation, relocation zones NOT in AB condition for threatened fish species] | |
| NFEPA | Fishsanc All Spp | NOFISSANC | Descriptive | | X | | | 0 [no of threatened and near-threatened fish species in sub-quaternary] | | 1-2 [no of threatened and near-threatened fish species in sub-quaternary] | >2 [no of threatened and near-threatened fish species in sub-quaternary] |
| | | STATUS | Rated SQ | | X | | | | | 1 [At least 1 | 2 [At least 1 fish |

| DATASET | DATA | ATTRIBUTE | SCALE | CONTRIBUTION TO SENSITIVITY RATING TYPE | | | | ATTRIBUTE RATING ASSOCIATED WITH EACH SENSITIVITY LEVEL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Water quality | Biodiversity | Hydrological | Habitat quality | Low | Medium | High | Very High |
| | | | | | | | | | | vulnerable or near-threatened fish species known in sub-quaternary] | species in in sub-quaternary is endangered or critically endangered] |
| **SUPPLEMENTARY FISH DATA** | | | | | | | | | | | |
| SANBI IUCN fish data | SANBI supplementary fish species: Threatened taxa | BINOMIAL (species name) | Count data for species data – each overlaid | | X | | | 0 [no of threatened species] | | 1-2 [no of threatened species] | >2 [no of threatened species] |
| MPTA | MPTA data of concern (FISH) (MTPA_concerns_aquaSEA) | MTPA CONC | Rated polygons | | X | | | | 3 [areas where there are concerns with regard to aquaculture but no critical flaws and restricted or controlled aquaculture could occur] | | 1 [areas where no aquaculture should occur on account of species of conservation concern and biodiversity sector plan] |
| SKEP | SKEP data of concern | NO_ENDEME | Rated buffered line | | X | | X | | | | ≥1 [No endemics in mapped polygon] |
| SKEP | SKEP data of concern | Biodiversity | Rated buffered line | | x | | X | | | | 1 [polygon is a local centre for aquatic endemism] |
| ECape Fish – MARXAN | Excel spreadsheet with sites and SQHASH links | OCCUR CODES | Rated SQ | | X | | | 0 [Was recorded but probably | 1 Present, Low confidence: | 3 [Present, moderate confidence; achieve | 5 [Present, High confidence; Achieve |

| DATASET | DATA | ATTRIBUTE | SCALE | CONTRIBUTION TO SENSITIVITY RATING TYPE | | | | ATTRIBUTE RATING ASSOCIATED WITH EACH SENSITIVITY LEVEL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Water quality | Biodiversity | Hydrological | Habitat quality | Low | Medium | High | Very High |
| | | | | | | | | absent now; include if target can't be met elsewhere] | Achieve target here THIRD] | target here SECOND] | target here FIRST] |
| **CONDITION DATA: PES / EI AND ES AND LANDUSE (NB ECape, KZN and WCape use terrestrial CBAs or landuse instead)** | | | | | | | | | | | |
| DWS (2014) desktop PESEIS | PESEIES | PES CATEGO | Rated line | X | X | X | X | | E,F | C,D | A, B |
| | | MEAN EI CL | Rated line | X | X | X | X | LOW | MODERATE | HIGH | VERY HIGH |
| | | MEAN ES CL | Rated line | X | X | X | X | LOW | MODERATE | HIGH | VERY HIGH |
| **AQUATIC CBA DATA** | | | | | | | | | | | |
| <u>WESTERN CAPE</u> CBA (2017) | CBA-WC | SUB CAT2 | Rated buffered polygons | X | X | X | X | | CBA: TERRESTRIAL | | CBA:RIVER CBA:WETLAND |
| | ESA-WC | SUBCAT1 | Rated buffered polygons | X | X | X | X | | ESA AQUATIC ESA TERRESTRIAL | | |
| <u>EASTERN CAPE</u>: AA_CBA_MAP_DRAFT2 (2017) | W_CBA1_EC_FreshwaterMARXAN_River_BUFFER1km_v1 | W_CBA1 | Polygons – buffered by 1km | | X | | X | | 3 [ESA1] | | |
| | W_CBA1_EC_FreshwaterMARXAN_Rivers_20170619_v1 | F_CBA1 | Rated buffered lines | | X | | X | | 3, 2 [ESA2 and CBA2, respectively] | 4 | 5 [CBA1] |
| | W_CBA4_StrategicWaterAreas_v1 | F_CBA4 | Rated areas (SQ) | X | | X | | | 3, 2 [ESAs] | | |
| | W_CBA7_EC_Integrated Wetlands_v1 | F_CBA7 | Rated polygons – buffered by 100m in sensitivity layer | | X | | X | | 3 | | 4 |
| | lc_int2014 Image file | LC5_CLASS | Rated polygons | X | X | X | X | | | Natural | |
| KZN 2016 | KZN_CBA_Optimal_wll_03032016 | LEGEND | Buffered polygons | | X | | X | | ESA | | |
| | KZN_ESA_wll_01022016 | | Buffered polygons | | X | | X | | | CBA-OPTIMAL | |

| DATASET | DATA | ATTRIBUTE | SCALE | CONTRIBUTION TO SENSITIVITY RATING TYPE | | | | ATTRIBUTE RATING ASSOCIATED WITH EACH SENSITIVITY LEVEL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Water quality | Biodiversity | Hydrological | Habitat quality | Low | Medium | High | Very High |
| Gauteng: C-Plan (GDARD 2014) | Gauteng: C-Plan v33 1110 ge | BDF DESC and CATEGORY | Rated buffered polygons | X | X | X | X | | Prior Quat Catch Pan cluster & CATEGORY= ESA | | Prior Quat Catch Pan cluster & CATEGORY= CBA |
| **PROTECTED AREA DATA** | | | | | | | | | | | |
| SAPAD | | MAJ_TYPE | Rated buffered polygons | X | X | X | X | | | | PA [Protected Environment] |

# APPENDIX 3: SENSITIVITY MAPS

# Appendix 3

## Sensitivity Maps

## Revised: November 2019

**Figure A3.1: Eastern Cape**

Results of sensitivity assessment – data layers included and rated as outlined in Table A2.2 (Appendix 2) and Section 4.3. See Table A2.1 (Appendix 2) for data sources. Sensitivity ratings shown are the highest accorded per sub-quaternary for any sensitivity criterion. Inset: Study area coded with FEPA River data.

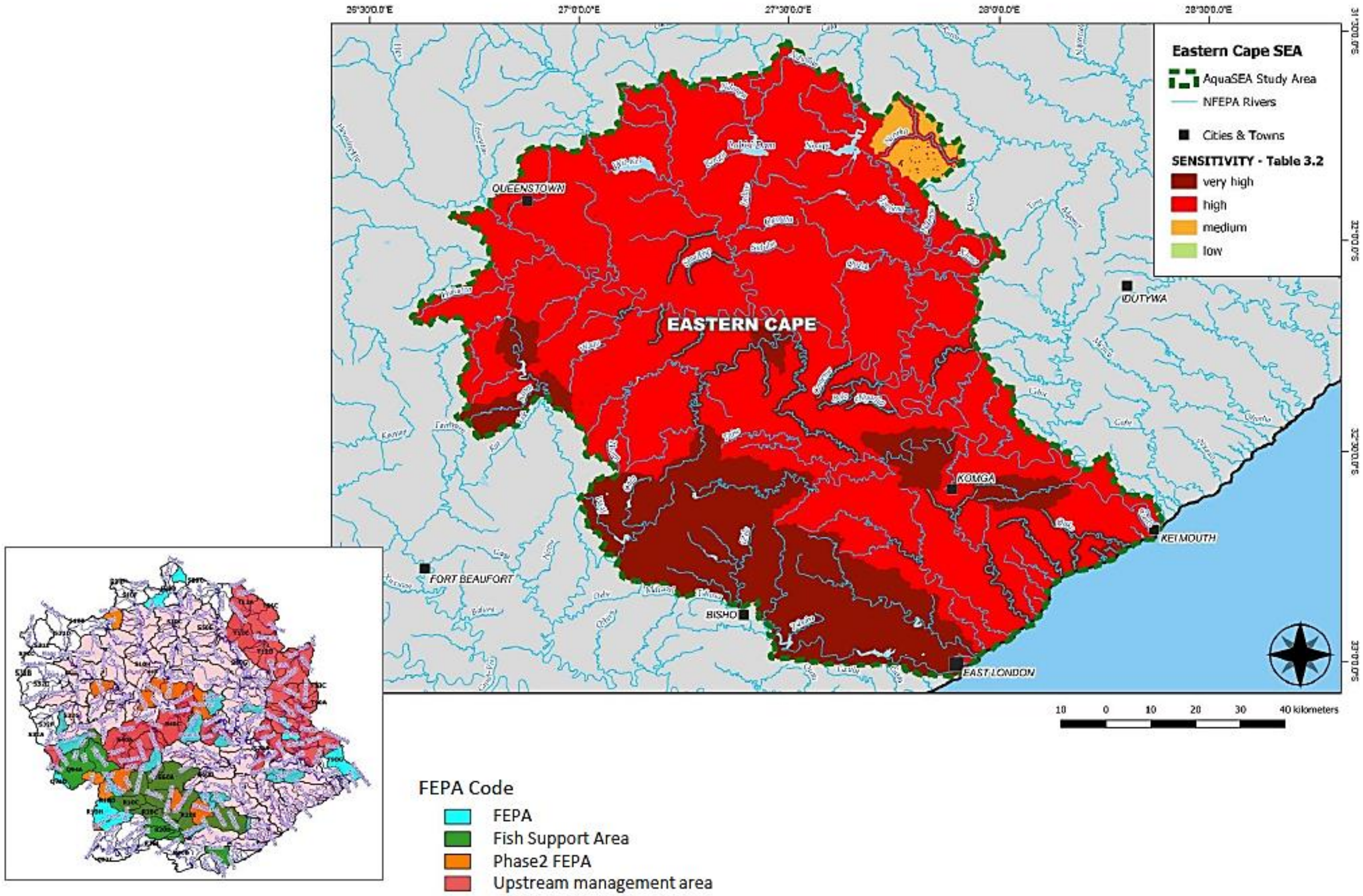


**Figure A3.2: -Eastern Cape Protected Areas and river attributes**

Inputs into Sensitivity assessment, showing locations of protected areas (all rated Very high sensitivity/ no development areas), seasonal rivers and "flagship" or free flowing rivers – these are of particularly high conservation importance. See also baseline figures in Appendix 1

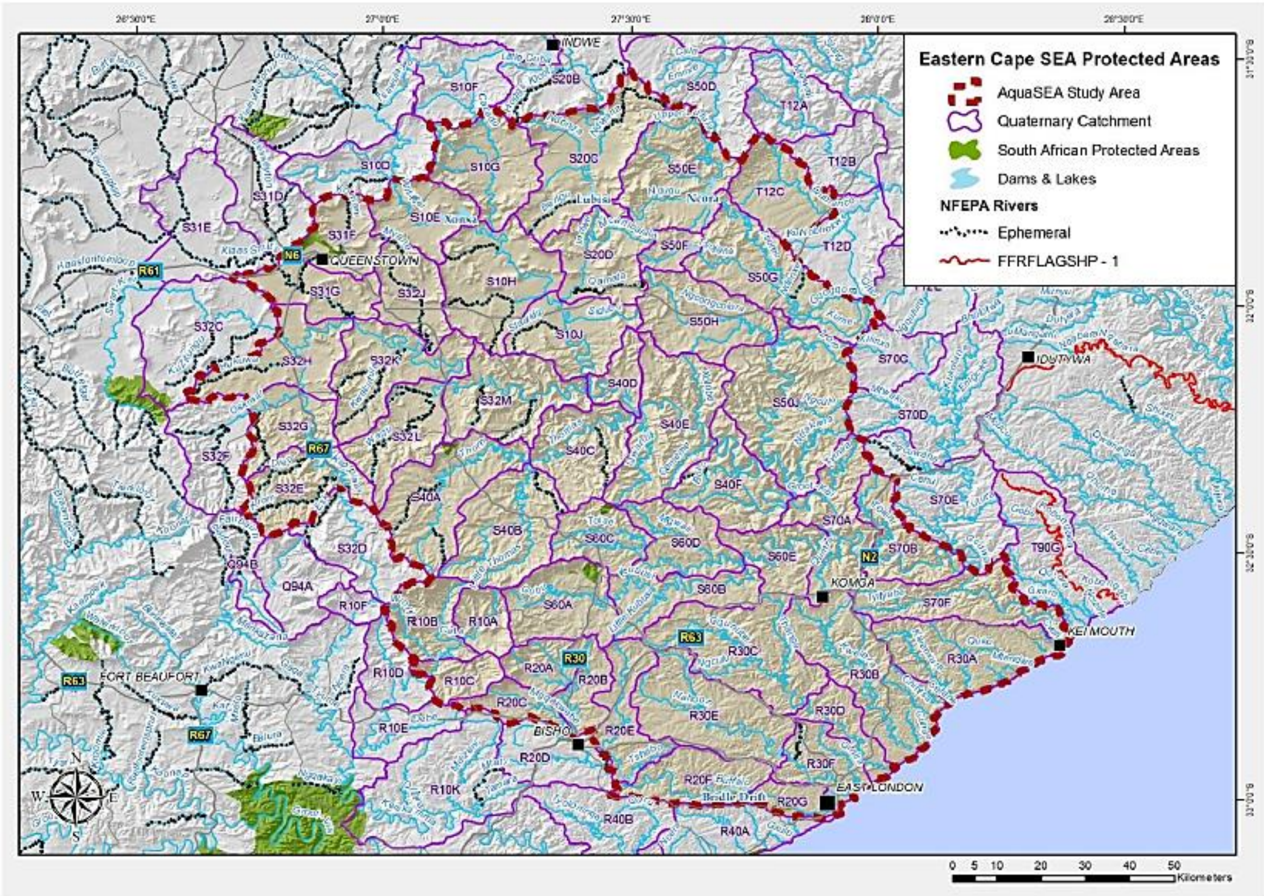


**Figure A3.3: Free State – KwaZulu Natal**

Results of sensitivity assessment – data layers included and rated as outlined in Table A2.2 (Appendix 2) and Section 4.3. See Table A2.1 (Appendix 2) for data sources. Sensitivity ratings shown are the highest accorded per sub-quaternary for any sensitivity criterion. Inset: Study area coded with FEPA River

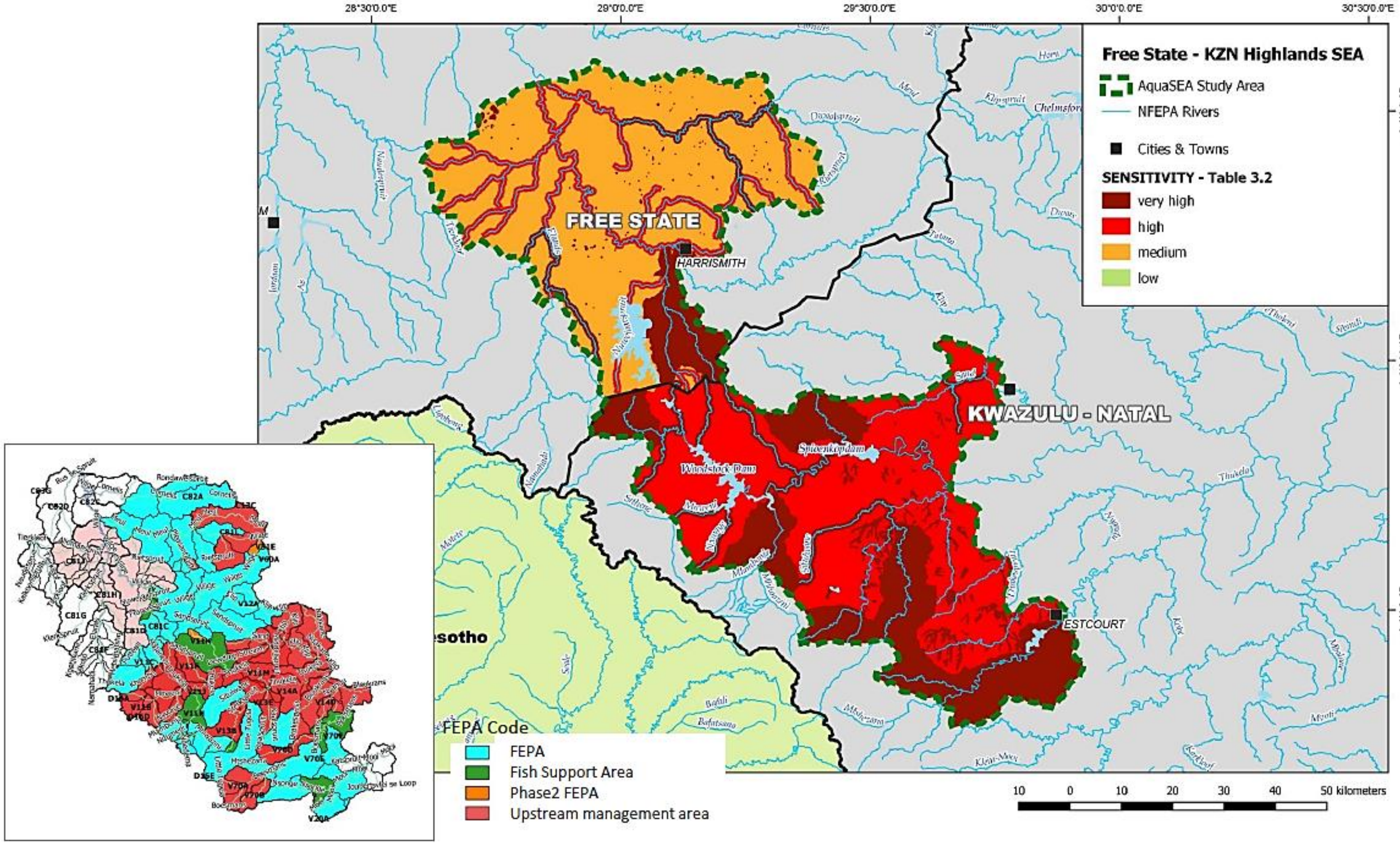


**Figure A3.4: Free State – KwaZulu-Natal Protected Areas and river attributes**

Inputs into Sensitivity assessment, showing locations of protected areas (all rated Very high sensitivity/ no development areas), seasonal rivers and "flagship" or free flowing rivers – these are of particularly high conservation importance. See also baseline figures in Section 3.3

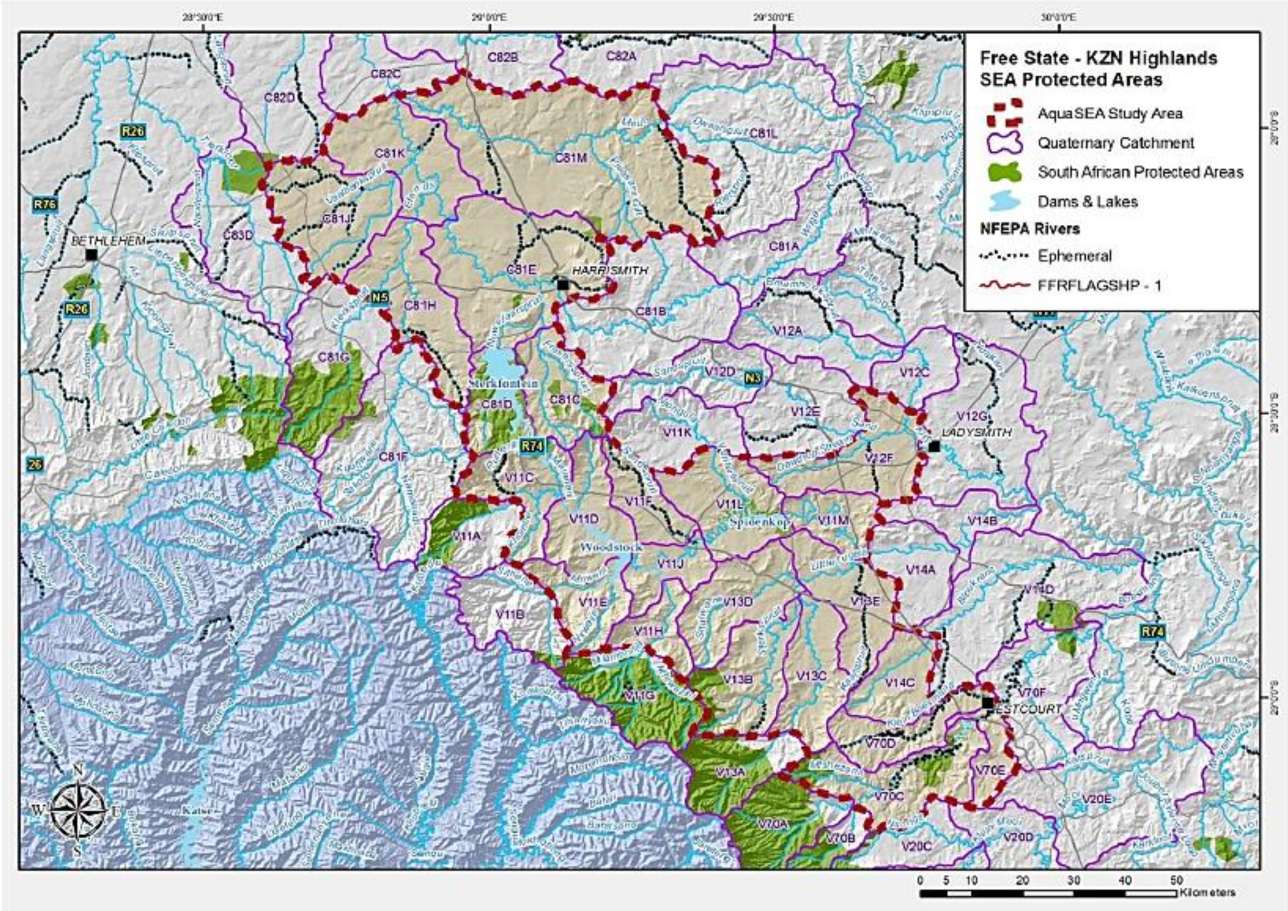
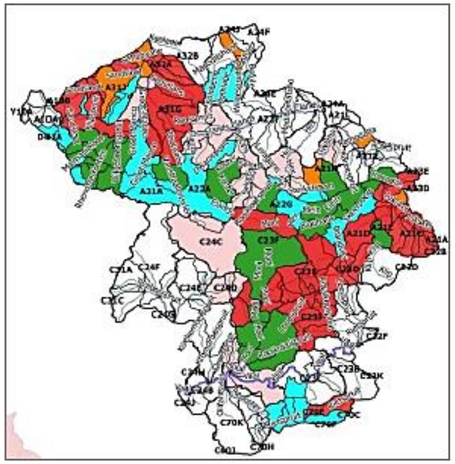
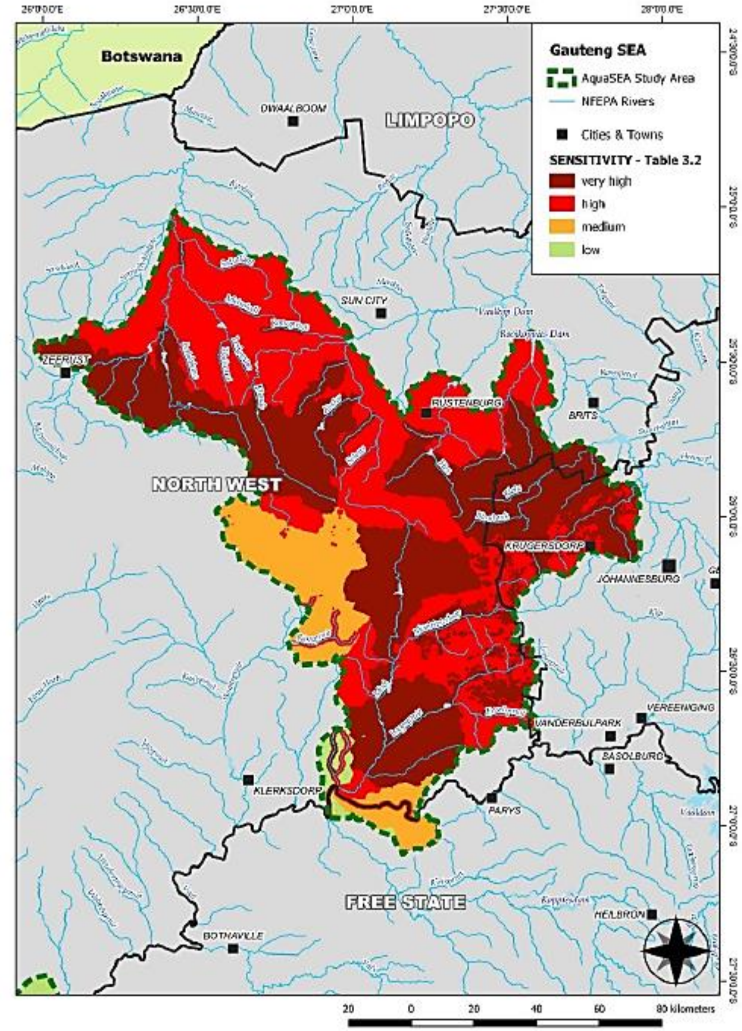


**Figure A3.5: Gauteng – North West**

Results of sensitivity assessment – data layers included and rated as outlined in Table A2.2 (Appendix 2) and Section 4.3. See Table A2.1 (Appendix 2) for data sources. Sensitivity ratings shown are the highest accorded per sub-quaternary for any sensitivity criterion. Inset: Study area coded with FEPA River






**FEPA Code**

- FEPA
- Fish Support Area
- Phase2 FEPA
- Upstream management area

**Figure A3.6: Gauteng – North West Protected Areas and river attributes**

Inputs into Sensitivity assessment, showing locations of protected areas (all rated Very high sensitivity/ no development areas), seasonal rivers and "flagship" or free flowing rivers – these are of particularly high conservation importance. See also baseline figures in Section 3.3

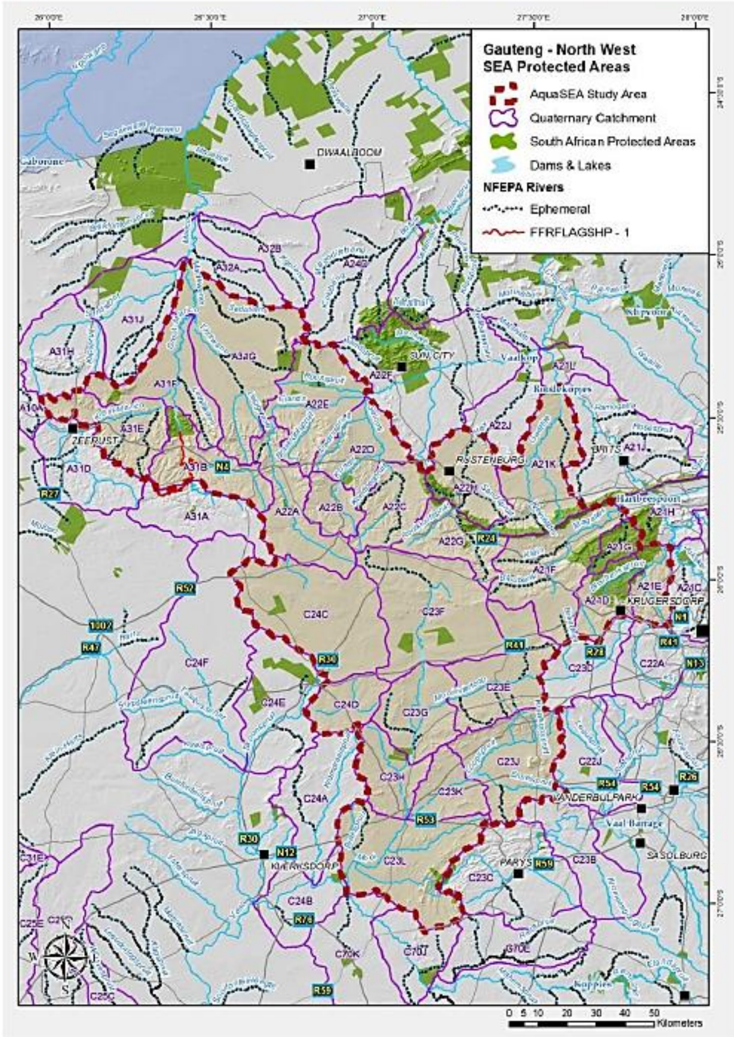
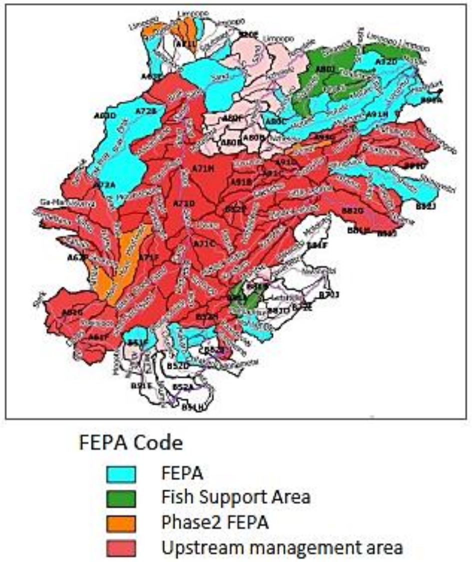
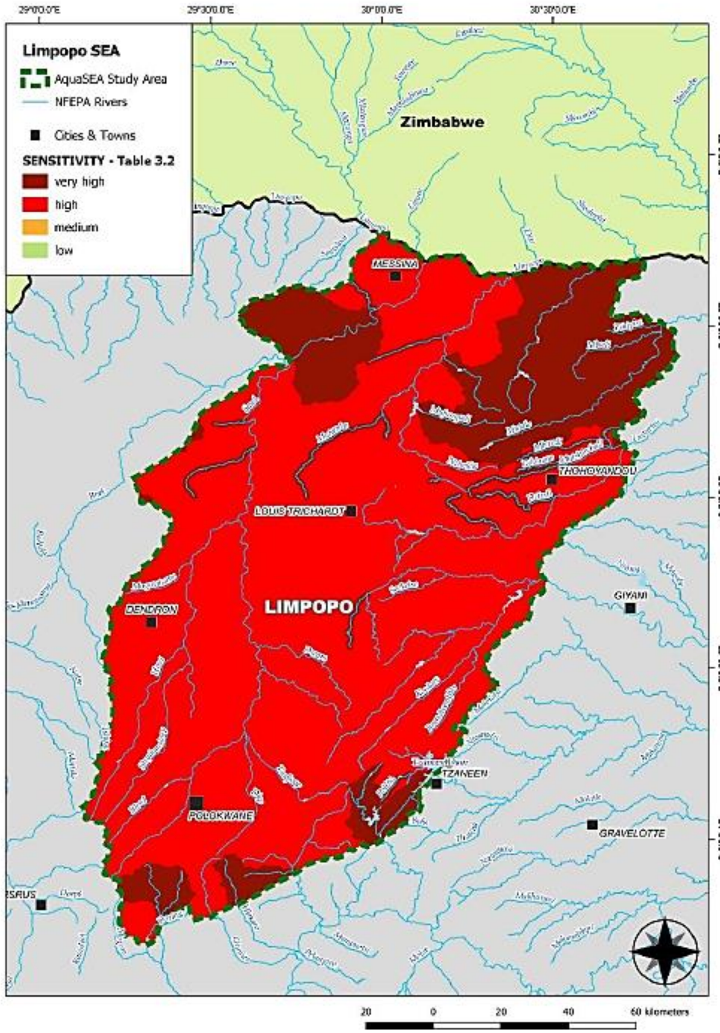


**Figure A3.7: Limpopo**

Results of sensitivity assessment – data layers included and rated as outlined in Table A2.2 (Appendix 2) and Section 4.3. See Table A2.1 (Appendix 2) for data sources. Sensitivity ratings shown are the highest accorded per sub-quaternary for any sensitivity criterion. Inset: Study area coded with FEPA River



## Figure A3.8: Limpopo Protected Areas and river attributes

Inputs into Sensitivity assessment, showing locations of protected areas (all rated Very high sensitivity/ no development areas), seasonal rivers and "flagship" or free flowing rivers – these are of particularly high conservation importance. See also baseline figures in Section 3.3

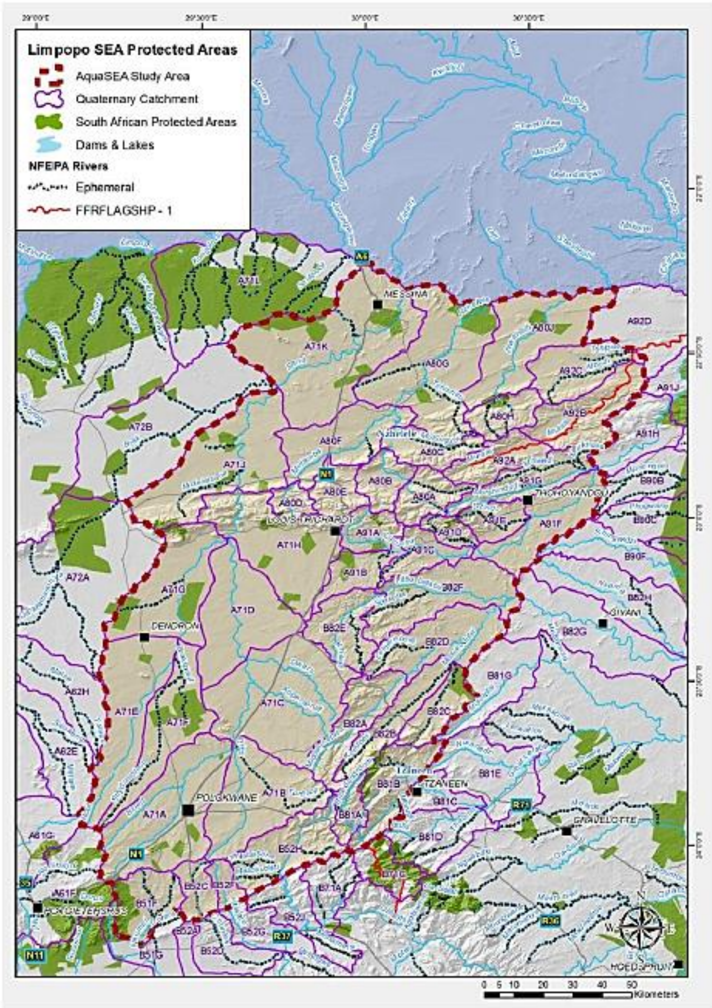
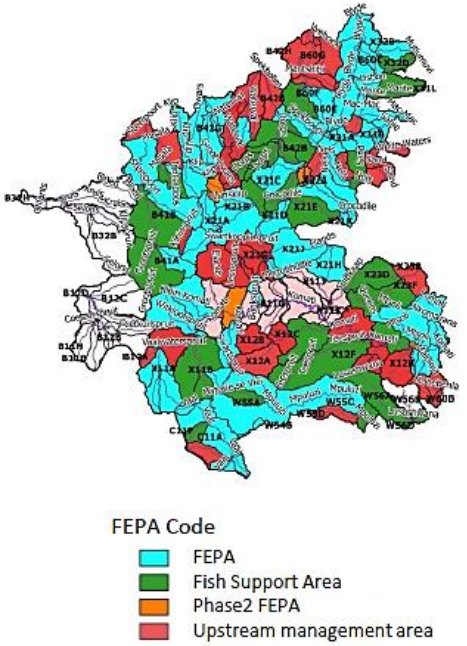


**Figure A3.9: Mpumalanga**

Results of sensitivity assessment – data layers included and rated as outlined in Table A2.2 (Appendix 2) and Section 4.3. See Table A2.1 (Appendix 2) for data sources. Sensitivity ratings shown are the highest accorded per sub-quaternary for any sensitivity criterion. Inset: Study area coded with FEPA River



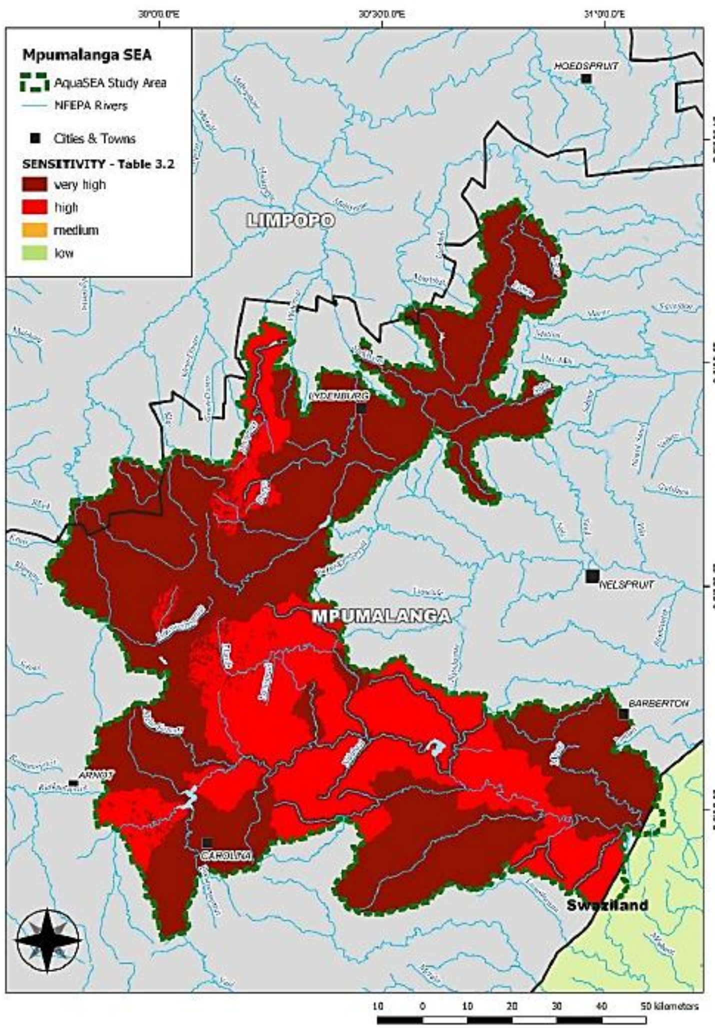



**Figure A3.10: Mpumalanga Protected Areas and river attributes**

Inputs into Sensitivity assessment, showing locations of protected areas (all rated Very high sensitivity/ no development areas), seasonal rivers and "flagship" or free flowing rivers – these are of particularly high conservation importance. See also baseline figures in Section 3.3

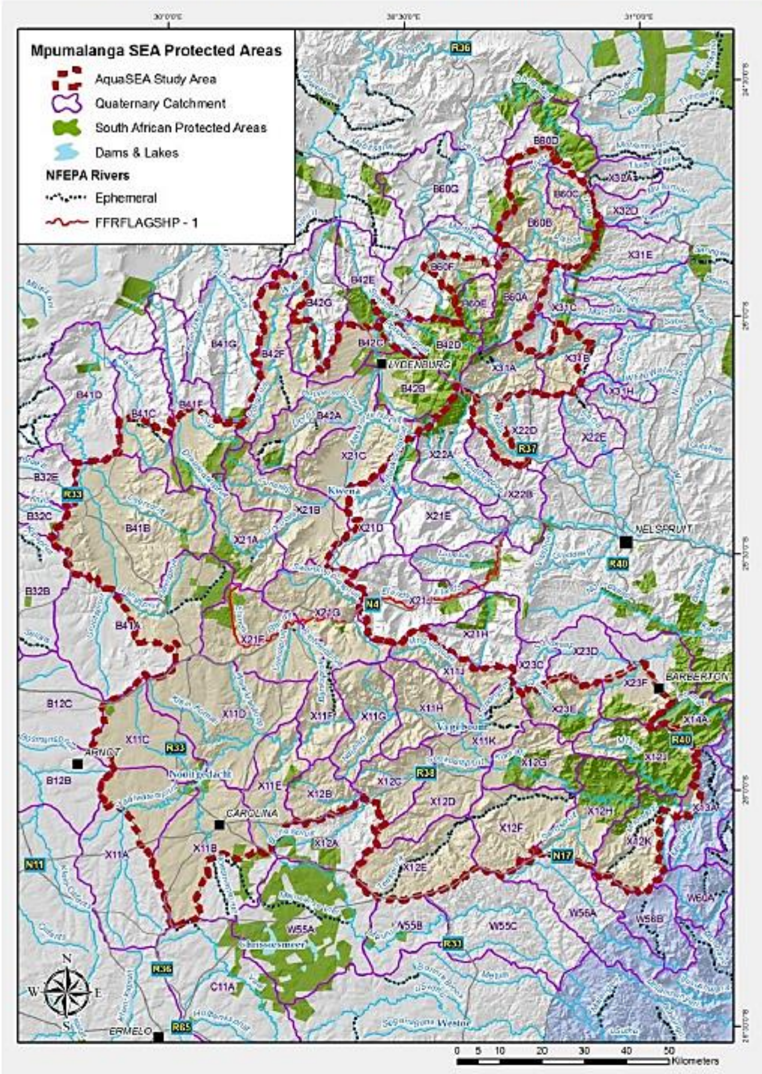


**Figure A3.11: Richards Bay**

Results of sensitivity assessment – data layers included and rated as outlined in Table A2.2 (Appendix 2) and Section 4.3. See Table A2.1 (Appendix 2) for data sources. Sensitivity ratings shown are the highest accorded per sub-quaternary for any sensitivity criterion. Inset: Study area coded with FEPA River

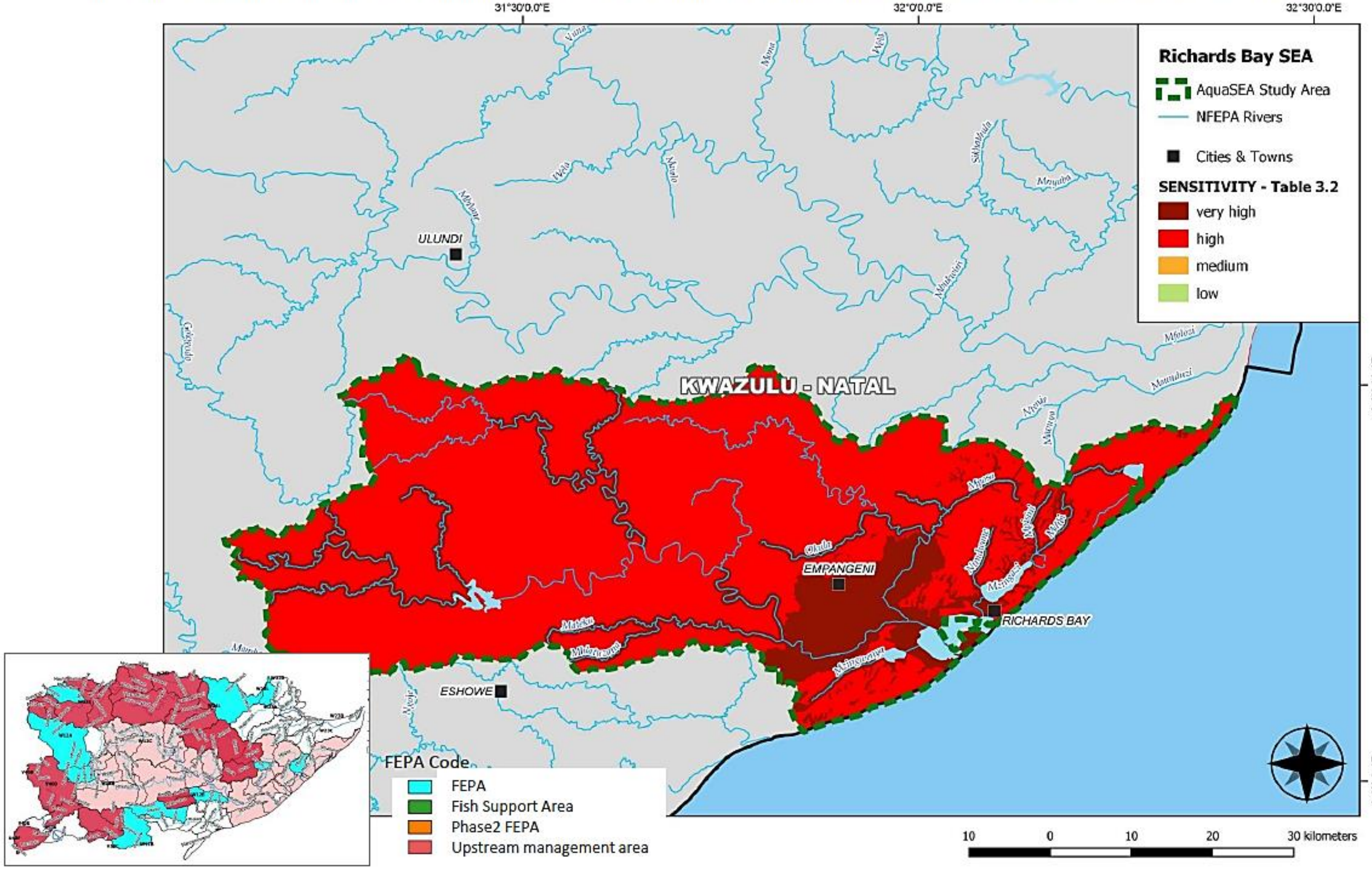


**Figure A3.12: Richards Bay Protected Areas and river attributes**

Inputs into Sensitivity assessment, showing locations of protected areas (all rated Very high sensitivity/ no development areas), seasonal rivers and "flagship" or free flowing rivers – these are of particularly high conservation importance. See also baseline figures in Section 3.3

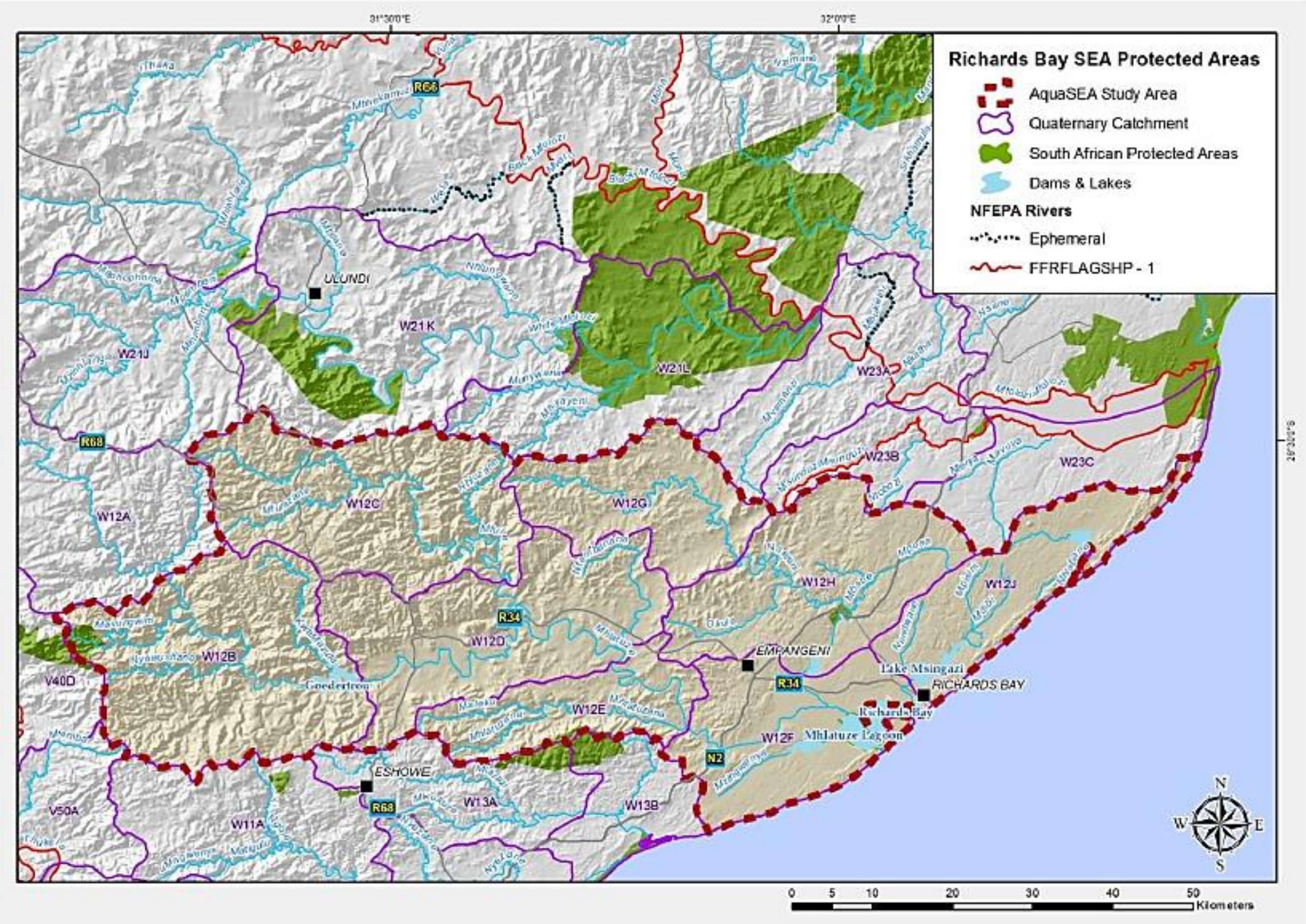


**Figure A3.13: Western Cape**

Results of sensitivity assessment – data layers included and rated as outlined in Table A2.2 (Appendix 2) and Section 4.3. See Table A2.1 (Appendix 2) for data sources. Sensitivity ratings shown are the highest accorded per sub-quaternary for any sensitivity criterion. Inset: Study area coded with FEPA River

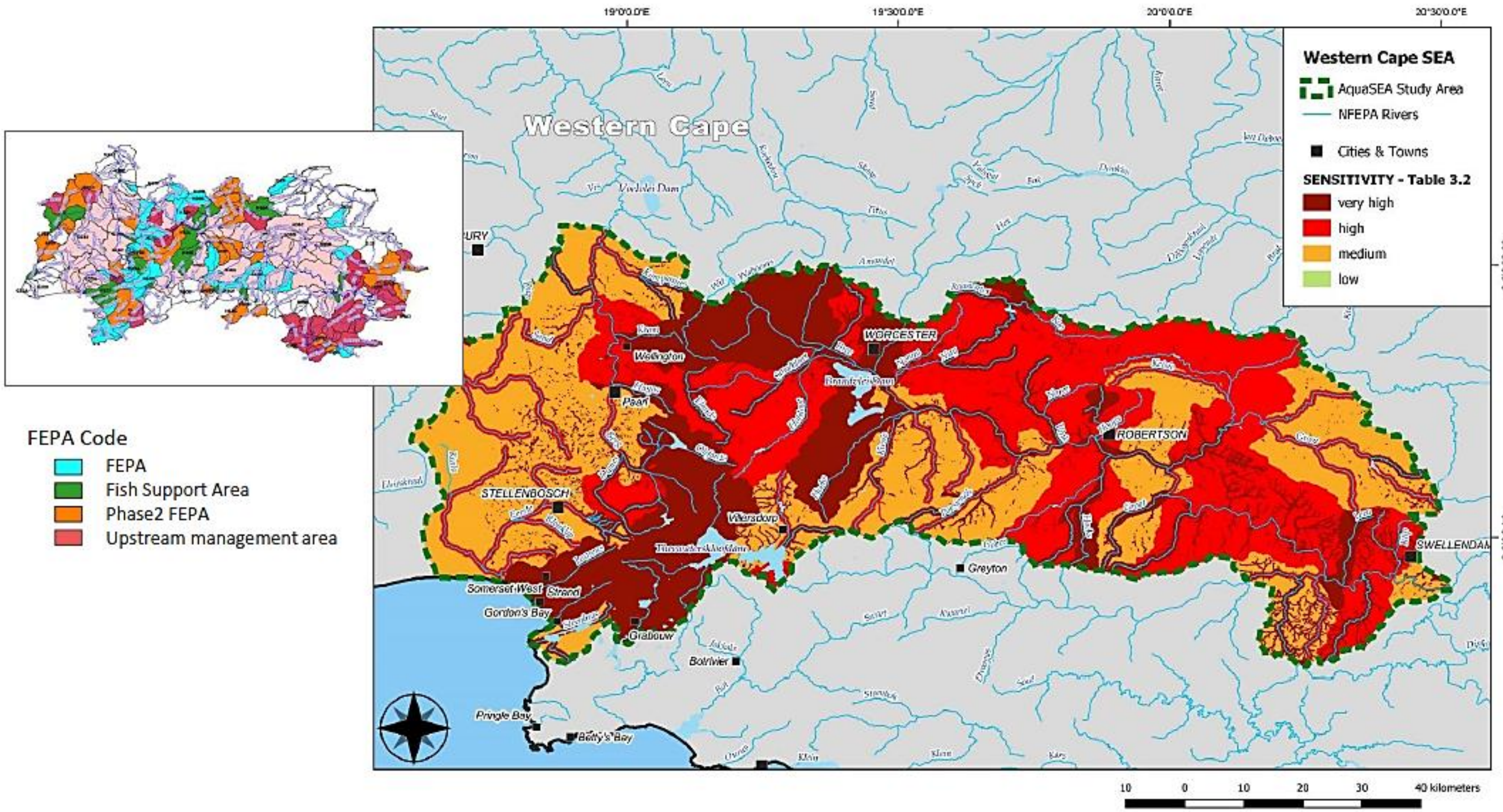


**Figure A3.14: Western Cape Protected Areas and river attributes**

**Inputs into Sensitivity assessment, showing locations of protected areas (all rated Very high sensitivity/ no development areas), seasonal rivers and "flagship" or free flowing rivers – these are of particularly high conservation importance. See also baseline figures in Section 3.3**

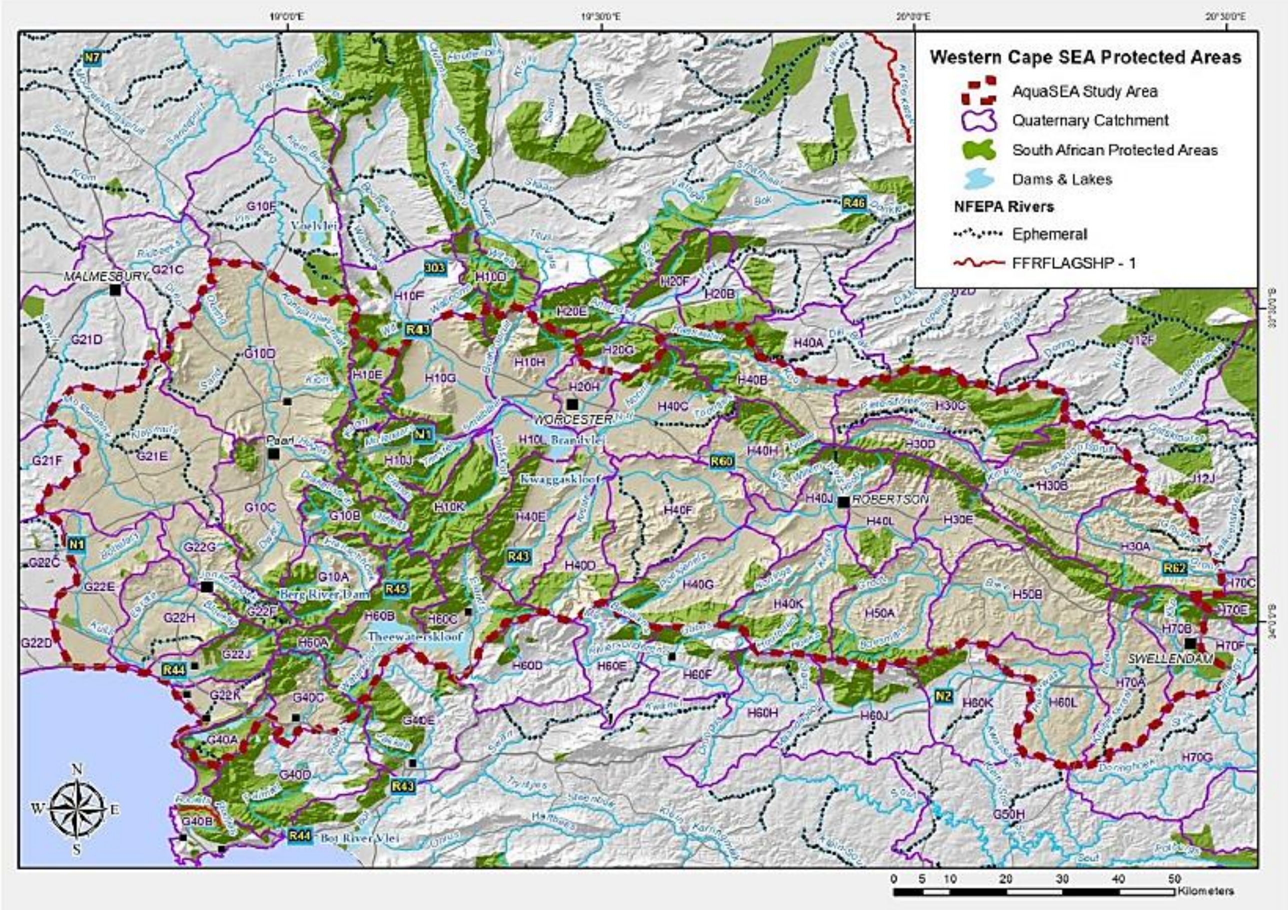


**Figure A3.15: Vaalharts**

Results of sensitivity assessment – data layers included and rated as outlined in Table A2.2 (Appendix 2) and Section 4.3. See Table A2.1 (Appendix 2) for data sources. Sensitivity ratings shown are the highest accorded per sub-quaternary for any sensitivity criterion. Inset: Study area coded with FEPA River

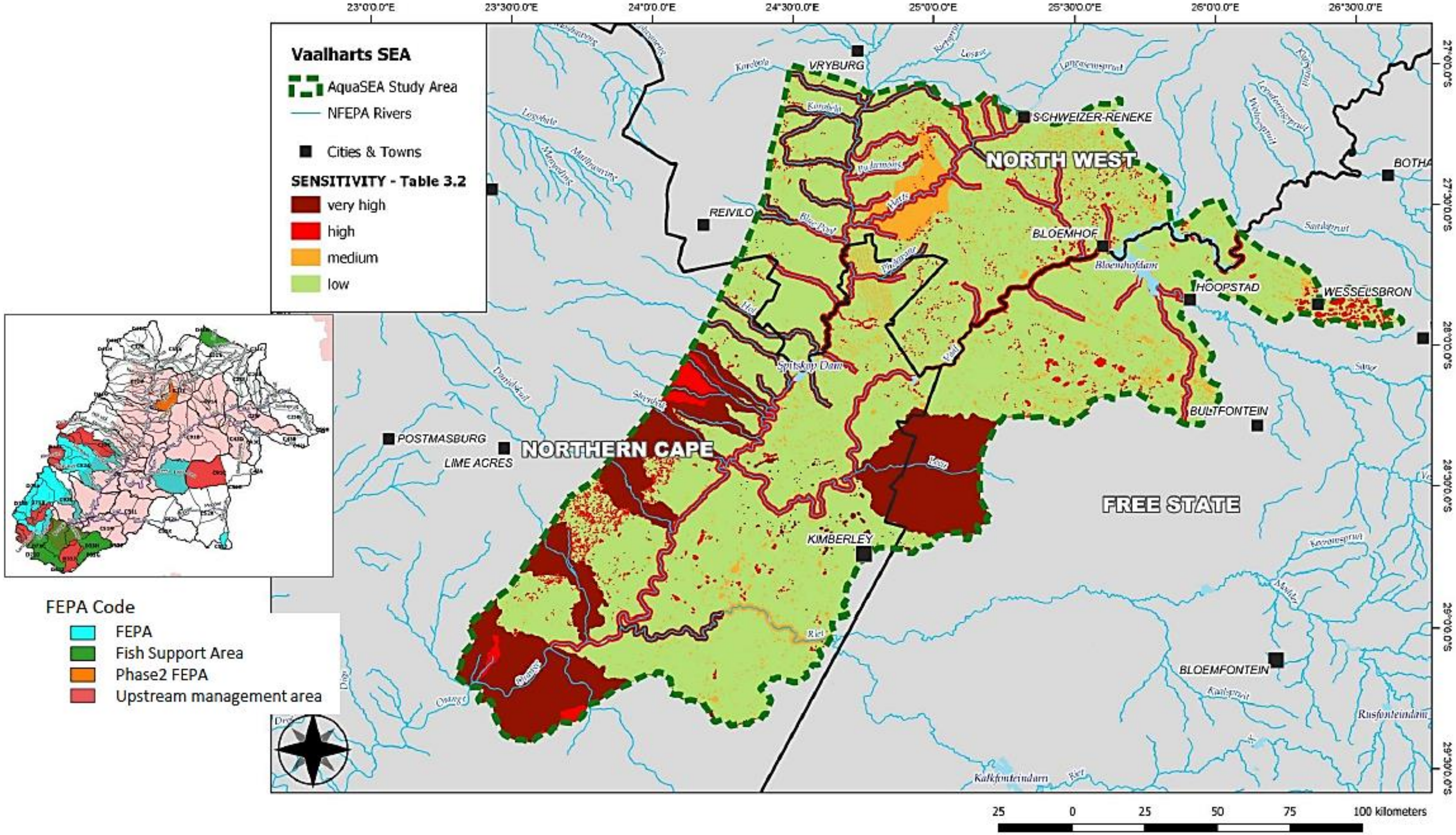


**Figure A3.16: Vaalharts Protected Areas and river attributes**

**Inputs into Sensitivity assessment, showing locations of protected areas (all rated Very high sensitivity/ no development areas), seasonal rivers and "flagship" or free flowing rivers – these are of particularly high conservation importance. See also baseline figures in Section 3.3**

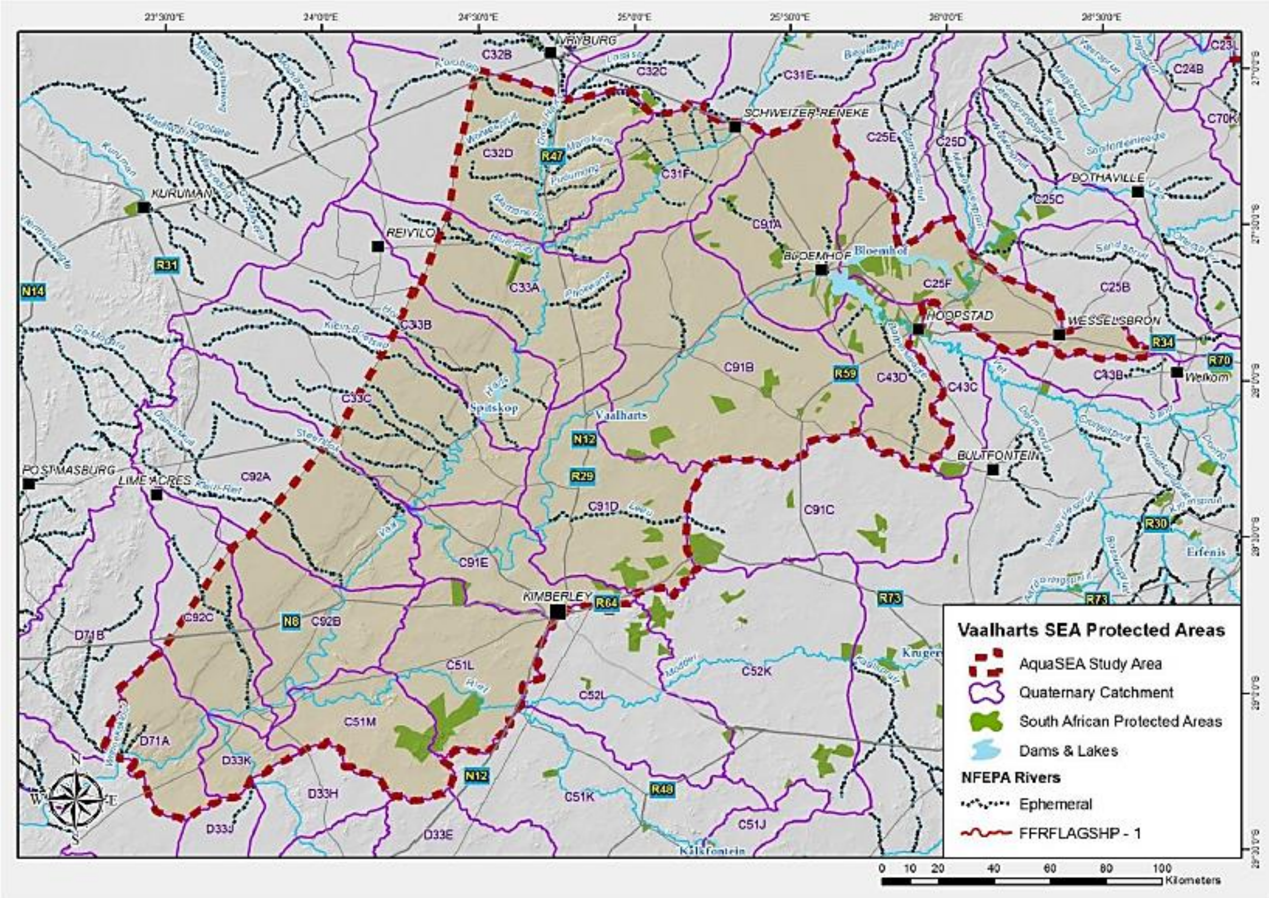


**Figure A3.17: Vanderkloof-Gariep**

Results of sensitivity assessment – data layers included and rated as outlined in Table A2.2 (Appendix 2) and Section 4.3. See Table A2.1 (Appendix 2) for data sources. Sensitivity ratings shown are the highest accorded per sub-quaternary for any sensitivity criterion. Inset: Study area coded with FEPA River

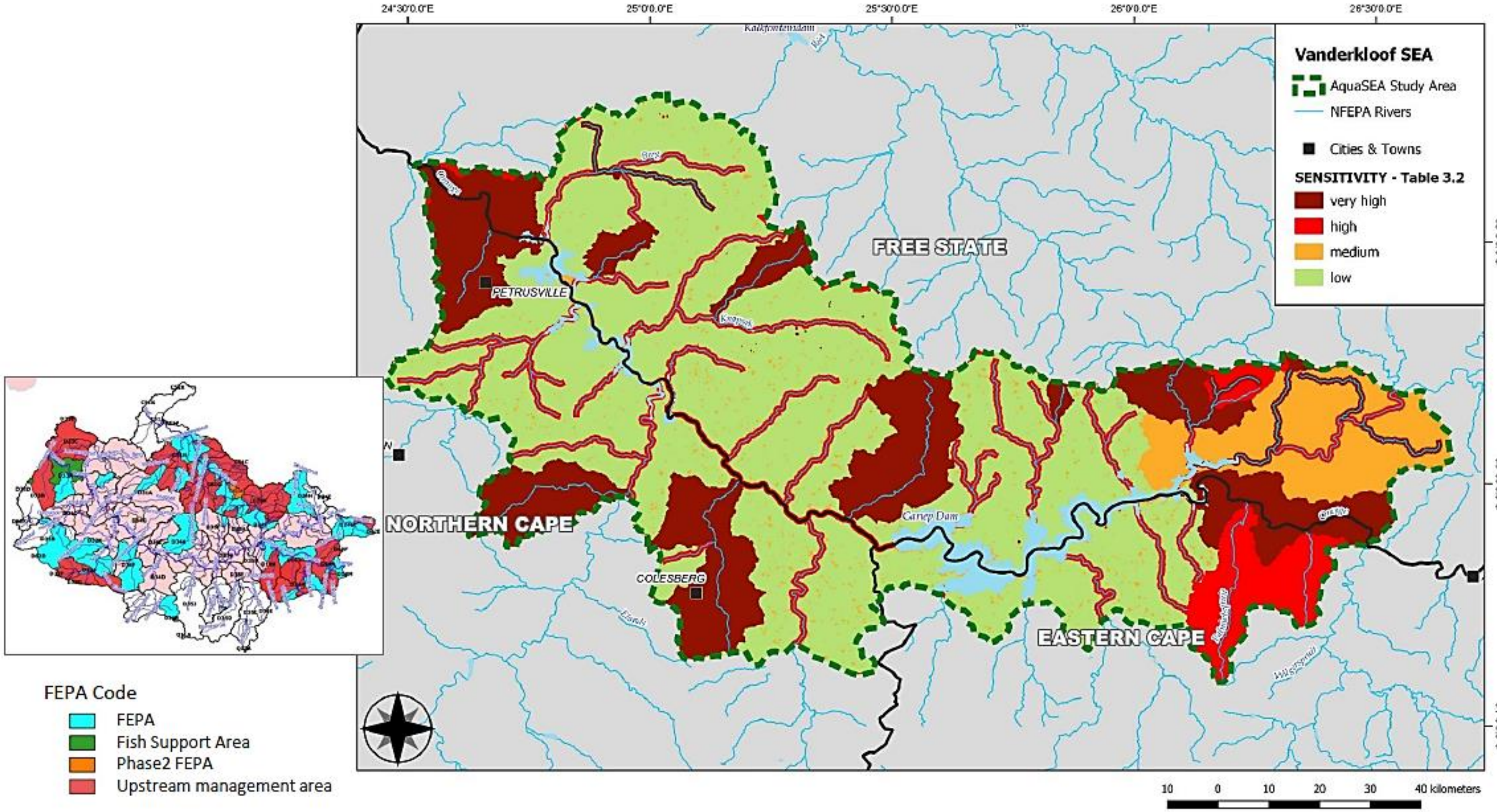


**Figure A3.18: Vanderkloof-Gariep Protected Areas and river attributes**

**Inputs into Sensitivity assessment, showing locations of protected areas (all rated Very high sensitivity/ no development areas), seasonal rivers and "flagship" or free flowing rivers – these are of particularly high conservation importance. See also baseline figures in Section 3.3**