Management of multiple stressors to the lower reach of the Thukela River ecosystem

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ABSTRACT

South Africa is a water scarce country which is experiencing an increase in the demand and development of water resources. The Thukela River in KwaZulu-Natal is the second largest river in South Africa and the largest in the KwaZulu-Natal Water Management Area. It is a key component of maintaining water security locally and in the rest of South Africa with several inter-basin transfer schemes. The lower reach of the Thukela River and associated estuary have been characterised as an ecologically important section of the Thukela River catchment as the river flows into the Indian Ocean and largely contributes to the formation of the Thukela Banks, a large mud bank off the coast that is also an important fisheries area. The eMandeni Stream is a tributary of the Thukela River, which has been augmented from a drainage line into a stream through the constant release of effluent from upstream industries and waste water treatment works. It is a highly impacted stream that flows into the lower reach of the Thukela River upstream of the Thukela Estuary. The aim of the study was to: 1) Review the historical and biodiversity information of the most developed areas within Thukela River catchment; 2) assess the trends in the wellbeing of the ecosystem of the lower reach of the Thukela River and 3) review a regional scale ecological risk assessment to evaluate the ecological consequences of alternative water use and protection scenarios on the water resources within the study area.

The outcomes of the study indicate that the Thukela River is an important water resource for the people of South Africa and its growing economy, through the various goods and services it provides. Unfortunately, the uncontrolled use of the water resources often has a negative impact on the associated aquatic ecosystem. The aquatic ecosystem in many of the rivers' reaches within the catchment are ecologically important and sensitive with various areas categorised as fish support and sanctuary areas. The lower reach of the Thukela River is currently in a fair state, but historical trends indicate that it has fluctuated between a fair and poor state. These results were generally lower than the results of the 2003-2004 Reserve study,

and mostly did not attain the high C (fair state) recommended ecological reserve category set for this reach of the river. The eMandeni Stream is highly impacted by stressors associated with the upstream Isithebe Industrial complex, the waste water treatment works and the Sappi mill but only marginally impacts the Thukela River due to the size and dilution capacity of the Thukela River. Low flows will make the Thukela River more sensitive to these stressors and may impact on the health of the associate marine environment. The risk assessment highlighted the benefits to the Thukela River, if partially treated effluent from the Sappi mill was released into eMandeni Stream as a management option to consider. It is recommended that possible impacts to the Thukela Estuary and the offshore Thukela Bank need to be taken into consideration when any management decisions are made. The results of the risk assessment must be validated, and an updated Ecological Reserve study should be completed for the Thukela River, taking into consideration the freshwater requirements of the marine environment. Resource Quality Objective should also be established to enable decision makers to make informed decisions on the management of the Thukela system. The functionality of the UBTS fishways should be investigated as well as the impacts of the weir as a barrier for fish migration. Changes in water resource use practices is required to attain a better balance between the use and protection of the lower reach of the Thukela River and estuary.

PREFACE

The data described in this dissertation were collected in Kwazulu-Natal, Republic of South Africa from January 2017 to June 2018. Experimental work was carried out while registered at the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Dr. Gordon O'Brien and Prof. Graham Jewitt.

This dissertation, submitted for the degree of Master of Science in the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, School of Life Sciences, Pietermaritzburg campus, represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others, it is duly acknowledged in the text.

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Melissa Wade

February 2019

I certify that the above statement is correct and as the candidate's supervisor I have approved this dissertation for submission.

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Dr Gordon C. O'Brien

Supervisor

February 2019

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DECLARATION 1 - PLAGIARISM

I, Melissa Wade, declare that

1. The research reported in this dissertation, except where otherwise indicated, is my original research.

2. This dissertation has not been submitted for any degree or examination at any other university.

3. This dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

4. This dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
   a. Their words have been re-written but the general information attributed to them has been referenced
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Melissa Wade

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DECLARATION 2 - PUBLICATIONS

DETAILS OF CONTRIBUTION TO PUBLICATIONS that form part and/or include research presented in this dissertation.

Publication 1: Literature review (Chapter 2).

Authors: Wade M, O'Brien GC and Jewitt G.

Ms title: Review of the socio-ecological importance of the lower Thukela River, South Africa: its past, present and future.

Author contributions:

MW conceived paper with GOB and GJ. MW collected and analysed data, and wrote the paper. GOB & GJ edited the manuscript and provided valuable comments.

Publication 2: Ten year river monitoring review and assessment (Chapter 3).

Authors: Wade M, O'Brien GC, Desai M and Jewitt G.

Ms title: Ten years of change in the wellbeing of the lower Thukela River ecosystem associated with water resources use, South Africa.

Author contributions:

MW conceived paper with GOB and GJ. MW collected and analysed data, and wrote the paper. MD analysed data and provided information. GOB & GJ edited the manuscript and provided valuable comments.

Publication 3: Risk assessment (Chapter 3).

Authors: Wade M, O'Brien GC, Stassen R, Desai M and Jewitt G.

Ms title: Regional scale Ecological Risk of multiple stressors to the socio-ecologically important lower Thukela River, South Africa.

Author contributions:

MW conceived paper with GOB and GJ. MW, RS, MD collected and analysed data, and MW wrote the paper. GOB & GJ edited the manuscript and provided valuable comments.

Signed: ………………………………………………

Melissa Wade

February 2019

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CHAPTER 1

1 INTRODUCTION

South Africa can be characterised as being rich in biodiversity (DEAT, 1998) but poor in water resources (DWA, 2013). The scarcity of water in the country requires careful management to meet not just the basic water needs of the people of the country but also to ensure economic growth without threatening the wellbeing of the aquatic ecosystem (DWA, 2013). The National Water Act (Act No. 36 of 1998) is the legal framework to facilitate the sustainable management of the countries water resource by addressing the use, protection, development, control, conservation and management of the water resources (DWAF, 1999). As the demand for water increases, decision makers and managers are faced with the increasingly difficult task of sustaining the balance between the use and protection of water resources. One such example is the Thukela River catchment that not only meets the water requirements within its own catchment but is essential to supplying the water requirements of other areas in the country (DWA, 2013).

The Thukela River is the second largest river in South Africa and the largest river in KwaZulu-Natal (KZN), with a catchment area of over 28 000 km^2 and a mean annual runoff (MAR) of approximately 3 799 million m^3 (DWAF, 2003a; DWA, 2013). The Thukela River rises in the Drakensburg mountains and flows eastward until it flows through the open river mouth estuary into the Indian Ocean where the sediment load from the river forms the offshore Thukela Bank (De Lecea and Cooper, 2016). The major tributaries of the Thukela River include the Little Thukela, Bushmans, Mooi, Klip, Bloukrans, Sundays and Buffalo Rivers that together contain 88 quaternary catchments (DWAF, 2004a). The climatic conditions and rainfall patterns vary widely, ranging from cold and wet conditions in the Drakensberg, to hot and dry conditions in the Thukela valley, to hot and humid at the coast (DWAF, 2004a). The varied rainfall patterns results in extreme variability in flow during different seasons where the speed of the current can more than double during summer floods (Oliff, 1960a). The variation in the level of the river leads to cycles of exposure and inundation of banks and beds resulting in the ever-changing extent of habitats in the river which in turn effects the flora and fauna of the river (Oliff, 1960a).

The history of the utilisation of the Thukela River catchment dates back to long before European settlers arrived, were the catchment was home to various local indigenous tribes, including Shaka Zulu (Ross, 2008). Over time, the British annexed the region (Ross, 2008) and the discovery of gold and coal within the catchment led to the development of towns and later urban settlements including; Bergville, Colenso, Dannhauser, Dundee, Estcourt, Glencoe, Mooi River, Ladysmith, Newcastle, Utrecht, Volksrust, Mandeni, Winterton and Wakkerstroom (Kemp, 1967; DWAF, 2001, DWAF, 2003a). In these areas, water from the catchment is required for consumption and sanitation as well as other indirect uses and the growing need for reliable water supplies led to the development of extensive water related infrastructure including the construction of various dams and transfer schemes to among others, the Vaal and the uMgeni River systems (DWAF, 2003a; DWA, 2013). Other water usages include agriculture (subsistence and commercial), various industries, coal mining, power supply and timber (DWAF, 2003a). As the water requirements within the catchment increased, so has the impact on the receiving aquatic ecosystems.

The Thukela River has a variety of instream habitats, the condition of which vary considerably from season to season due to extreme variability in flow (Oliff, 1960a). The riparian vegetation of the river is mainly restricted to a few types of emergent marginal species due to the river’s rapid flows. The biotic communities of the river are also distinct, based on the main habitats in the various areas of the river (Oliff, 1960a). An Ecological Reserve Determination study undertaken of the whole Thukela River catchment in 2003 – 2004 indicated that the ecological state of the main stem river ranged from a Largely Natural state to a Largely Modified state

(DWAF, 2003b). Impacts to the Thukela River catchment include high organic and faecal eutrophication in certain rivers and the presence of *Escherichia coli* due to the establishment of informal settlements and the breakdown of municipal services. Pollution from dormant mines, effluent from industries, abstraction for irrigation and overgrazing of livestock all contribute to the modified state of the rivers within the Thukela River catchment (DWAF, 2003b).

Another important factor to consider is the impact that the reduction of flow within the Thukela River catchment has on the aquatic ecosystem. According to Van Niekerk and Turpie (2012), flow of the Thukela River had changed by 27% and this not only has an impact on the riverine fish life but has an significant impact on the receiving coastal and marine environment (DWAF, 2003c; Van Niekerk and Turpie, 2012; De Lecea and Cooper, 2016; Scharler *et al.*, 2016). The Thukela River plays an important role in forming the Thukela Banks as its estuary is river-dominated and small and allows most matter to pass through it into the sea. This riverine organic matter and nutrients from the Thukela River is very important as it largely maintains the biology of the KZN Bight, a continental shelf off the east coast of South Africa. It also supports subsistence, commercial and recreational fishing but possible future reductions in flow from the Thukela River, due to water abstraction, may negatively impact the ecology of the Bight (De Lecea and Cooper, 2016). The lower reach of the Thukela River is therefore important as it is the link between the river and the receiving marine environment.

The lower reach of the Thukela River from the confluence with the Nembe River to the Thukela Estuary, is about a 30 km stretch of river. On the northern bank of the river is the Sundumbili settlement and the town of Mandeni through which the eMandeni Stream flows. Upstream of the eMandeni Stream is the Isithebe industrial area and within Mandeni is the Sappi paper and pulp mill. On the Thukela River, upstream of the confluence with the eMandeni Stream is the Lower Thukela Bulk Water Supply Scheme which was completed in 2017 and supplies water to areas within the KwaDukuza and Mandeni Local Municipalities (Umgeni Water, 2017a). Impacts on the water resources in the area include various water quality related impacts, as well as water quantity and habitat state impacts (Stryftombolas 2008; DWAF 2003c) which could also be impacting the Thukela Estuary and ultimately the marine environment.

The task of managing an important and complex system like the Thukela River catchment is enormous as a large portion of South Africans directly or indirectly dependent on the ecological services provided by water resources within the catchment, but this use must be balanced with the protection of the resources to ensure the sustainability of the water resources in the future. The main aim of the study is to review the wellbeing of the socio-ecological system associated with the developed areas of the lower Thukela River catchment and provide considerations for the sustainable management of the river resources to mitigate excessive impacts on the river, estuary and marine environment. To achieve this aim the following objectives have been established:

- Review of the past and present development within the Thukela River catchment, how the water resources were used to support the socio-economic development of the region and how this has impacted on the aquatic ecosystem;
- Assess the trends in the wellbeing of the ecosystem of the lower reach of the Thukela River from 2008 to 2018;
- Undertake a regional scale ecological risk assessment to evaluate the ecological consequences of alternative water use and protection scenarios on the water resources within the study area.

Hypotheses established for this study include; (1) there is a decreasing trend in the ecological state of the lower reach of the Thukela River towards the threshold of sustainability, due to the increased use of water resources in the catchment, and (2) the risk assessment will show that the Sappi Thukela mill is having a negative impact on the lower reach of the Thukela River but

(3) through the implementation of mitigation measures, a better balance between the use and protection of the system can be achieved.

This dissertation is structured with stand-alone data chapters that are intended to be submitted to international peer review journals for publication. The chapters are:

Chapter 1: Introduction chapter

Chapter 2: The socio-ecological important Thukela River: a review of its past, present and future

Chapter 3: Trends in the wellbeing of the lower Thukela River ecosystem

Chapter 4: Relative Ecological Risk Assessment of Multiple Stressors to a Range of Social and Ecological Endpoints in the lower reach of the Thukela River

Chapter 5: Conclusions chapter.

CHAPTER 2

2 THE SOCIO-ECOLOGICAL IMPORTANT THUKELA RIVER: A REVIEW OF ITS PAST, PRESENT AND FUTURE

2.1 INTRODUCTION

South Africa is a semi-arid, water stressed country with an average rainfall of only 450 mm per year, that is unevenly distributed across the country (DEA, 2012). Unfortunately, it is adequate water resources that is a prerequisite for ensuring the social and economic development of a country as water is needed for all sectors including agriculture, energy, mining, industry, tourism, urban growth and rural development (DWA, 2013). It is not only the quantity of water that is available that is important but also the health of the aquatic ecosystems that need to be considered as addressed in the National Water Resource Strategy; "*The limited water resources require careful management to enable the provision of basic water services to every citizen, while meeting the needs of economic growth without threatening the environmental integrity of water resources*" (DWA, 2013). Challenges faced by resource managers include security of supply, environmental degradation and resource pollution (DWA, 2013). The demand for use and access of South African water resources is increasing and the current state of the water resources indicates that a change is required in the way water is managed, used and allocated to reach a balance between the use and protection of the water resources (DEA, 2012).

The major river basins in the South Africa include; the Vaal, Inkomati, Limpopo, Maputo, Orange-Senqu, Thukela and uMfolozi basins (DEA, 2012). Of these, the Thukela River in KwaZulu-Natal (KZN) (Figure 2.1), is the second largest river in South Africa and the largest river in the KZN Water Management Area (WMA) and is a critical component of water resource utilisation in South Africa (DWAF 2003a; DWA, 2013). The Thukela River means "*the Startling One"* and has a total catchment area of approximately 29 042 km^2 in extent and represents 31.8% of KZN's total surface area of approximately 91 481 km^2 (DWAF, 2004b).

There are eight major sub-catchments within the Thukela River catchment and these, in order downstream, include: The Upper Thukela (above Bergville), Little Thukela, Klip, Bushmans, Sundays, Mooi, Buffalo and Lower Thukela (Oliff, 1960a). Of these, the Buffalos River is the largest and most important tributary of the Thukela River (Oliff, 1960a).

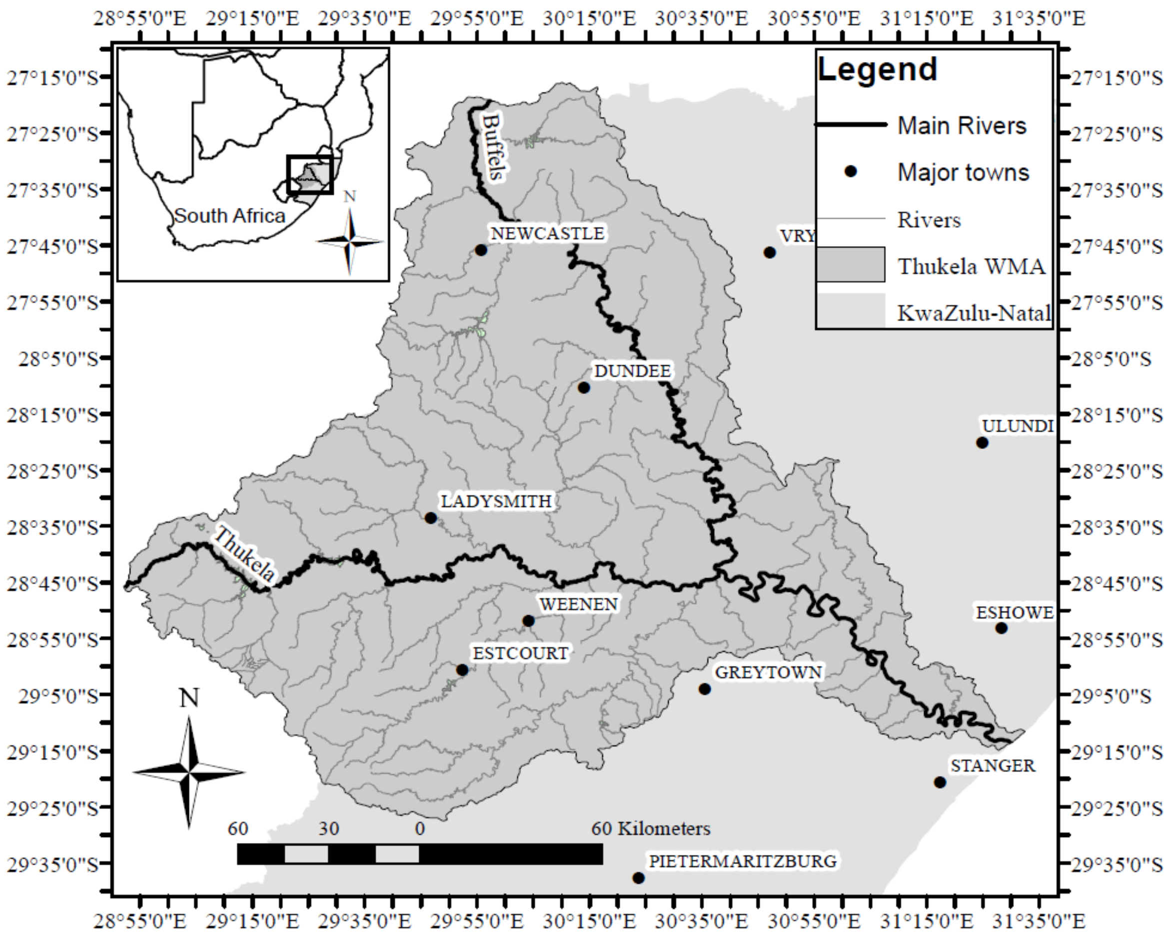

Figure 2.1: The Thukela River catchment with major towns

The Thukela River rises in the Drakensberg Mountains and flows 502 km eastwards to discharge in the Indian Ocean (DWAF, 2001; DWA, 2013). It originates within KwaZulu-Natal, close to where Lesotho and the Free State province of South Africa meet with KwaZulu-Natal on the Mont-aux sources plateau of the Drakensberg Mountain (DWAF, 2001; DWA, 2013). The great Thukela fault runs in an east to west direction in the upper catchment, providing a weakness in the upper strata into which the river has cut deeply (DWAF, 2003d).

The upper river course features many waterfalls, dropping a total of 948 m before cutting through the Thukela Gorge at the foot of the escarpment (DWAF, 2001; DWA, 2013). It is joined by many tributaries until at Jameson's Drift it enters the wide, open Thukela Trough. From there, the river cuts through a block of sandstone and enters the coastal plain and eventually discharge into the sea through the Thukela Estuary at the Thukela River mouth (DWAF, 2001; DWA, 2013). The Thukela Estuary is an open river mouth estuarine system, which is river dominated and therefore small. This allows for most matter to pass through the mouth into the sea without being deposited, consequently forming the Thukela Bank (De Lecea and Cooper, 2016).

The Thukela River catchment possesses a wide variety of climatic conditions; ranging from cold and wet conditions in the Drakensberg, to hot and dry conditions in the Thukela valley, to hot and humid at the coast (DWAF, 2004a). Most of the regions rainfall occurs in the summer between September and April with dry winter months; but the rainfall can be very erratic with long periods of drought alternated with very wet periods (DWAF, 2004a) The rainfall in the catchment differs due to the topography with higher rainfall in the highest points of the escarpment (1905 mm a year) and lower rainfall in the sheltered valleys of the lower parts of the catchment (as low as 635 mm year) (Oliff, 1960a). The coastal area receives about 1103 mm a year. This results in a Mean Annual Precipitation (MAP) of 843 mm for the whole catchment and a (virgin condition) Mean Annual Runoff (MAR) of 3 799 million m^3 (Oliff, 1960a; DWAF, 2003a). The MAR, expressed as an average unit runoff, is approximately 131 mm or 16% of the MAP (DWAF, 2003a). The MAR ranges from over 600 mm in the higher rainfall areas of the Drakensberg to 50 mm or less in the drier central regions (DWAF, 2003a). The MAP for most of the tributary catchments ranges between 762 – 940 mm with the exception of the catchments close to the Drakensberg escarpment, which experience higher rainfall (Oliff, 1960a).

The rainfall patterns within the Thukela River catchment results in extreme variability in flow during different seasons (Oliff, 1960a). The speed of the current can more than double during summer floods that can result in walls of muddy water of up to 1.5m high to move downstream (Begg, 1978). These floods vastly increase the silt loads and are often so powerful that it causes movement of the river beds with some bank erosion and the increase in volume of water increases the area that the river covers (Oliff, 1960a; Begg, 1978). This variation in the level of the river leads to cycles of exposure and inundation of banks and beds resulting in the ever-changing extent of habitats in the river which in turn effects the flora and fauna of the river (Oliff, 1960a).

The geology of the Thukela River catchment is roughly divided into the upper five-sixths of the catchment which lies on the formation of the Karroo System, and the remainder of the catchment towards the coast which lies on the beds of the Primitive System and the Table Mountain Series of the Cape System (Oliff, 1960a). The catchments of the Upper Thukela, Upper Bushmans and Upper Mooi Rivers all originate high on the face of the basaltic and rhyolitic lavas of the Drakensberg. In contrast, rocks of the Ecca series are found under the upper half of the Buffalo river catchment, the Sundays River catchment in the north, the lower Mooi River and lower Bushmans River catchments in the south and the local catchments surrounding Colenso, Nkasini and Tugela Ferry. The lower Buffalo, Mfongosi, Insuzi and Inadi catchments and local areas around Ngobevu and Middledrift lie upon Dwyka tillite, and the old granites and gneisses of the Tugela and Mfongosi systems. The more coastward, eastern part of the main river below Middledrift, is composed of rocks of the Table Mountain and Ecca series (Oliff, 1960a). These different geological formations influence the geomorphology of the rivers and the erosion resistance of the various formations also influence the characteristics of the water in different sections of the various rivers (Oliff, 1960a; DWAF, 2004a).

The water of the upper, more mountainous parts of the catchment contains little dissolved and suspended material due to good ground cover and the less erodible soils from the underlying basaltic lavas, the Stormberg beds, and the Upper Beaufort beds (Oliff, 1960a). The water from the wide, shallow valley of the middle part of the catchment contains higher concentrations of dissolved material, comprising largely of calcium and magnesium bicarbonates due to the underlying lower Beaufort beds, and Natal Ecca beds. This section of the river also accumulates considerable amounts of silt in the river that can be due to sparse vegetation cover, dense rural settlements and steep valley side slopes due to a rejuvenated system (DWAF, 2003d). The underling Primitive Granites and Gneisses, Table Mountain Sandstones and Natal Coastal Ecca beds of the lower coastal part of the catchment provide water with lower concentrations of dissolved material than is generally found in the middle part of the basin, though the individual concentrations of chlorides and sulphates are somewhat higher than in other parts (Oliff, 1960a).

The Thukela River finally discharges its water into the Indian Ocean through the open mouth Thukela Estuary (Begg, 1978; DWAF, 2004c). The estuarine area of the river is restricted and is classified as a River Mouth, due to the high riverine runoff but changes in the river flow can result in substantial changes in the morphology and nature of the estuary (Whitfield and Harrison, 2003). During high flows, the estuary extends into the sea and becomes unconfined by banks (Begg, 1978; DWAF, 2004c). The axial length is approximately 800m during low flow with an estimated shoreline length of 2km. The maximum width during natural flow periods is around 350m with a channel width of 50m but this can increase to over 1km during floods. A 700m unstable sandbar, without vegetation, forms across the mouth of the estuary but is occasionally moved when the river is in flood to form an offshore sandbar directing floodwater into the sea in a southernly direction (Begg, 1978; DWAF, 2004c).

Off the Thukela River mouth is the KZN Bight that is a continental shelf off the east coast of South Africa, bordering the Agulhas Current (Scharler *et al.*, 2016). The Bight extends from St Lucia to just south of Durban and its broadest point is offshore of the Thukela River (De Lecea and Cooper, 2016). The Thukela River plays an important role in forming the Thukela Banks as its estuary is river-dominated and small and allows most matter to pass through it into the sea. This riverine organic matter and nutrients from the Thukela River is very important as it largely maintains the biology of the Bight. The sediment output from the river is estimated at about 6.79 x 10^6 m^3 that is discharged into the Bight and forms a large mudbank called the Thukela Banks. The Thukela Banks is located off the Thukela River and covers an area of about 300 km^2 towards the north-east of the Bight. It extends from 200 m to 16 km offshore and is the only near-shore area on the east coast of South Africa where prawn trawling is possible. It also supports subsistence, commercial and recreational fishing but possible future reductions in flow from the Thukela River, due to water abstraction, may negatively impact the ecology of the Bight (De Lecea and Cooper, 2016).

The vast extent of the Thukela River catchment makes it an important resource for sustaining social and economic development in the country but it is close to being fully utilised (DWA, 2013). In this review we describe the past and present developments within the Thukela River catchment, how the water resources were used to support the socio-economic development of the country and how this impacted on the aquatic ecosystem. The present section of the review is taken from 1998 when the National Water Act (Act 36 of 1998) was ratified and provided the framework for protecting water resources against over exploitation and ensuring that there is water for socio-economic development and for the future (DWAF, 1999). The review ends with concerns for the future of the Thukela River and its sustainability.

2.2 THE THUKELA RIVER – THE PAST (1800 – 2000)

2.2.1 Past development in the catchment

Various African tribes made the Thukela River valley their home and used the services it provided long before European settlers arrived. Over three hundred years ago, many of the Lala clans settled on the southern banks of the river while the Qwabes tribes lived on the northern banks (Bulpin, 1956). The Lala people were known to be great miners and smelters of iron which was used for spear making, hoes and tools. Further upstream, the Luthuli people occupied the Mpaphala "*The Open Place*" but in the middle of the 18th century the Qwabes tribe drove them on to Port Natal (Bulpin, 1956). In 1781 the legendary Shaka was born near the White Mfolozi River and after the death of Dingiswayo, he was able to establish his rule in the region between the Mfolozi and Thukela Rivers and later, as his territory increased, he established the Zulu kingdom (Ross, 2008). Shaka was murdered by his brother Dingane in 1828 and the Zulu kingdom dominated the eastern valleys between the Thukela and Phongolo Rivers. In the late 1830s, Voortrekkers crossed the Drakensberg Mountains into KwaZulu-Natal and after various conflicts with Zulu impis, settled south of the Thukela River to establish farms and in 1842 this region was annexed as a British colony (Ross, 2008). In later years, Europeans showed an interest in mining in the Thukela valley with various claims of striking gold. Over the next few years from 1868, various individuals and Syndicates tried to prospect for gold in the Thukela Valley and surrounding tributaries, but most efforts led to disappointment (Bulpin, 1956). The discovery of the coal fields in the late 1800's also resulted in the development of the region surrounding Newcastle (Kemp, 1967).

The main urban settlements that have developed within the Thukela River catchment over the years include Bergville, Colenso, Dannhauser, Dundee, Estcourt, Glencoe, Mooi River, Ladysmith, Newcastle, Utrecht, Volksrust, Mandeni, Winterton and Wakkerstroom with Newcastle being the largest urban centre but generally the Thukela River catchment is sparsely populated with the widely scattered rural community being much larger than the urban population (DWAF, 2001, DWAF, 2003a). In these rural communities where the population densities are low, water from springs, boreholes and rivers are used. The urban centres require water for consumption and sanitation as well as other indirect uses and the growing need for reliable water supplies led to the development of extensive water related infrastructure (DWAF, 2003a).

This infrastructure includes a number of dams being built within the Thukela River catchment to regulate flow, for times of drought, provide flood attenuation and supply areas outside of the catchment (Taylor *et al.*, 2001). The first major dam that was built was the Windsor Dam which was constructed in 1949 in the Klip River to secure water supply to Ladysmith and for flood control (Bell and Mason, 1998; DWAF, 2003a). In 1961 the Chelmsford Dam (now known as the Ntshingwayo Dam) in the Ngagane River was commissioned to provide water for Newcastle and shortly after that, in 1962, the Craigie Burn Dam in the Mnyamvubu River was completed to secure water in the Mooi River area. In 1987, the Zaaihoek Dam in the Slang River was built for inter-basin transfer to supply water to an Eskom power station (DWAF, 2003a).

The largest water related infrastructure development in the Thukela River catchment would be the Vaal-Thukela inter-basin transfer scheme (TUVA) which was approved in 1970 (Van Vuuren, 2008). This scheme transfers water from the upper Thukela River to the Vaal system via the Sterkfontein Dam and was commissioned due to the increasing demand for water from the ever-growing Pretoria-Witwatersrand-Vereeniging (PWV) complex (Van Vuuren, 2008). This transfer scheme was completed in two phases and included the following major components in the Thukela River catchment (Davies, 1982; DWAF, 2003a):

- The Spioenkop Dam (1971) which regulates the flow of the Thukela River for downstream users.
- The Driel Barrage and pump station (1976) which forms the main storage, abstraction and supply components on the Thukela river.
- The Putterill, Clifford Chambers and Khombe Weirs that divert flow in the upper Thukela River and its tributaries.
- The Woodstock Dam (1982) which regulates the flow of the upper Thukela and provides the required increased assured yield.
- The Kilburn Dam, situated in a minor tributary of the upper Thukela River, which provides storage for the reciprocating volume of water required for the pumped storage operation.

With this infrastructure and Eskom's Drakensberg pumped storage scheme, it is possible to transfer on average 530 million m^3 of water per annum to the Vaal system (DWAF, 2004b).

Water supply to Durban, Pietermaritzburg and other urban areas from Howick to the coast has also been problematic as they receive their water from the severely stressed Mgeni River catchment (Markowitz, 2016; Umgeni Water, 2017a). In 1983, severe drought condition resulted in the initiation of the Mearns Emergency Transfer Scheme, to transfer water from the Mooi River to the Mgeni River catchment (Markowitz, 2016). This resulted in the construction of the Mearns Weir and pump station on the Mooi river at Mearns that was used as and when needed (Umgeni Water, 2017a). Another transfer scheme, the Mhlathuze augmentation, was implemented in 1995 which included the installation of a pumping scheme to transfer water from the Thukela River at Middledrift into the Goedertrouw Dam to supply users during droughts (DWAF, 2003a).

The major landuse in the Thukela River catchment is agriculture with most commercial farmers having access to river water for supplementary irrigation (Taylor *et al.*, 2001). Most irrigation operations use sprinkler systems but in the larger scale commercial farms, central pivot irrigation is used (Taylor *et al.*, 2001). In 1995, almost all the economically viable land for irrigation was utilised and most of this irrigation took place in the Upper Thukela, Little Thukela and Mooi River areas (DWAF, 2003a).

Industrial development has occurred in urban areas like Newcastle, Dundee, Estcourt, Ladysmith and Mandeni (DWAF, 2001). In Newcastle in 1920, JK Eaton formed the Newcastle Iron and Steel Works and started the construction of the first blast furnace for the commercial production of crude iron which was completed in 1921 by the Union Steel Corporation of South Africa Limited (USCO) (Dondofema *et al.*, 2017). By 1937, the African Metals Corporation (Amcor) Limited had purchased the Newcastle Works began production of high ferromanganese. In 1969 the South African government announced that the third Iscor (South African Iron and Steel Industrial Corporation Limited) Works would be established in Newcastle, by taking over and expanding the Amcor ironworks and would produce 4 500 tonnes of crude iron a day (Dondofema *et al.*, 2017). In 1995, Iscor was extracting 8.4 million m^3/a from the Ngagane River and another industry in Newcastle, AECI/Karbochem, was extracting 2.4 million m^3/a of water from the Chelmsford Dam (DWAF, 2003a). In the lower Thukela River region, the SAPPI Pulp and Paper Mill was erected in 1953 in Mandeni, above the Thukela Estuary (Macdonald, 2004). The Sundumbili township was developed in the area to house the workers of the SAPPI mill and in 1968 development of infrastructure for the Isithebe industrial area started with the first factories opening in 1971. By 1983, 80 factories were operational within this industrial area (Ardington, 1984). SAPPI Pulp and Paper Mill is a bulk water user in the Thukela River catchment and in 1995, the mill was extracting 19.8

million m^3/a from the lower Thukela River (DWAF, 2003a). Other industries in the catchment include the manufacture of textiles, clothing, footwear and leather (DWAF, 2003a).

Two power stations were also built in the catchment. The Colenso coal power station was completed in 1924. It contributed to the establishment of Eskom and become its first major power station but was closed in 1985 as it had reached the end of its lifespan (Boers, 1985). This power station had an intake point in the Thukela River and a barrage was built across the river to regulate the flow past the intake (ESKOM, no date a). The second power station, the Ingagane power station, is located outside of Newcastle and was completed in 1959. It used water from the newly constructed Chelmsford Dam in the Ngagane River, which was gravity fed via a 16 km long pipeline. This power station was mothballed in 1990 with the intention of bringing it back to service in 1996 but this did not happen (ESKOM, no date b).

The particular geology of the Thukela River catchment, namely the Middle Ecca series of the Karoo system, contain coal deposits which resulted in a number of coal mining companies forming and opening in the Dundee and Newcastle vicinity by 1888 (Kemp, 1967). Since then development proceeded steadily and by the mid 1960's there were over 30 working mines in the KwaZulu-Natal province, some located within the within the Thukela River catchment. The Klip River coalfield; comprising an area that stretches from Ladysmith north as far as the Incandu river at Newcastle, and eastward beyond Dundee as far as the Buffalo River and is drained by the Buffalo and Sundays Rivers and their tributaries (streams of the Thukela River catchment). The Utrecht coalfield extends from near Newcastle to Paulpietersburg and northwards to the old Transvaal border and is drained by the Buffalo and Blood Rivers and their tributaries (streams of the Thukela River Catchment) and by the Pongola River, its tributary the Pivaans and their smaller streams (Kemp, 1967). After the turn of the twentieth century, there was a decline in the coal mining in the KwaZulu-Natal province, with four collieries operational in the Klip River coalfield and one in the Utrecht coalfield (Jeffrey, 2005). Mines are considered to be bulk water users but the availability of reliable information on water requirements is limited (DWAF, 2003a).

Another important water user in the Thukela River catchment is the commercial timber industry resulting in commercial afforestation throughout the upper and middle parts of the catchment (DWAF, 2003a). The impact of afforestation on runoff and the yield of a catchment depends on the storage in the catchment. In 1995, wattle, pine and eucalyptus were all grown in the Thukela River catchment, with the largest afforested areas in the Mooi River key area. The total afforestation area was about 226.3 km^2 with a reduction in runoff of 15.5 million m^3/annum (DWAF, 2003a).

Offshore, regular trawling for prawns in the inshore Thukela Banks started in 1976 by two vessels and by 1982 four vessels were operating in the region (Turpie and Lamberth, 2010). A commercial linefishery industry also started operating in the vicinity of the Thukela Banks, constituting about 38% of the provinces commercial catch. Recreational boat-based linefishery predominately for gamefish species was known to occur (Turpie and Lamberth, 2010).

2.2.2 Past ecology

In the years 1953 to 1955, a detailed hydrobiological study was undertaken by Oliff (1960a) of the Thukela River. The study divided the main Thukela River into eight distinct zones based on the gradient of the river and the associated fauna. The first four zones, namely; the Source zone, the Waterfall zone, the Mountain Torrent zone and the Foothill Torrent zone constituted the upper river where the river is mostly a mountain torrent extending from the source to the vicinity of the Caverns Causeway. The remaining four zones namely; the Foothill Sand Bed zone, the Rejuvenated river zone, the Valley Sand Bed zone and the Estuarine zone, extend from the Caverns Causeway to the sea and in these zones the river is generally more stable and the flow rate more reduced (Oliff, 1960a).

The results of the hydrobiological study indicated that the flora of the river mainly comprised of reeds (*Phragmites communis*), sedges (*Cyperus marginatus*) and grasses (*Cynodon dactylon*) due to the rapid flows and erosion of the river during the high flow season (Oliff, 1960a). Algae and diatoms were recorded in late autumn and winter months when the flow slowed, water cleared, and concentrations of nutrients increased. Growth of algae in the Tugela Ferry area was prolific in August and September that impacted on the fauna in the marginal vegetation. In the Upper Thukela River, the growth of algae also occurred in the summer and was attributed to the absence of large amounts of silt in this region (Oliff, 1960a). The description of the flora per zone is provided in Table 2.1.

Table 2.1: Description of the flora per zones based on the hydrobiological study (Oliff, 1960a)

Zones	Flora Description
Source zone (Mount-aux-Sources)	• Stream fringed by stream-bank grasses. • Some mosses grow in the bed, particularly on steep faces in rapids or falls.
Mountain Torrent zone below the falls, (National Park)	• Rocky banks result in no submerged aquatic vegetation. Only grasses and annuals on banks sometimes form fringes in the water.
Foothill Torrent zone (Lower National Park and Caverns' Causeway)	• Where the water is flowing rapidly, the marginal vegetation is usually composed of *Cyperus marginatus*, *Pennisetum natalense* and *Ornithogalum zeyheri*. • Where water flows slower, grasses such as *Hyperhaenia glauca*, *H. Hirta*, and occasional patches of *Phragmites communis* occur.
Lower Sand Bed zones (Oliviershoek Bridge to the mouth)	• Characterised by more stable banks and generally a complete fringe of river bank vegetation usually comprised of *Cynodon dactylon*, *Cyperus marginatus*, *Hemarthria altissima*, *Phalasis sp*. and *Phragmites communis*. • In the winter months, in the slow-flowing stretches, some patches of *Potamogeton crispa, Polygonium setulosum, Chara sp*. and *Najas sp.*, as well as algae, largely *Spirogyra spp*. occur.

The fauna communities of the main habitats in the zones were distinct and comprised usually of mayflies (50-90%) (Oliff, 1960a). Caddis flies (5-50%), *Simulium* spp. larvae (%-95%) and

Chironomidae (5-25%) were also occasionally present in the winter months. Some of the common species were distributed widely in the river and found in most zones except for the upper river zones (Oliff, 1960a). The common taxa found within each habitat are listed in Table 2.2.

Table 2.2: Main fauna within the three different habitats of the Thukela River (Oliff, 1960a)

Rapids	Marginal Vegetation	Bottom Sediments
Baetis harrisoni	*Austrocaenis capensis*	*Limnodrilus sp . 1*
Centroptilum excisum	*Baetis bellus*	*Branchiura cf. sowerbyi*
Caenis sp. 1	*B. sp. 2*	*Paragomphus cognatus or P. hageni*
Euthraulus elegans,	*Pseudocloeon vinosum*	*Chironomidae*
Neurocaenis discolor,	*Pseudagrion salisburyense*	*Procladius spp . 1 and 2*
Neoperla spio	*Microvelia major*	*Tanytarsus sp.*
Cheumatopsyche zuluensis,	*Rhagovelia nigricans*	*Ceratopogonidae spp .*
Elmidae sp. 1	*Laccocoris limnigenus*	
Chironomidae spp.	*Chironomidae*	
Ceratopogonidae spp.		
Rana fuscigula		

The fish species deemed most important by Oliff (1960a) within the river zones included rainbow trout (*Oncorhynchus mykiss*) and the small catfish, (*Amphilius natalensis*) in the lower Torrential zone and the Tugela labeo, (*Labeo rubromaculatus*), and the KZN scaly, (*Labeobarbus natalensis*), within the Sand Bed zones above Colenso, and in the Rejuvenated River zone. Red-eye mudfish (*Labeo cylindricus*) were recorded in the rapids. Further downstream, in the Valley Sand Bed Zone barbel (*Clarias gariepinus*) was abundant and dominated. In the lower section of this zone and in the estuary, representatives of marine groups, such as gobies (*Gobiidae*), mullets, (*Mugilidae*) and estuarine bream (*Sparidae*) were found. One of the gobies (*Gobius aeneofuscus*) was noted to be found particularly far upstream, in fresh water (Oliff, 1960a).

2.2.3 Past impacts on water resources

All these water users do not just have an impact on the quantity of water available but also on the quality of the water resources. Studies indicated that in the 1950s the water of the Thukela River was generally of a good quality but impacts from pollution was recorded in other rivers within the catchment (Oliff, 1960a). The Little Bushmans river was receiving organic and inorganic material in solution and suspension from fibre board-mill effluent-disposal farms as well as increased concentrations of dissolved solids, free and saline ammonia, sulphates, chlorides, and calcium from the effluent of this mill (Oliff, 1960b). A milk processing factory also contributed to a large amount of organic matter entering the Little Bushmans River as well as increased concentrations of nitrates and nitrites. Sewerage from Escourt town sewerage works would occasionally flow into the river during heavy rains or flooding. The Little Bushmans River was a source of pollution for the Bushmans River it flows into, but the main source of pollution was the sewerage disposal farm where sewerage polluted the river by overland and sub-surface drainage into channels on the river bank and into the river (Oliff, 1960b). In the Mooi River catchment, pollution from effluents from a milk and meat processing factory in Mooi River Town were noted (Oliff and King, 1964). Overall, organic pollution was recorded in many rivers downstream of settlements and increases in total dissolved solids and organic matter from irrigation also occurred (Oliff, 1960b; Oliff and King, 1964).

Impacts from coal mining activities were also noted within the Thukela River catchment, especially within the Sundays River catchment and the Umzinyatshana and Ingagane catchments which are both within the larger Buffalo River catchment (Oliff *et al.*, 1956; Kemp, 1967). Acid mine drainage was found to be a major source of stream pollution in the Natal Coalfields. Most small streams near mines were in a very badly polluted condition and effects upon major rivers, though slight, could clearly be detected. The main Thukela River was also being impacted as the sulphur index in the river increased below the confluences with the Sundays and Buffalo Rivers. Studies predicted that in 20 to 40 years most small streams and rivers of the Natal Coalfields would be extensively polluted and that the major rivers would be showing considerable pollution too (Kemp, 1967).

In the lower Thukela River, the SAPPI Paper and Pulp mill was a potential source of pollution for the Thukela Estuary as organic pollution from the mill was reported in the lower reaches of the river and was classified as verging on public nuisance levels (Begg, 1978). Sugar cane encroachment, excessive siltation and pollution from the Mandeni waste water treatment work were also impacting on this section of the river (Begg, 1978).

2.3 THE THUKELA RIVER – THE PRESENT (1998 - 2018)

In 1994 South Africa became a democracy and Section 24 of the new Constitution (1996) states that:

"*Everyone has the right—*

(a) to an environment that is not harmful to their health or wellbeing; and

(b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that—

(i) prevent pollution and ecological degradation;

(ii) promote conservation; and

(iii) secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development."

The Constitution also mandated the government to protect the environment which is achieved through various environmental legislation including the National Environmental Management Act (Act 107 of 1998) (NEMA) and the National Water Act (Act 36 of 1998) (NWA).

The NWA was published in 1998 and became the legal framework for the effective and sustainable management of water resources in South Africa (DWAF, 1999). The NWA recognises that water is a scarce and precious resource that belongs to the people of South Africa and therefore it needs to be managed in a sustainable way to benefit all South Africans. The Act therefore aims to protect, use, develop, conserve, manage and control water resources as a whole (DWAF, 1999).

To protect the water resources of the country, NWA specifies a series of resource directed measures that need to be followed to protect the health of water resources (DWAF, 1999). These measures include:

1. Establish a classification system - provides the guidelines and procedures for classifying different classes of water resources.
2. Classifying each major resource – determining the class for each significant water resource.
3. Determining Resource Quality Objectives (RQO) - targets or objectives for each water resource in terms of the level of protection it requires.
4. Setting the Reserve – determining the amount of water required to meet basic human needs and to protect aquatic ecosystems.

The Act also specifies how water can be used. Water use is anything that has an impact on the quantity and quality of water in the resource and the environment surrounding water resources (DWAF, 1999). Other than the water set aside for the Reserve, there are other priorities for which water needs to be allocated and these include; water to meet international rights and obligations, water use of strategic importance, inter-catchment water transfers and contingencies to meet project future water needs. The remainder of the water can be used by other authorised users (DWAF, 1999).

The use of water resources from 1998 would have to be done within the framework of the NWA and take into consideration the balance between the use and protection of water resources.

2.3.1 Present development in the catchment

There have been various new developments to water resource infrastructure within the Thukela River catchment after 1998. In 2003, the Mooi-Mgeni River transfer scheme Phase 1 was commissioned to replace the Mearn Weir and pump station (Umgeni Water, 2017a). The completion of Phase 1 resulted in the pumping of water from the Mearn weir in the Mooi River through a pipeline system into the Lions River which eventually flows into the Midmar Dam in the Umgeni system (DWAF, 2003a). Phase 2 of the transfer scheme was completed in 2016 and included the construction of the Spring Grove Dam on the Mooi River (Umgeni Water, 2017a).

In 2016, the Eskom Ingula pumped storage scheme was completed to meet the increasing electricity demand of South Africa (Otieno *et al.*, 2017). This pump storage scheme is located on the provincial boundary of the Free State and KwaZulua-Natal, on the watershed between the Vaal River and the Thukela River catchments. The scheme consists of the upper Bedford Dam on the Bedford River, a tributary of the Wilge River, and the lower Bramhoek Dam on the Bramhoek River, a tributary of the Klip River. The two dams are connected by underground waterways passing through an underground powerhouse to generate a capacity of 1 332 MW of electricity (ESKOM, 2013; Otieno *et al.*, 2017).

More recently (2017), Umgeni Water commissioned the Lower Thukela Bulk Water Supply Scheme that would initially abstract 55 Ml of water per day from a weir on the Lower Thukela River near Mandeni using a run-of-river abstraction mechanism (Umgeni Water, 2017a). A treatment work was also built to treat the water to potable standards and supply areas within the KwaDukuza and Mandeni Local Municipalities (Umgeni Water, 2017a). Through these transfer schemes, the Thukela River system has been supporting significant economic activities both within the catchment as well as outside of the catchment (Pienaar, 2005).

The urban areas within the Thukela River catchment have also grown. The 2011 South African National census shows varying population densities for the major towns within the catchment and the water demand over the years have increased as urban populations and industries have grown (Table 2.3) (STATS SA, 2011)

Table 2.3: Population density of urban area within the Thukela River catchment based on the 2011 South African National Census (STATS SA, 2011)

Town name	Population	Population density (Persons/km^2)
Bergville	1 274	269
Colenso	6 388	654
Dannhauser	6 493	122
Dundee	34 924	719
Estcourt	22 071	363
Glencoe	17 548	660
Mooi River	2 874	251
Ladysmith	64 855	771
Newcastle	56 144	741
Utrecht	5 290	92
Volksrust	24 281	955
Mandeni	3 904	217
Winterton	276	321
Wakkerstroom	6 852	78

2.3.2 Present ecology

A comprehensive Reserve Determination Study of the Thukela River was undertaken in 2003/4, almost 50 years after the hydrobiological study. For the Reserve study, the Thukela River catchment was separated into the Upper and Lower Thukela (Figure 2.2 and Figure 2.3) and further divided into different segments and Resource Units (RU) (DWAF, 2003d). A segment was defined as a length of channel along which there is no significant change in the flow discharge or sediment load. For the main Thukela River, 78 segments were identified Each RU is significantly different from each other to warrant their own specification of the Reserve and to clearly delineate the geographic boundaries of each RU. Eleven RUs were identified for the Thukela River and allocated the letters A-K (Figure 2.2 and Figure 2.3). The delimitation of each RU in Figure 2.2 and Figure 2.3 is illustrated by the blue and green colouration of the river. Sites were selected within some RUs, where the quantity component of the Ecological Reserve was determined. These sites are called Instream Flow Requirements (IFR) sites and 7 were allocated for the Thukela River, namely; IFR1, IFR2, IFR4A & B, IFR 9, IFR15 and IFR16 (DWAF, 2003d).

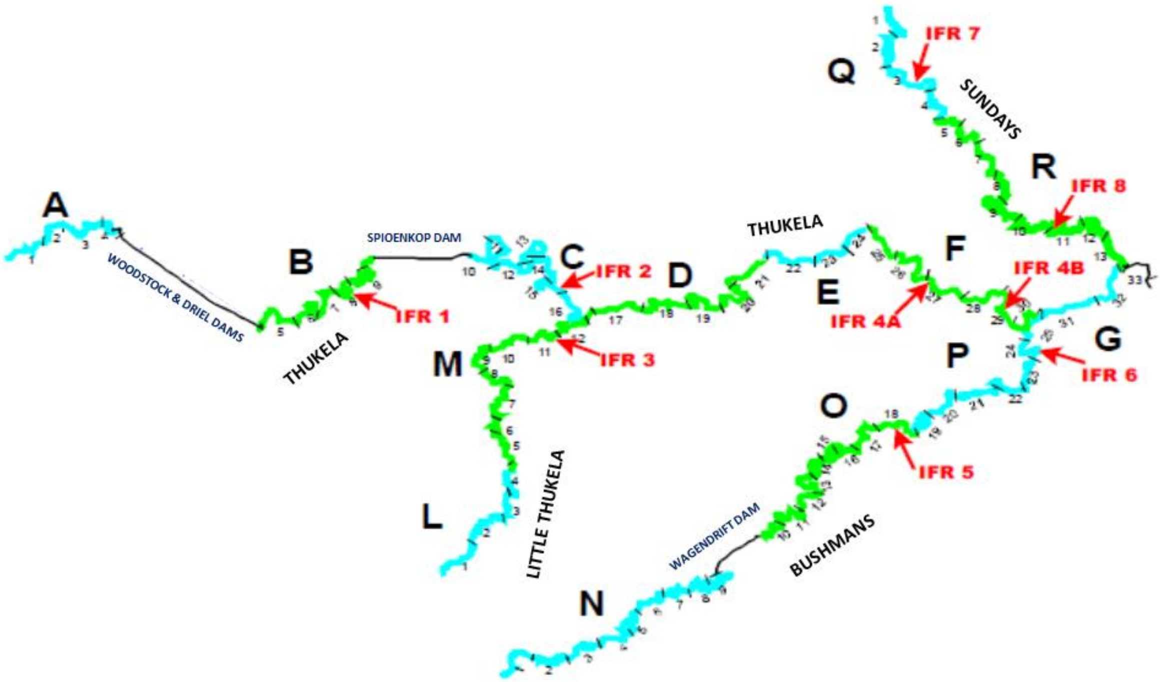

Figure 2.2: Upper Thukela study area (DWAF, 2003c)

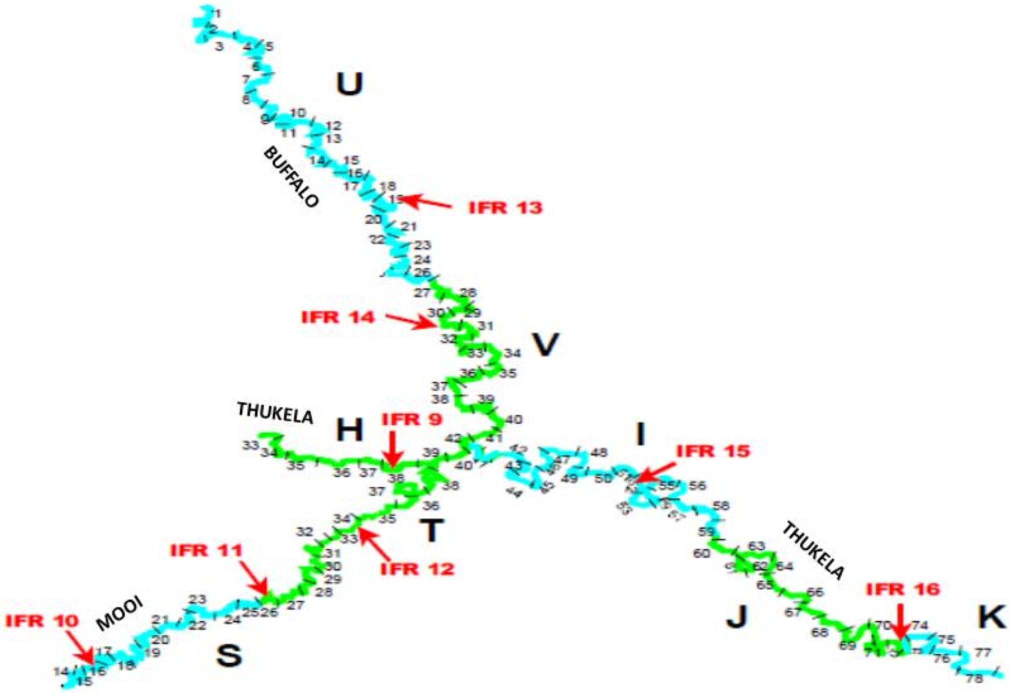

Figure 2.3: Lower Thukela study area (DWAF, 2003c)

2.3.2.1 Fish

The Thukela Ecological Reserve study indicated that there are 23 indigenous freshwater fishes and 10 alien fish species within the Thukela River system (Table 2.4) (DWAF, 2003c). Many other estuarine species and or marine stragglers have been observed (>40 species - O'Brien and Venter, 2012), especially in the lower Thukela River. The distribution and upstream migration of some indigenous species are limited by waterfalls within the Thukela River catchment, whereas the introduction of alien species or the translocation of indigenous species can impact negatively on the species that naturally occur in a region (DWAF, 2003c). The Hart Hills falls near Colenso is an example of this as it is a natural migration barrier and in a pristine condition, only five species of fish would have been present above these falls and six to ten immediately below. The catfish *Clarias gariepinus* is one species that occur naturally below the falls but has been translocated above the falls and has adversely impacted on the indigenous species and the bass in the upper reaches of the river system. Another threat to indigenous fish species are bass (*Micopterus spp.*), especially Smallmouth bass (*M. dolomieu*), that have been introduced to numerous impoundments within the Thukela River catchment and have escaped into rivers. The Bushmans and Mooi Rivers especially have been impacted by well-established populations of Smallmouth bass. The Thukela-Vaal inter-basin water transfer scheme (TUVA) has also resulted in the transfer of fish species from one river system to and another and from one impoundment and section of the Upper Thukela River to another. The Kilburn Dam has been invaded by one yellowfish species and two mudfish species from the Vaal system and the Natal yellowfish from the Thukela River have been transported into the Sterkfontein Dam in the Vaal River catchment. The catfish *Clarias gariepinus* is also spread throughout the Upper Thukela River catchment even though it does not naturally occur in this part of the river and may also be transferred through the water transfer scheme (DWAF, 2003c).

The Reserve study used historical data from the KZN Wildlife records as well as professional opinion to determine the fish that would be present in each RU; if the RU was in a pristine condition (DWAF, 2003c). This list was used as a reference condition to which the results of the field surveys undertaken during the study were compared to. A description of the results of the field surveys are provided in Table 2.5.

Table 2.4: List of indigenous and alien fish species found in the Thukela River system (KZN Wildlife records) (DWAF, 2003c)

Scientific Name	Common Name
Indigenous species	
Anguilla bengalensis	African mottled eel
Anguilla marmorata	Giant mottled eel
Anguilla mossambica	Longfin eel
Gilchristella aestuaria	Estuarine round-herring
Barbus anoplus	Chubbyhead barb
Barbus natalensis	KwaZulu-Natal Scaly
Barbus paludinosus	Straightfin barb
Barbus trimaculatus	Threespot barb
Barbus viviparus	Bowstripe barb
Labeo molybdinus	Leaden labeo
Labeo rubromaculatus	Thukela labeo
Amphilius natalensis	Natal mountain catfish
Clarias gariepinus	Sharptooth catfish
Mugil cephalus	Flathead mullet
Myxus capensis	Freshwater muller
Oreochromis mossambicus	Mozambique tilapia
Pseudocrenilabrus philander	Southern mouthbrooder
Tilapia sparrmanii	Banded tilapia
Eleotris fusca	Dusky sleeper
Awaous aeneofuscus	Freshwaer goby
Glossogobius callidus	River goby
Glossogobius giuris	Tank goby
Taenioides jacksoni	Bearded eelgoby
Alien species	
Barbus aeneus	Smallmouth yellowfish
Cyprinus carpio	Carp
Labeo capensis	Orange River mudfish
Labeo umbratus	Moggel
Oncorhynchus mykiss	Rainbow trout
Salmo trutta	Brown trout
Lepomis macrochirus	Bluegill
Micropterus dolomieu	Smallmouth bass
Micropterus punctulatus	Spotted bass
Micropterus salmoides	Largemouth bass

Table 2.5: Description of fish field survey results for each Resource Unit for the Reserve study (DWAF, 2003c)

Resource Unit	Description of Field Survey Results
A	• Few rainbow trout present, that were released for angling in the Thukela headwaters. • *Clarias gariepinus* is a scavenger and predator that has been illegally translocated or transported via the TUVA canals and will impact on hatchlings and juvenile fish population of all species. • Carp are present in Woodstock Dam and lower reaches of RU due to illegal introduction and or via the TUVA canals. Carp disturb the mud substrate, aggravating the turbidity of the water column. • The alien species *Barbus aeneus*, *Labeo capensis* and *Labeo umbratus* can invade Woodstock Dam and the RU via the TUVA pumped storage scheme pipes and turbines linking Sterkfontein and Kilburn dams.
B	• Altered flow regimes and periodic heavy silting from Driel Barrage since 1975 has severely impacted fish populations. • *Amphilius natalensis* eradicated due to silting. • *Anguilla mossambica* populations decreased as they are not able to ascend Spioenkop Dam wall. • *Barbus anoplus* and *Labeo rubromaculatus* occur in the headwaters of Spioenkop Dam and have access to the lower reaches of the RU. • *Clarias gariepinus* have presumably been illegally translocated by anglers and appeared in the 1980s. It has spread throughout RU A to D, stretching from Colenso to Woodstock Dam where it is technically an alien species. • Carp were introduced to the Spioenkop Dam for angling and may invade the RU. • Channel from Bergville abattoir impacted on water quality and fish populations at one point but had abated. • Quality of angling has declined over the past 20 years.
C	• *Clarias gariepinus* and *Cyprinus carpio* have entered the RU from the upstream Spioenkop Dam. • The presence of *Oreochromis mossambicus* could be due to their introduction to private and State dams for angling and therefore occur in waters other than their natural distribution range.
D	• *Clarias gariepinus* and *Cyprinus carpio* have entered the RU from the upstream Spioenkop Dam. • Largemouth bass populations inhabit the RU.
E	• This RU could not be sampled so all species reported are only expected to occur. • *Tilapia sparrmanii* occurs near Unit E and are expected to occur in this RU too. • Any *Oreochromis mossambicus* found are most likely escaped from local farm dams.

Table 2.5 cont.: Description of fish field survey results for each Resource Unit for the Reserve study (DWAF, 2003c)

Resource Unit	Description of Field Survey Results
F	• One specimen of the freshwater goby *Awaous aeneofuscus* was recorded in Segment 29, that is the most inland that this species has been recorded in KZN. • One specimen of the eel *Anguilla marmorata* was caught at Ganna Hoek (Segment 25). • Mozambique tilapia and carp have invaded the RU and will have a negative impact on the indigenous fish abundances. • Habitat availability and spawning-stimulus flood frequency have probably been affected by flow reduction due to upstream dams.
G	• The RU could not be sampled so the list of species occurring here is based on the species known to occur immediately upstream and downstream of the RU. • Few carp are known to be found here. • Mozambique tilapia have probably escaped from local farm dams. • The intensive use of the riparian zone has impacted on the instream habitat and resulted in reduced fish abundances.
H	• Historical records from 1968 and 1970 showed that *Amphilius natalensis* occurred in boulder riffles and rapids when the Jolwayo weir and canal system was out of action. The later increase in informal agriculture and irrigation would likely have caused the riffle habitats to become silted, eliminating *Amphilius*. • As the freshwater goby was sampled further upstream, it is expected to occur due to the prevalence of sandbank conditions. • *Oreochromis mossambicus* are expected to occur naturally here as this RU is the upstream limit from the coast of their natural distribution range. • Carp occasionally occur but with no great impact on local habitat. • *Anguilla bengalensis* probably occurs so there are probably three eel species present here. • Numerous shrimp *Macrobrachium lepidactylus* were noted and fish were abundant.
I	• The absence of *Amphilius natalensis* is probably due to riffle habitat degradation. • *Anguilla bengalensis* was sampled and although this species occurs widely, its abundances seem to be low. • *A. marmorata* was not sampled but due to its occurrence further upstream it is assumed it will occur here too. • Carp is expected occasionally due to its occurrence in the RUs upstream and downstream. • At the head of Segment 59, the Thukela-Mhlatuze inter-basin water transfer scheme periodically draws water from a deep pool in the Thukela just above Middle Drift. Its impact on river flows and consequently on riverine habitats was limited.
J	• Nine species of the 11 expected species were sampled, with the exception of the eels *Anguilla bengalensis* and *A. marmorata*. These eels do occur further upstream, so they must pass through the RU to get there. • The absence of *Amphilius natalensis* during sampling and historical databases reflect a change in species richness from the Reference condition. • Large numbers of the shrimp *Macrobrachium lepidactylus* were noted. • Carp thought to be present occasionally.

Table 2.5 cont.: Description of fish field survey results for each Resource Unit for the Reserve study (DWAF, 2003c)

Resource Unit	**Description of Field Survey Results**
K	• Of the 21 species expected, only *Anguilla bengalensis*, *A. marmorata* and *Pseudocrenilabrus philander* were not collected. As 3 eel species were collected further upstream, all must have occurred in this RU at some point. • Although *Pseudocrenilabrus philander* was not collected, it is expected to occur. • Although the effluent from the SAPPI paper mill causes a thick coating of sewage fungus on the riverbed, there is still a large variety of fish. • The abundance of gobies, including the freshwater goby *Awaous aeneofuscus* at Harold Johnson, indicates that the impact from the Mandeni pollution only lasts for a few kilometres. • The presence of carp as well as reduced fish populations, absence of *Amphilius*, the presence of skin spot on numbers fish and the extreme barrenness of the riverbed immediately below Mandeni are all evidence of the negative impact of the Mandeni outfall on the ecological state of the river.

The National Freshwater Ecosystem Priority Areas (NFEPA) project provides strategic spatial priorities for conserving South Africa's freshwater ecosystems and for supporting the sustainable use of water resources (Nel *et al.*, 2011). NFEPA supports the water protection goals of the NWA by providing guidance on how many and which rivers, wetlands and estuaries should remain in a natural or near-natural state (Nel *et al.*, 2011). This information is provided in the form of maps and the map for the Thukela WMA is provided in Figure 2.4.

The Thukela River catchment has many fish sanctuary areas, especially in the upper reaches of many of the rivers, that are indicated on the map (Figure 2.4) by red or black fish symbols. Red fish symbols mean that at least one population of critically endangered or endangered fish species is found within the sub-quaternary catchment (Nel *et al.*, 2011). A black fish symbol indicates the presence of fish populations that are vulnerable and near threatened. Sub-quaternaries that are shaded in dark green are river Freshwater Ecosystem Priority Areas (FEPAs) and contain rivers that are currently in a good condition (A or B ecological category) Sub-quaternaries that are shaded in medium green are fish support areas that are in an ecological condition lower than an A or B (Nel *et al.*, 2011).

Most of the Buffels river and many of its tributaries are river FEPAs or fish support areas. The freshwater ecosystem of the Bushmans River is also important fish sanctuary areas or FEPAs. These both feed into the middle section of the Thukela River and between the two confluences are fish populations that are vulnerable or near threatened.

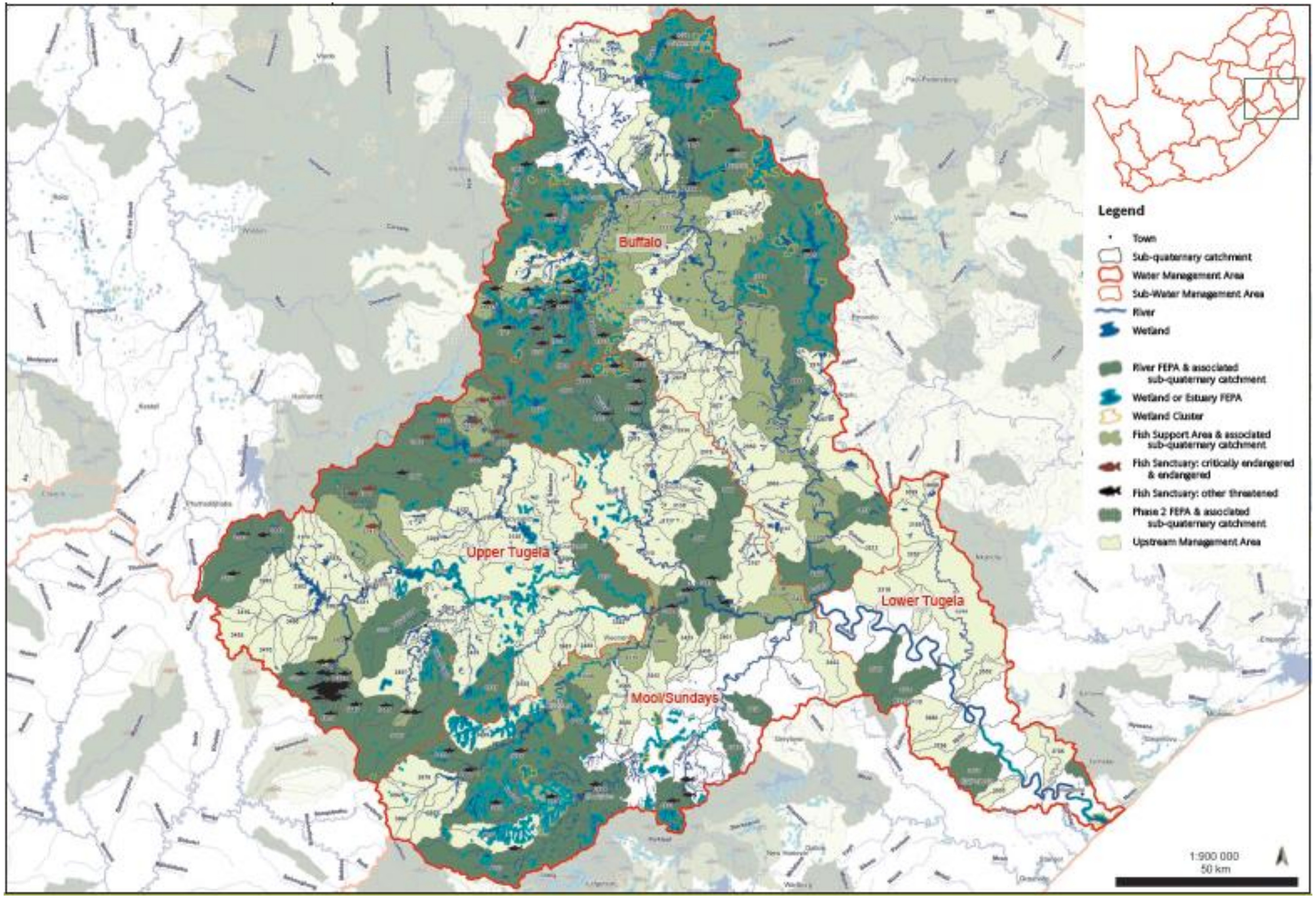

Figure 2.4: National Freshwater Ecosystem Priority Areas for the Thukela Water Management Area (Nel *et al.*, 2011)

2.3.2.2 Macroinvertebrates

Many studies have been undertaken on the macroinvertebrates of the Thukela River, after the 1953 – 1955 hydrobiological study, mainly to determine the impacts that future water transfers from the Thukela system will have on the macroinvertebrate communities. Many of the hydrobiological study sites were resurveyed in 1985 by BK Fowles but due to lack of funding no reports were completed. A study undertaken by de Moor *et al* (1999) 45 years after the hydrobiological study, to advise on the instream flow requirements of aquatic invertebrates in the Thukela and Bushmans Rivers concluded that the species composition of known macroinvertebrate taxa had not changed much over the 45-year period for both rivers. The dominant taxonomic groups were still Ephemeroptera and Trichoptera. A great diversity of Ephemeroptera were sampled in both rivers with all except one South African family being found. Eight of the 18 South African families of Trichoptera were also sampled (De Moor *et al.*, 1999). The results of these studies provided baseline information that was used to determine the reference conditions for the Thukela Ecological Reserve study. Table 2.6 provides a summary of the description of the present ecological state of macro-invertebrates for each RU on the Thukela River during the Reserve study (DWAF, 2003c).

Table 2.6: Description of the Present Ecological state of the macroinvertebrate communities for each Resource Unit based on the outcomes of the Reserve study (DWAF, 2003c)

Resource Unit	Present Ecological State
A	• No surveys were undertaken but it is assumed that there have been minimal changes as most of the RU is under conservation.
B	• Possible changes in stones biotope include an increase in Simuliidae and Ancylidae. • *Pseudopannota maculosa* not found in current survey although it was common in 1960. • Beatids still dominate vegetation biotope but lacking were Heptageniidae and Elmidae from this biotope. • The lack of mayflies other than Baetids and Polymitarcyidae from IFR site suggest some impact.
C	• The loss of Perlidae, Caenidae, Oligoneuridae, Elmidae and Tipulidae point to changes in stones biotope. • In the vegetation biotope, Oligochaeta and Baetids were dominant. Elmidae and Hydraenids were not sampled but may have been missed. • Eight families were sampled in the sediment in 2001.
D	• No survey undertaken so results are speculative. • The geomorphology assessment describes significant changes to invertebrate habitat.
E	• No information available but will probably be similar as for RU F, if not better as the polluted Klip River enters at the lower point of this RU.
F	• The freshwater prawns, *Macrobrachium vollenhoveni* were found in the riffles and stony runs and they become more abundant further downstream at all riffle sites. They may be inhabiting the niche often occupied by crabs. • There are four rare species of mayfly which occur only downstream of RU F. • Several taxa including; Oligoneuridae, Prosopistomatidae and *Neurocaenis discolour* were not found in the stones and the previous high abundance of Hydropsychids has reduced to low numbers. Baetids and Simuliids were still dominant. • Dominant species in the vegetation was Baetids but lacking was *Berosus* (Hydrophillidae) and largely Hydrophsychidae. Trichorythidae was more common in 2001. • Fauna in sediment was possibly better than before. No Gomphids were sampled but were probably missed. Elmids and abundant Chironomidae were sampled which was new. • Overall the RU is in a good condition and changes in population are probably due to variability in populations and nor due to significant change.
G	• No survey was undertaken but due to the remoteness of the surrounding environment, it is assumed that the present state would be the same as, if not better than, RU F.
H	• No evidence that the fauna has seriously degraded.

Table 2.6 cont.: Description of the Present Ecological state of the macroinvertebrate communities for each Resource Unit based on the outcomes of the Reserve study (DWAF, 2003c)

Resource Unit	Present Ecological State
I	• In 2001, invertebrates were similar at the upper site (above Jameson's Drift Bridge) except for a lack of Hydropsychidae. Oligoneuridae and Prosopistomatidae were also not found but may have been missed during sampling. • Unexpectedly, Heptageniidae were found in 2001 in stones out of current which is not there normally habitat. Sand grain cased caddis were also common under the stones out of current. • No Beatids were found in the sediment but this could be because the sample was taken from a pool detached from the main river. • A site lower down the RU, that had a diverse habitat, had large numbers of Perlidae, suggestion good water quality.
J	• Invertebrates were scarce on the bedrock and few cobbles in the river. • No *Caradina* present that had previously been abundant. This could be due to low flows and poor marginal vegetation. • Deterioration due to poor riparian habitat and possible water quality problems.
K	• No data available.

2.3.2.3 Riparian Vegetation

The riparian zone is best described by the fluvial geomorphological and hydrological characteristics of the river, but anthropogenic activities can have an impact on the riparian vegetation. Table 2.7 provides a summary of the present ecological state of the riparian vegetation described during the Reserve study. Generally, the riparian vegetation for the Thukela River was considered to be in a moderately to seriously modified state with the long term trajectory of change to be negative (DWAF, 2003c).

Table 2.7: Present Ecological State of the riparian vegetation for each Resource Unit as based on the outcomes of the Reserve study (DWAF, 2003c)

Resource Unit	Present Ecological State
A	• Riparian zone - highly eroded, trampled and incised. • Marginal zone - significantly sedimented. • Vegetation cover - high. • Species composition - mixed grasses with isolated woody patches. • Vegetation structure - largely natural.
B	• Riparian zone - highly eroded, incised, narrowed and encroached. • Marginal zone - sedimented, eroded and encroached. • Vegetation cover - medium. • Species composition - extensive woody exotic trees and shrubs, mixed grasses. • Vegetation structure - largely unnatural due to exotics.
C	• This reach is characterised by the significant encroachment of reeds on sediment islands and river fringes as well as by numerous woody exotic species in patches. • Riparian zone - eroded and invaded by exotic species in patches. • Marginal zone - sedimented and significantly encroached by reeds. • Vegetation cover - medium to high. • Species composition - mainly indigenous woody trees and shrubs, exotics in patches. • Vegetation structure - largely natural.
D	• This reach is characterised by the significant encroachment of reeds on sediment islands and river fringes as well as by numerous woody exotic species in large areas. • Riparian zone - eroded and invaded by exotic species in large areas. • Marginal zone - sedimented and significantly encroached by reeds. • Vegetation cover - high. • Species composition - mainly indigenous woody trees, exotics in large areas. • Vegetation structure - mainly natural, but artificial in large areas.
E	• The vegetation characteristics in this reach are very typical of a gorge characterised by bedrock.

Table 2.7 cont.: Present Ecological State of the riparian vegetation for each Resource Unit as based on the outcomes of the Reserve study (DWAF, 2003c)

Resource Unit	Present Ecological State
F	• Natural vegetation has been removed by natural flooding events, but subsequent recovery has been extensive, especially in area protected from livestock activity and because the area is mainly a gorge.
G-J	• The riparian zone, major riparian substrate and natural vegetation has been removed by natural flooding events from which it has not been able to recover due to the impact from grazing, browsing, trampling and vegetation removal. • Small areas of riparian and marginal vegetation are present in areas protected from the activity of livestock.
K	• Narrow isolated patches of riparian vegetation are present within a reduced riparian zone • Vegetation is dominated by *Ficus sycomorus* and *Trichelia emetica.* • Sugarcane has replaced riparian zone in large areas. • Exotic species are abundant. • Reed encroachment is common on the river fringe and in marginal zones.

2.3.2.4 Thukela Estuary

The Reserve study rated the Thukela Estuary as being Important, based on the Estuarine Importance Scores provided in Table 2.1. The Estuarine Importance is an indication of the value of the estuary to maintaining ecological diversity and functioning of the estuarine system on a local and broader scale (DWAF 2004c).

Table 2.8: Estuarine Importance scores allocated to the Thukela Estuary (DWAF 2004c)

Criterion	Score	Weight	Weighted Score
Estuary size	80	15	12
Zonal rarity type	70	10	7
Habitat diversity	50	25	13
Biodiversity importance	76.5	25	19
Functional importance	100	25	25
Estuarine Importance Score			**76**

The Estuarine Health Index was applied to determine the state of the Thukela Estuary, the results of which are provide in Table 2.9. The score of 70 indicates the estuary is in a moderately modified state (DWAF 2004c). A description of the biological component of the Thukela Estuary is provided below.

Table 2.9: Estuarine Health Score results for the Present Ecological State of the Thukela Estuary (DWAF 2004c)

Variable	Weight	Score	Weighted Score
Hydrology	25	87	22
Hydrodynamics and mouth condition	25	80	20
Water quality	25	54	14
Physical habitat alteration	25	80	20
Habitat health score			**75**
Microalgae	20	65	13
Macrophytes	20	60	12
Invertebrates	20	60	12
Fish	20	70	14
Birds	20	70	14
Biotic health score			**65**
Estuarine Health Score			**70**

Phytoplankton

The middle reaches possess the greatest diversity of phytoplankton in the estuary especially in the upper layers of the water column (DWAF, 2004c). In the upper reaches the greatest diversity was found towards the bottom of the water column in less saline conditions. Phytoplankton is a critical source of carbon for zooplankton. Flagellates dominate the phytoplankton community reaching their peak abundance in the middle of the estuary. The co-dominant taxa are diatoms that increase in abundance towards the lower reaches of the estuary. Dinoflagellates are important primary producers in the middle to upper reaches of the estuary principally in the lower water column. Euglenoids, green algae and cyanobacteria were typical of the water column in the upper reaches of the estuary indicative of pronounced organic inputs. Biomass measured as chlorophyll a, increased along the axial length of the estuary from the mouth to the upper reaches. The highest biomass recordings were in the low to mid water column from the middle to the upper reaches of the estuary (DWAF, 2004c).

Benthic microalgae

Nitzschia umbonata, *N. clausii* and *Gyrosigma scalproides* are found almost exclusively in the cohesive sediment located in the intertidal zone (South Bank) (DWAF, 2004c). *Navicula gregaria, N. phyllepta* and *Amphora exigua* are found in the fine sand found throughout the rest of the estuary. Chlorophyll a was highest 1.5km from the mouth (intertidal: 7.5 µg/g subtidal: 4.1 µg/g) and lowest in the fine sediment 1 km from the mouth (intertidal: 4.7 µg/g and subtidal: 3.5 µg/g). There were more euglenoids in the fine sand compared to the cohesive sediment and there were very few cyanobacterial cells present throughout the estuarine sediment (DWAF, 2004c). The most common species are listed below in Table 2.10.

Table 2.10: Common microphytobenthos species of the Thukela Estuary (DWAF, 2004c).

Freshwater Species	Brackish Species	Marine Species
Cyclotella meneghiniana	*Bacillaria paradoxa*	*Nitzschia subconstricta*
Cyclotella cyclopuncta	*Nitzschia clausii*	*Nitzschia granulata*
Cymbella turgidula		
Navicula viridula var. rostellata		
Nitzschia acicularis		

Macrophytes

Behind the south vegetated bank there is a wetland that covers an area of approximately 21 ha. The dominant plant species is *Phragmites australis*, with a homogenous stand of *Schoenoplectus scirpoides* and patches of the *Hibiscus tiliaceus* (DWAF, 2004c). Dense stands of *Schinus terebinthifolius* interspersed with dune forest species occur approximately 2km from the mouth. Initially the woody vegetation occur behind stands of *P. australis* but then are interposed with pockets of *P. australis* but further up the estuary they occur at the water's edge. During the 1996 flood a plume of sediment was deposited on the north bank and during 2001 a 19.65 ha stand of *S. scirpoides* was found to have colonised this (DWAF, 2004c).

Zooplankton

During low flow conditions, the estuary supports a marine zooplankton community that extends as far as seawater penetrates (DWAF, 2004c). Coastal Copepods are the most abundant component of the community. Estuarine zooplankton are largely absent but it is unknown if an estuarine community exists in the upper reaches, but this is unlikely given the short duration of the low flow season. During high flow conditions, a zooplankton community is nearly absent. Freshwater organisms may be present with the community comprising predominantly of insect larvae. Larvae of the decapods Varuna and Macrobrachium may also be present (DWAF, 2004c). Data on endemic or red data species do not exist for zooplanktonic invertebrate communities.

Macrobenthos

The estuary possesses two discrete benthic community phases: A Freshwater phase (dominated by freshwater and freshwater tolerant estuarine invertebrates) and an Estuarine phase (dominated by marine and estuarine invertebrates) (DWAF, 2004c). The occurrence and duration of these communities depends on flow conditions. The estuary supports over 150 taxa but is not as diverse as other systems along the same coast. During an initial survey in 1997-1998 the benthic community was dominated by the freshwater component. The freshwater community is not atypical of a freshwater dominated system but what was unusual was the dominance of freshwater organisms in the benthos in what was considered the 'estuarine' area, i.e. area where estuarine organisms should dominate. During this survey, a large backwater area existed adjacent to the mouth that supported the largest diversity of species and biomass of the system. More than 90% of the biomass was supported by oligochaetes. A more recent survey (August 2001) reported that with migration of the mouth to the north, the community structure has changed. Estuarine communities dominate the same area with polychaetes contributing the largest portion to biomass. The current community is tolerant of reduced salinities except for particular amphipod and bivalve species (DWAF, 2004c).

Macrocrustaceans

Under low flow conditions *Penaeus japonicus* and *Metapenaeus monoceros* juveniles dominated the macrocrustacean community in the lower and middle reaches. *Upogebia africana*, *Sesarma sp.* and *P. canaliculatus* were also present (DWAF, 2004c). Single records of *Macrobrachium rude* and *M. equidens* were documented. Under high flow conditions no penaeieds were recorded but *Macrobrachium* species dominated the community principally in the middle and lower reaches of the estuary. This comprised of gravid females and juveniles of *M. rude*, *M. equidens*, *M. lepidactylus* and *M. scabriculum*. Other taxa found included *Sesarma sp*. and *Varuna litterata* (DWAF, 2004c).

Estuarine fish

A total of 40 species representing 20 families have been recorded from the estuary (DWAF, 2004c). Of the species recorded 6 species are dependent on estuaries for breeding, 9 are dependent on estuaries as nurseries, 12 are partially dependent on estuaries as nurseries and 4 are marine species that sporadically occur in the lower reaches where seawater penetration is maximal (DWAF, 2004c). Thukela system could be considered an important nursery area for juvenile Zambezi sharks (Van Niekerk and Turpie, 2012). The only freshwater species regularly recorded is *Oreochromis mossambicus* is regularly recorded in the estuary but may only proliferate under closed mouth conditions. *Anguillid eels* use the estuary as a migratory route to and from the catchment (DWAF, 2004c).

There is a tremendous abundance of Mugilid juveniles in the estuary possibly as a consequence of the shallowness of the estuary and high organic loading (DWAF, 2004c). They occur throughout the estuary, especially *Valamugil cunnesius* while some species (e.g. *Myxus capensis*) extending into the riverine areas above the estuary. There tends to be an absence or scarcity of large piscivorous species within the estuary. This is probably due to the shallowness of the system, widely fluctuating densities of potential prey, and freshwater dominated nature of the river mouth (DWAF, 2004c).

Majority of the species present are detritivores and depend largely on allochthonous and autochthonous inputs into the detrital food web (DWAF, 2004c). These species also incorporate microphytobenthos into their diet but not phytoplankton. Another major source of energy is macrobenthos. River flow occasions in the Thukela River poses stress in the fish community of the Thukela Estuary with a decline in fish abundance with increasing river flow. Such decline is a result of both the high river discharge and zero salinities throughout the system with many marine species finding their temporal refuge in the sea (Whitfield and

Harrison, 2003). Six (15%) of fish species recorded in the estuary are regarded as endemic to southern Africa (DWAF, 2004c).

Below the SAPPI effluent discharge there has been a reduction in fish compared to the historical surveys undertaken in 2005 and 2006 (Ferreira *et al.*, 2008). This lack of fish in this part of the river is an indication of disturbance in the fish community. The ecological integrity assessment of the fish communities of the Thukela Estuary showed that the Thukela is in the moderate to poor state of health. Furthermore, the community assemblages of the Thukela Estuary are dominated by the tolerant fish species. These species are tolerant to altered water quality and quantity as well as habitat availability and state, such drivers appear to be altered in the Thukela estuary (Ferreira *et al.*, 2008).

Birds

Extensive data is lacking for the Thukela Estuary but from data that is available a total of 64 species have been recorded (DWAF, 2004c). Three groups have been categorised based on their association with the estuary (Cyrus and Mackay, 2007):

- A summer group which utilise the estuary for feeding (dominated by Palaearctic migrants)
- are A winter group which utilise the estuary for feeding
- A group that uses the estuary as a roosting site (feeding takes place at sea)

The birds exploit the sand banks in the estuary for roosting with seasonal variances in species composition and abundance. However, gulls and terns tend to be the most abundant taxa (Cyrus and Mackay, 2007). The number of species present averages approximately 25 per month with the highest abundance recorded during November to March (summer) when they can reach up to 4600 individuals. During winter, the roosting component may make up to 50% of the individuals present (Cyrus and Mackay, 2007). The species feeding in the estuary are divided into two groups; the piscivores or the benthic invertebrate feeders. The benthic invertebrate feeders dominate in terms of species and abundance. There are indications that densities of estuarine feeders may have increased between the early 1980s and the late 1990s, possibly as a consequence of anthropogenic impacts in other systems but data is limited (DWAF, 2004c).

Four Red-Data species have been recorded but none of them are resident or breed in the area. The two pelican species *Pelicanus onocrotalus* (Near-threatened) and *P. rufescens* (Vulnerable) are post-breeding winter visitors present in small numbers. The other two species *Phoenicopterus ruber* and *Sterna caspia* listed as Near-threatened. No endemics have been recorded (Cyrus and Mackay, 2007).

2.3.2.5 Present Ecological State

The Present Ecological State (PES) refers to the health or integrity of various biophysical attributes of rivers compared to the natural or close to natural reference condition (Kleynhans and Louw, 2007). The PES of the driver (physico-chemical, geomorphology) and response (riparian vegetation, fish, aquatic macroinvertebrates) components of the river can be determined as well as the integrated state called the Ecostatus. The ecological categories used to describe the PES are provided in Table 2.11 (Kleynhans and Louw, 2007).

Table 2.11: Present Ecological State ecological categories (Kleynhans and Louw, 2007)

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

The Reserve study determined the PES for the different driver and response components for the RUs of the Thukela River and these are provided in Table 2.12. These results indicate that in the early 2000s the water quality for the Thukela River was largely natural (B category) with few modifications and the geomorphology was generally in a moderately to largely modified state (C-D category). The PES for the riparian vegetation varied between a B and E category (seriously modified state) for the Upper Thukela River but the riparian vegetation of the Lower Thukela River was seriously modified for RU H and I and largely modified for RU J. The geomorphology, fish and aquatic macroinvertebrate were all in a largely modified state for RU B that is the stretch of river between Driel Barrage to the back-up of Spioenkop Dam. The remainder of the fish communities were in a largely natural state with only RU's C, I and J in a moderately modified state. The macroinvertebrate community for RU A, is the only component that was in a natural to largely natural state (A/B category). Most of the macroinvertebrate communities for the remaining RUs were in a largely natural to moderately modified state.

Table 2.12: Present Ecological State of the driver and response components for each Resource Unit of the Thukela River (DWAF, 2003e)

Resource Unit	Present Ecological State				
	Water quality	Geomorphology	Riparian Vegetation	Fish	Aquatic Invertebrates
A	B	C	C/D	B	A/B
B	B	D	E	D	D
C	B	D	C	C	B/C
D	B	C	D	B	B/C
E	B	B	B	B	B/C
F	C	B/C	C	B	B/C
G	B	C/D	E	B	B/C
H	B	D	E	B	C
I	B	D C	E	C	B
J	B	C/D	D	C	C

The integrated Ecostatus results are provided in Table 2.13 as well as the results of a PES EIS (Ecological Importance and Sensitivity) study undertaken in 2012 (DWS, 2014). The PES EIS study was a desktop study based on expert knowledge and available information with the objective to provide desktop level information on ecological issues as it relates to the protection and management of Sub-Quaternary Reaches (SQRs). The Ecological Importance (EI) refers to biophysical aspects in the SQR that relates to its capacity to function sustainably and the Ecological Sensitivity considers SQR attributes that relates to the sensitivity of biophysical (response) components to general environmental (driver) changes such as flow, physico-chemical and geomorphic modifications (DWS, 2014). The results indicate that most SQRs along the Thukela River have a high EIS (Table 2.12). The PES results for this study are also generally a category higher than for the Reserve study PES results but both studies indicate a deterioration in the ecological integrity of the upper reaches of RU B associated with Bergville, RUs G downstream of the confluence with the Bushmans River, RU H downstream of the confluence with the Sundays River and RU I downstream of the confluence with the Buffalo Rivers. The lower reach of the Thukela River associated with the town of Mandeni and the SAPPI Paper and Pulp Mill was also indicated to be in a moderately modified state. An ecological risk and environmental water requirement assessment undertaken in 2017 of this reach indicated that this reach was in a moderately modified state from 2005 to 2014 but deteriorated to a largely modified state from 2015 due to synergistic effects of land use and the severe drought the region had endured (O'Brien *et al.*, 2017). The Reserve study report stated that the recommended ecological category for the lower estuarine reach, should be a high C (moderately modified) category (DWAF 2004c).

Table 2.13: The ecological importance and sensitivity and present ecological state results for the various reaches and resource units of the Thukela Rive (DWAF 2003e, DWAF 2004c; DWS 2014)

Sub-quaternary Reach	Reach Description	Resource Unit	Ecological Importance	Ecological Sensitivity	PES 2004	PES 2012
V11A-03277	Upper part in Drakensberg Park	A	High	Very high	B/C	B
V11C-03196	Gauging weir		High	High		B
V11C-03261	Back flooding of Woodstock Dam		High	High		B
V11J-03381	Upper reach in Driel Barrage and includes Bergville	B	Moderate	Very high	D	C
V11L-03301	Bottom reach in Spioenkop Dam		High	High		B
V11M-03280	Upper reach in Spioenkop Dam	C	High	High	C	C
V14B-03296	Colenso	D E	High	High	C B	B
V14E-03233	Road crossing	F	High	High	B/C	A
V14E-03352	Irrigation		High	High		B
V60G-03247	Small subsistence farming		High	High		B
V60G-03348	Subsistence farming		High	High		B
V60G-03372	Subsistence farming and rural villages		High	High		B
V60G-03385	Extensive cultivation in floodplain and rural villages		Moderate	High		C
V60H-03431	Extensive cultivation in floodplain	G	Moderate	High	C/D	D
V60J-03343	Old subsistence farming	H	High	High	D	C
V60J-03395	Cultivation and rural villages (Tugela Ferry)		Moderate	High		C
V60K-03419	Subsistence farming		High	High		C
V40A-03384	Some subsistence farming in riparian zone	I	High	High	C	C
V40B-03429	Over-grazing		High	High		B
V40B-03438	Some sediments		High	High		B
V40E-03457	Rural communities		High	High		B
V40E-03556	Some subsistence farming		High	High		B

Table 2.13 cont.: The ecological importance and sensitivity and present ecological state results for the various reaches and resource units of the Thukela Rive (DWAF 2003e, DWAF 2004c; DWS 2014)

Sub-quaternary Reach	Reach Description	Resource Unit	Ecological Importance	Ecological Sensitivity	PES	
					2004	2012
V50A-03602	Road crossing	J & K	High	High		B
V50A-03616	Small subsistence farming		High	High	C/D	B
V50A-03707	Old subsistence farming		High	High		B
V50B-03786	Small subsistence farming		High	High		B
V50C-03860	Upstream impacts		High	High		B
V50C-03882	Villages in lower reach		High	High		B
V50D-03903	Semi-urban areas including Mandeni and Sappi. Lower reach is estuarine		High	High	C	C

2.3.3 Present impacts on water resources

Many of the past impacts to water resources mentioned above have continued into the present. The increase in population, especially informal settlements and the breakdown of municipal services within various areas of the catchment has led to high organic and faecal eutrophication in certain rivers and the presence of *Escherichia coli* (DWAF, 2003b). Agricultural activities like large scale irrigation, overstocking and overgrazing of livestock within the catchment has resulted in eutrophication and sedimentation. Pollution from the numerous dormant and closed coal mines in the Wasbankspruit and Sundays River catchments and the upper and middle Buffalo River catchment continues resulting in the increases in nitrates, phosphates and sulphates in the receiving rivers. The Mzinyashane River system is noted to be the most severely affected by acid mine drainage from coal mining activates (DWAF, 2003b).

The Mandeni area in the lower reaches of the Thukela River includes the Isithebe industrial area, the SAPPI Paper and Pulp mill, Tugela Rail, a textile and vegetable oil factories and the Sundumbili waste water treatment works (DWAF, 2003b). Many of these activities impact the water quality of the lower reaches of the Thukela River, either directly through water abstraction and effluent discharge or more indirectly as they impact on the eMandeni Stream which flows into the Thukela River. The effluent from the SAPPI mill often reduces the dissolved oxygen in the Thukela River downstream of the discharge point and sometimes water is released from the Spioenkop Dam to dilute the waste water (DWAF, 2003b).

The development within the Thukela River catchment has changed the flow of the Thukela River by 27% (Van Niekerk and Turpie, 2012). This can impact on riverine fish life as well as have a significant impact on the receiving coastal and marine environment (DWAF, 2003c; Van Niekerk and Turpie, 2012). Water abstraction and inter-basin transfers can exasperate the impacts of siltation caused by bad land use management (DWAF, 2003c). Siltation leads to the partial infilling of pools as well as to the smothering of spawning gravel beds, since the natural river flows are unable to remove all the additional silt. Low flows also result in increases in riparian and in-stream vegetation that can initially improve the amount of cover available for fish, boosting populations of the smaller species, but could also lead to the infilling and elimination of parts of pool habitats (DWAF, 2003c). Studies have also identified a significant relationship between reduced freshwater flow and patterns in catches of 14 linefish species, more than 40 km offshore on the Thukela Banks (Van Niekerk and Turpie, 2012). The changes in freshwater flow can impact fisheries resources, alter catch composition and ultimately reduce the economic return of fisheries (Lamberth *et al.*, 2009; Turpie and Lamberth, 2010). The Thukela Estuary is listed as being critically endangered indicating that there is a significant loss of ecosystem processes and a loss in the abundance, community composition or species richness of associated biota (Van Niekerk and Turpie, 2012).

2.4 THE THUKELA RIVER – THE FUTURE

The NWRS indicates that the available water resources within the Thukela River catchment is almost fully utilised but there is still potential for building large dams on the Thukela River to augment transfers to the Vaal River system and water from the catchment has been reserved for this future use (DWA, 2013). The proposed dams include the Jana Dam on the Thukela River and the Mielietuin Dam on the Bushmans River. If further transfers are delayed in the future, a dam on the Thukela River may be needed to supply water to the KZN coastal metropolitan area and developments along the North Coast. The Mooi, Little Thukela and Sundays Rivers are already fully utilised or in deficit while the Buffalo River has a small surplus that can be used by the Newcastle Local Municipality for domestic and industrial use (DWA, 2013).

Another proposed future project includes Phase 2 of the Lower Thukela Bulk Water Supply Scheme that will double the treatment capacity from 55Ml/day to 110Ml/day (Umgeni Water, 2017b). A pipeline will be constructed to feed a new 30Ml reservoir located on the outskirts of Mandeni and is an option to supply King Cetshwayo District Municipality and the City of uMhlathuze with water (Umgeni Water, 2017b).

These developments may further reduce the flow of fresh water to the Thukela Estuary that can have an impact biologically, economically and socially as the freshwater is important for the ecological functioning of the estuary and offshore Thukela Banks (De Lecea and Cooper, 2016). This area is an important fisheries region for both commercial and recreational fishing and a food source for the poor. Other considerations are how climate change might have an impact on the future hydrology of the system, so it has been suggested by De Lecea and Cooper (2016), that collaborative management between different government sectors is needed to clearly define management objectives for the area and to identify the trade-offs that need to be made as South African legislation makes provision for the allocation of sufficient freshwater flows to sustain aquatic ecosystems and so the freshwater flow requirements of the marine environment should also be taken into consideration (Lamberth *et al.*, 2009).

The NWA is clear that a balance needs to be achieved between the use and protection of water resources but the application of this is difficult due to the complex nature of the goods and services that the Thukela River provides on not just a local scale but a national scale. If the goods and services provided by the aquatic ecosystem are continually exploited, a cycle of unsustainable use may be started and ideally the aquatic ecosystem should be managed so that economic growth and development can take place whilst supporting environment protection (Jewitt, 2002).

2.5 CONCLUSION

The Thukela River catchment has proven over the years to be an important water resource for the people of South Africa and its growing economy, through the various goods and services it provides. Not only is the water used to develop various economic sectors and social needs within the catchment but also provides water to other parts of the country to meet national growing needs. Unfortunately, the use of the water resources often has a negative impact on the associated aquatic ecosystem. The aquatic ecosystem in many of the rivers' reaches within the catchment are ecologically important and sensitive with various areas categorised as fish support and sanctuary areas. The ecological state of the Thukela River in 2003 - 2004 varied from a Largely Natural to a Largely Modified state and impacts to the water resources have been attributed to, among others, dormant mines, effluent from industries, failure of municipal services, water transfer schemes, abstraction for irrigation and overgrazing of livestock. An important impact to consider is the reduction in flow throughout the system, as this does not just impact on the riverine fish life but has a significant impact on the marine ecosystem including the Thukela Bank and the biology of the Bight. Any decisions made in the future that will reduce the flow of the Thukela River will have to take into consideration the freshwater requirements of the marine environment. Impacts to the offshore area should not just be considered in terms of the impacts to the marine and coastal environment but also to the socio-economic impacts associated with the commercial, recreational and subsistence fishing that takes place there; and therein lies the challenge of managing the water resources. To ensure that the water requirements of the future are met, the present resources need to be protected and a balance between use and protection of the resources needs to be achieved.

CHAPTER 3

3 TRENDS IN THE WELLBEING OF THE LOWER THUKELA RIVER ECOSYSTEM

3.1 INTRODUCTION

Water is an essential resource that is required by South African law to meet all basic human needs for local communities and to maintain environmental sustainability (DWAF, 2004d). South Africa is classified as a water-scarce country and for this reason it is very important that the water resources be used sparingly, and that pollution be reduced and/or avoided (DWA, 2013). Unfortunately, people and organisations impact on the country's water resources on a daily basis. Industries, intensive and careless agricultural practices and increasing population are some of the factors contributing to the decline in the quality of water resources in South Africa (De La Rey *et al.*, 2004). The National Water Act (NWA) (Act 36 of 1998) is the principal legal instrument used to ensure that the water resources in South Africa are protected, used, developed, controlled, conserved and managed sustainably and in an equitable manner for the benefit of all (DWAF, 1999). Chapter 4 of the NWA provides the basis for regulating water use and the monitoring of effected water resources (*National Water Act*, 1998). Chemical monitoring of water resources is costly, time specific and does not take into account impacts like flow alterations and habitat degradation (Karr, 1981; Davies and Day, 1998; De La Rey *et al.*, 2004), so other approaches have been developed.

In 1996, aquatic biomonitoring became a routine tool in the management and monitoring of South African water resources through the assessment of the biological attributes of the water resource to determine its environmental health condition (De La Rey *et al.*, 2004; DWAF, 2008). Aquatic biota are good indicators of the health of the ecosystem they live in as they reflect the effects of any negative impacts on the system over time (Ollis *et al.*, 2006). The monitoring of aquatic biota like fish and aquatic macroinvertebrates was introduced as a cost-effective way to monitor the impacts of water uses on the aquatic ecosystem as it provides rapid results on the present and past history of the water quality of the river (De La Rey *et al.*, 2004). The results of the biomonitoring can also be presented in simplistic form as categorised indices that can be understood by resource managers and decision makers (Ollis *et al.*, 2006).

The SASS index was developed by Chutter in the 1990's and has become the standard index for the rapid assessment of rivers in South Africa as well as to assess the macroinvertebrate component of the Ecological Reserve (Dickens and Graham, 2002). It is a "*qualitative, multi-habitat, rapid, field-based method that requires identification of macroinvertebrates mostly to family level*" (DWAF, 2008). Some of the advantages of assessing aquatic macroinvertebrates are their easy identification with the naked eye, their rapid life cycle, their abundance and occupancy of most habitats, species within communities have varying sensitivities to stresses as well as the relative easy and cost efficient sampling method used (De La Rey *et al.*, 2004; Ollis *et al.*, 2006). Aquatic macroinvertebrates are therefore good indicators of localised conditions of a river over a short period of time (Uys *et al.*, 1996). The assessment of freshwater fish provides more insight into long-term impacts and general habitat conditions as they have a longer lifespan and are mobile (Uys *et al.*, 1996). Freshwater fish are also easy to identify, are typically found even in the smallest of streams and fish communities include a range of species that represent various trophic levels (Karr, 1981). As fish and macroinvertebrates are selectively sensitive or tolerant to changes in flow regimes, habitat and water quality (Uys *et al.*, 1996); these factors also need to be considered in an integrated monitoring approach.

In 2005, the integrated EcoClassification approach was introduced that allowed for the categorisation of the Present Ecological State (PES) of the various biophysical attributes of water resources, compared to a natural or close to natural reference condition (Kleynhans and

Louw, 2007). This information would provide insight into the causes and sources of pollution resulting in the deviation of the PES from the reference condition. The approach considers the driver biophysical components namely; physico-chemical, geomorphology and hydrology to provide a habitat template and the biological responses to these drivers namely; fish, aquatic macroinvertebrates and riparian vegetation. The ecological integrated state of all these components is referred to as the EcoStatus. Although the EcoClassification approach is mainly used for Ecological Reserve determination and Environmental Flow Requirement studies, it is also used in biological monitoring to assess biological response data in terms of changes to the driver components (Kleynhans and Louw, 2007). Various biotic indices were developed to interpret the data and provide a measure of the biological condition of a site (DWAF, 2008). The main biomonitoring techniques and indices used in South Africa include the South African Scoring System (SASS) for macroinvertebrates, the Fish Response Assessment Index (FRAI) for fish and the Index of Habitat Integrity (IHI) for habitat integrity (DWAF, 2008). These indices have been used to assess and monitor the lower reach of the Thukela River in the KwaZulu-Natal province for more than ten years.

The Thukela River is volumetrically the second largest river in South Africa and has a total catchment area of approximately 29 042 km^2 (DWAF, 2004b). The river rises in the Drakensberg Mountains and flows 502 km eastwards to discharge in the Indian Ocean where the deposits from the river play an important part in the formation of the offshore Thukela Banks (DWAF, 2001; DWA, 2013; De Lecea and Cooper, 2016). Numerous tributaries flows into the Thukela River, including the Bushmans, Sundays, Mooi and Buffalo Rivers (Oliff, 1960a). As the Thukela River is one of the largest rivers in the country, it is important in sustaining the social and economic growth of the country by meeting the demands for human consumption, agriculture and industry but still meeting the requirements of the freshwater and offshore aquatic ecosystems (DWA, 2013; De Lecea and Cooper, 2016).

The lower reach of the Thukela River and the associated Thukela Estuary is considered to be an ecologically important region of the Thukela River catchment as it provides habitat for unique species of marine migrant, estuarine and freshwater species and acts as a conduit for many anadromous species that populate the upstream reaches of the river (DWA, 2013; Jacobs, 2017). The lower reach of the Thukela River includes the Mandeni town, the Isithebe industrial area, the SAPPI Tugela Paper and Pulp mill, Tugela Rail, a textile and vegetable oil factories and the Sundumbili waste water treatment works (DWAF, 2003b). Many of these activities impact the water quality of the lower reaches of the Thukela River, either directly through water abstraction and effluent discharge or more indirectly as they impact on the eMandeni Stream which flows into the Thukela River (DWAF, 2003b). Ecological impacts on the Thukela River from these resource users have been reported and include decreases in oxygen levels along with increases in chemical oxygen demand, ammonia and conductivity (DWAF, 2004b; Ferreira *et al.,* 2008; Stryftombolas, 2008; O'Brien and Venter, 2012). Oxygen levels in the eMandeni Stream have also been reported to be lower than those in the Thukela River and the lower Thukela River together with the eMandeni Stream are the areas at the greatest threat of stressors affecting the ecosystem health (Stryftombolas, 2008; O'Brien and Venter, 2012). The aim of this chapter was to update the current ecological state assessment of the lower reach of the Thukela River and the eMandeni Stream by implementing the EcoClassification approach (Kleynhans and Louw, 2007) and comparing the results to historical data to identify trends in the ecological state of the system over time.

3.2 STUDY AREA

The study area includes approximately 30 km of the lower reach of the Thukela River, from the Nembe River tributary to the estuary. Within the study area is the eMandeni Stream, the town of Mandeni, the Sundumbili settlement, the Isithebe industrial area, and the SAPPI Tugela paper and pulp mill. Upstream of the confluence with the eMandeni Stream, is the Lower Thukela Bulk Water Supply Scheme which was completed in 2017 (Umgeni Water, 2017a).

The eMandeni Stream joins the Thukela River approximately 17 km upstream of the Thukela River Mouth. The stream is similar to the upstream Nembe River but access into the stream is restricted by a barrier approximately 500m upstream of the confluence with the Thukela River. The eMandeni Stream also receives a variety of partially treated effluents and runoff waste water from various industrial and urban centres in the region. Three of these centres include the Sundumbili community, Ithala (Isithebe) industrial area and eMandeni community and industrial complexes. The hazards generated by these areas include primarily various water quality related impacts, as well as water quantity and habitat state impacts (Stryftombolas, 2008; DWAF, 2003c).

Historically, this lower reach of the Thukela River and the eMandeni Stream have been monitored for more than ten years. Over this time, monitoring sites have been added and removed but the data are still relevant to show trends in the health of the various attributes of the aquatic ecosystem (Ferreira *et al.*, 2008; O'Brien, 2010; O'Brien and Venter, 2012; INR, 2014a; Desai *et al.*, 2015; O'Brien *et al.*, 2016, O'Brien *et al.*,2017; Wade *et al.*, 2017).

Table 3.1 provides a list of the historical sites that were included in the trend analysis and indicated in **Error! Reference source not found.**. Where historical sites were in close p roximity to each other (V5MAND-RAILB and V5MAND-WASTE; V5THUK-EWR18 and V5THUK-JOHNR), they were combined, and the site names were standardized. Historically V5THUK-RAILB was utilised as a control site for the Thukela River however, the site is situated on a dolerite dyke and possesses distinctive geomorphological characteristics from the remainder of the lower reach of the Thukela River as it traverses downstream. Consequently, the ecosystem is unique within the reach and is not representative of the dominant habitat in the region. A new control site, V5THUK-EWR17, was identified and sampled during 2017 and 2018. The site is located upstream of the eMandeni Stream and Sappi mill final effluent discharge point and its geomorphological and channel characteristics are congruent with the rest of the system downstream of the discharge point. Accordingly, this allows for an ideal inter-site comparison pertaining to ecological wellbeing of the system.

Table 3.1: Historical and current survey sites on the Thukela River and Emandeni Stream

Site name	Co-ordinates	Description
V5THUK-RAILB	-29. 171752 31. 390908	The site is on the Thukela River, 5km downstream of the DWA gauging weir, upstream of the Railway Bridge. It is a rocky, dolerite dyke that provides a diverse but unique habitat for the area.
V5THUK-EWR17	-29.168167° 31.402377°	This site is on the Thukela River, just downstream of the rocky dolerite dyke. The site is characterised by large sandbars forming an anabranching stream.
V5THUK-EWR18	-29.176260 31.440970	The site is on the Thukela River, approximately 1 km downstream of the SAPPI mill discharge point. The site is characterised by alluvial sands, sandbars and anabranching streams.
V5THUK-ULTM	-29.212618° 31.436526°	The site is on the Thukela River at "Ultimatum Tree", approximately 50 m downstream of the N2 bridge. Site is dominated by alluvial sands and numerous sandbars.
V5MAND-RAILB	-29.140775° 31.407094°	eMandeni Stream below Sundumbili sewerage works and adjacent to railway sliding.
V5MAND-WASTE	-29.146300° 31.407500°	eMandeni Stream below Sundumbili sewerage works.
V5MAND-WEIR	-29.170590° 31.421540°	Lower eMandeni Stream approximately 300m above confluence with Thukela River.

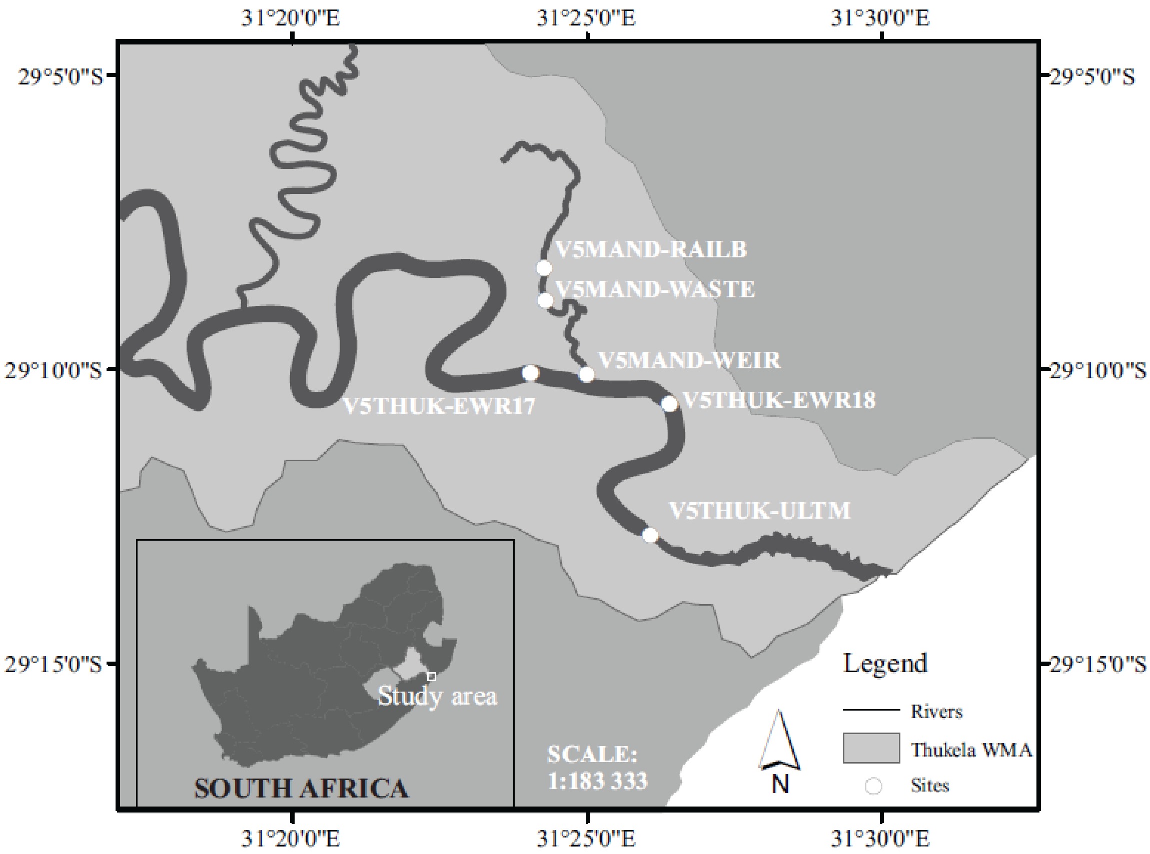

Figure 3.1: Localities of historical and current survey sites on the Thukela River and Emandeni Stream

Three sites on the Thukela River and two on the eMandeni Stream were assessed during the 2018 low flow field survey that occurred within the dry season, between May and October, when the flow in the river is generally lower than during the wet, rainy season. The V5THUK-EWR17 and the V5MAND-RAILB were the reference sites for each river to which downstream results were compared.

3.2.1 V5THUK-EWR17

The V5THUK-EWR17 site is located on the Thukela River, downstream of the Umgeni Water Bulk Transfer Scheme (UBTS) development and approximately 1 km downstream of the dolerite dyke (previous V5THUK-RAILB site) (Figure 3.2A-D). The area downstream of the rocky ridge provides important habitat to many aquatic animals in the Thukela River but the important habitat may only be available to many migrating animals during high flows, freshet and flood flows. These flows coincide with many important life cycle events of species that would use this habitat, including migration periods, spawning and recruitment periods. Although the UBTS incorporates a fishway, its functionality has not been confirmed. The V5THUK-EWR17 site is characterised by an open canopy, large sandbars, deep pools and anabranching streams. During the low flow survey, the water was turbid and light brown in colour. Some stones in current and bedrock was present, but the site was dominated by gravel and mud. Marginal vegetation in and out of current was also abundant. Water abstraction is evident at the site for nearby agricultural activities and sand mining also takes place (Figure 3.2A & C).

Figure 3.2: V5THUK-EWR17 site on the Thukela River; (A) downstream view, (B) upstream view, (C) pump for water abstraction on the bank, (D) cross-section of site

3.2.2 V5THUK-EWR18

The V5THUK-EWR18 site is located just downstream of the John Ross Bridge on the Thukela River (Figure 3.3A-D). The site is approximately 1.5 km downstream of the confluence with the eMandeni Stream and a similar distance from the Sappi Mill effluent discharge point. The site is characterised by alluvial sands, sandbars, anabranching streams, deep pools and undercut banks. During the low flow survey, the water had high turbidity, medium to low flow and was brown. Large quantities of raw pulp from the Sappi mill was suspended in the water and got caught in the nets (Figure 3.3C). Mud dominated the instream biotopes with some marginal vegetation in and out of current. No stones or bedrock was present.

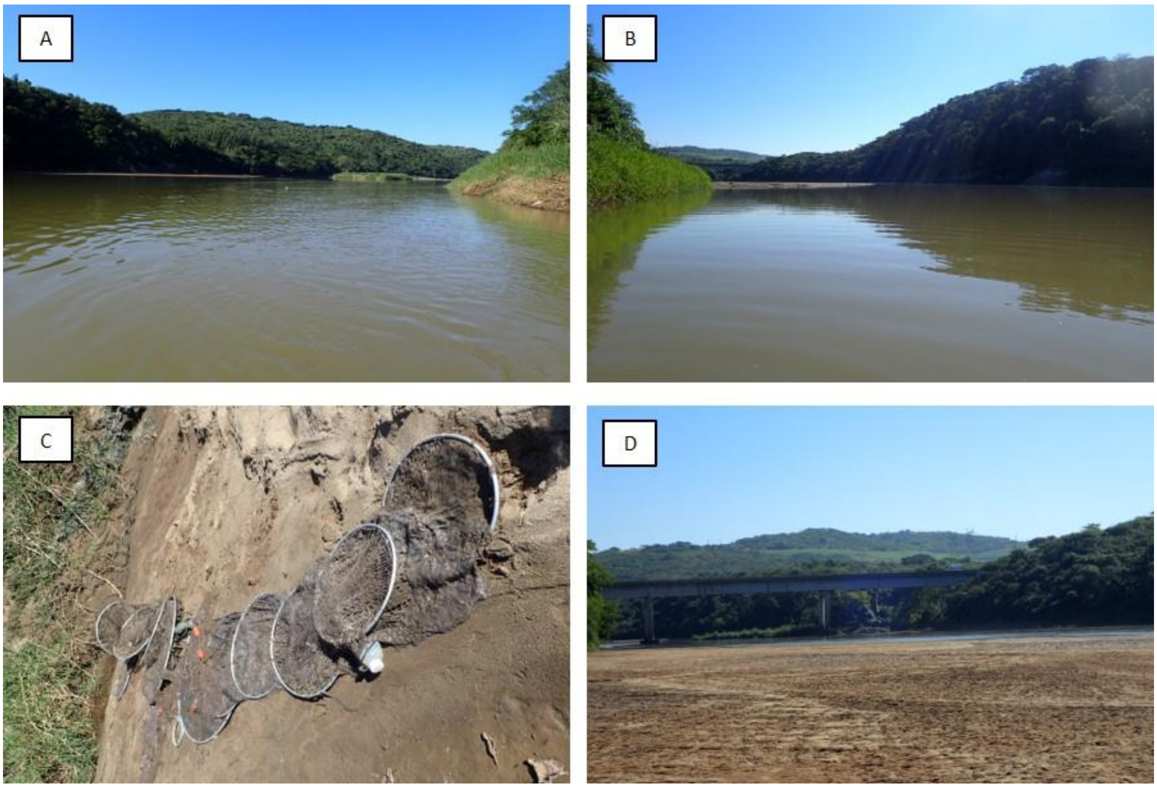

Figure 3.3: V5THUK-EWR18 site on the Thukela River; (A) downstream view, (B) upstream view, (C) raw pulp caught in the fyke net, (D) sandbank at the site

3.2.3 V5THUK-ULTIM

The V5THUK-ULTIM site is located further downstream on the Thukela River under the N2 bridge, downstream of the Harold Johnson Nature Reserve (Figure 3.4A-D). The site is characterised by alluvial sands, numerous sandbars deep pools, backwater areas and undercut banks. The canopy was open, and the water had high turbidity, medium to low flow and was brown during the low flow survey. Mud and vegetation out of current were the dominant biotopes with some vegetation in current and limited stones out of current (Figure 3.4B).

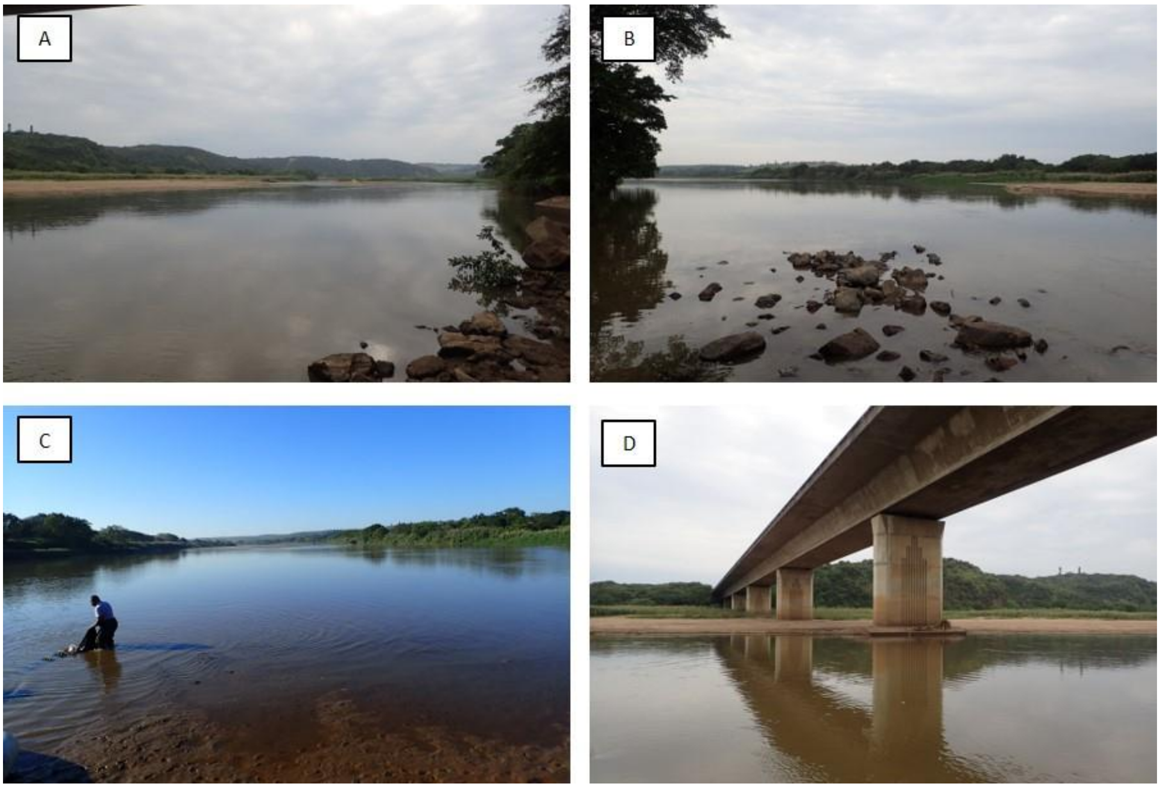

Figure 3.4: V5THUK-ULTIM site on the Thukela River; (A) upstream view, (B) stones out of current biotope (C) downstream view, (D) cross-section of the site under the N2 bridge

3.2.4 V5MAND-RAIL

The V5MAND-RAIL is the upstream site on the eMandeni Stream and is located below the Sundumbili sewerage works and adjacent to the railway sliding (Figure 3.5A – B). The water at the site during the low flow assessment had medium flow, was black in colour and had high turbidity. The habitat at the site was diverse with a riffle containing abundant stones in current, gravel and sand and some bedrock. Marginal vegetation out of current was also plentiful.

Figure 3.5: V5MAND-RAIL site on the eMandeni Stream; (A) upstream view, (B) downstream view

3.2.5 V5MAND-WEIR

The V5MAND-WEIR site is below the weir on the lower eMandeni Stream, ± 300 m upstream of the confluence with the Thukela River (Figure 3.6A-B). The weir is a gabion structure that crosses the river and the riparian zone is invaded by alien plant species. The water at the site during the low flow assessment had medium flow and was dark brown and very turbid. The site had a riffle with numerous stones in current. Gravel, sand and mud was plentiful with marginal vegetation out of current.

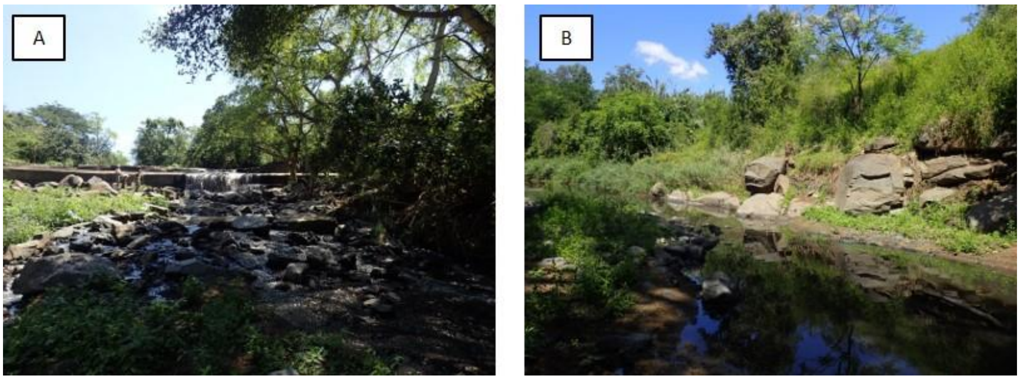

Figure 3.6: V5MAND-WEIR site on the eMandeni Stream; (A) upstream view, (B) downstream view

3.3 MATERIALS AND METHODS

3.3.1 EcoClassification

The ecological integrity assessment was carried out using the EcoClassification approach (Kleynhans and Louw, 2007) to determine the ecological state of the lower reach of the Thukela and eMandeni Stream. As mentioned in the Introduction section, this approach uses driver and response components of the aquatic ecosystem to determine the integrated ecological state of the aquatic system. In this chapter, water quality and habitat were assessed as the driver components and aquatic macroinvertebrates and fish as the response components. The PES for each component is expressed as an ecological category ranging on a scale from A to F with A representing a natural state and F a critically modified state. The details for each category are provided in Table 3.2.

Table 3.2: Summary of the name and description of the six ecological categories used in the Ecoclassification procedure (Kleynhans and Louw 2007; DWAF 2008)

Ecological Categories	Name	Description
A	Natural	Unmodified natural
B	Good	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.
C	Fair	Moderately modified. Loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.
D	Poor	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred
E	Seriously modified	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive.
F	Critically modified	Critically or extremely modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.

3.3.2 Driver Components

3.3.2.1 Water Quality

Water quality is a term that describes "*the physical, chemical, biological and aesthetic properties of water that determine its fitness for a variety of uses and for the protection of the health and integrity of aquatic ecosystems*" (DWAF 1996a). The water quality variables are the attributes or constituents whose variation in magnitude result in the alteration of the water quality (Dallas and Day, 2004). These variables are monitored to provide insight into the factors that may be negatively impacting the aquatic ecosystem. This includes the monitoring of *in situ* (on site) variables as well as the analysis of water samples in a laboratory.

The *in situ* variables were measured using a YSI Professional series multi meter and included the measurement of temperature, pH, oxygen concentrations and electrical conductivity. Sub-surface water samples were collected at each site in clean polyethylene bottles. The samples were frozen and analysed at Umgeni Water in Pietermaritzburg for nutrients, salts and some toxicants.

The results were assessed using the South Africa Water Quality Guidelines for domestic use and aquatic ecosystems (DWAF 1996a, DWAF 1996b). These guidelines provided a Target Water Quality Range (TWQR) for each variable which is a management objective that has been derived from quantitative and qualitative criteria (DWAF 1996a). The guidelines for domestic use have been included as aquatic ecosystem guidelines often do not have parameters defined for specific variables. The reason being that their fate in the environment is negligible (aquatic organisms are unaffected) or has not been determined. Furthermore, local communities in the area rely on the river water for their water needs.

Table 3.3: Domestic use and aquatic ecosystem target water quality ranges for constituents measured in the Thukela River and eMandeni Stream (DWAF 1996a, DWAF 1996b)

Variable	Unit	Aquatic ecosystem	Domestic use
Temperature	°C	<2°C, <10%Δ	-
pH		>0.5 or 5% Δ	6-9
Dissolved oxygen	mg/l	80 % - 120 % of saturation	-
Conductivity	mS/m	>15% Δ	0-70
Salinity	mg/l	10% Δ	-
Alkalinity	mg $CaCO_3$/l	-	-
Calcium	mg Ca/l	-	-
Chlorophyll 'a'	µg/l	-	0-1
Chloride	mg Cl/l	-	0 -100
Chemical oxygen demand	mg O_2/l	-	-
Conductivity	mS/m	-	-
Fluoride	mg F/l	0.75	0-1
Sodium	mg Na/l	-	0-100
Ammonia	mg N/l	0.007	0 – 1.0
Nitrite	mg N/l	-	0-6
Nitrate	mg N/l	-	0-6
Sulphate	mg SO_4/l	-	0-200
Soluble reactive phosphate*	µg P/l	-	-
Phosphate	µg P/l	<15% Δ and no change in trophic status	-
Turbidity	NTU	-	0-1
E.coli	MPN per 100ml	-	-
Heterotrophic Plate Counts @ 37°C	CFU per ml	-	0-100

Note: Δ is the maximum allowed change in a variable from reference concentrations

3.3.2.2 Habitat

The habitat integrity of a river refers to the "*maintenance of a balance composition of physico-chemical and habitat characteristics on a temporal and spatial scale that are comparable to the characteristics of natural habitats of the region*" (DWAF, 2008) and was assessed at each site using the Index of Habitat Integrity (IHI). Each site was assessed by considering the current condition of the instream and riparian zones compared to reference conditions. An impact based approach is used to determine the intensity and extent of anthropogenic changes to interpret the impact on the habitat integrity of the system (Kleynhans *et al.*, 2008). This was done during the site survey, in conjunction with a desktop assessment, using Google Earth, to determine surrounding land use and impacts. The results are interpreted as per the six EcoClassification ecological categories (Table 3.2).

3.3.3 Response Components

3.3.3.1 Aquatic Macroinvertebrates

The aquatic macroinvertebrates were sampled using the SASS5 methodology as specified by Dickens & Graham (2002). Briefly, this method involves the sampling of macroinvertebrates in different biotopes namely; stones in and out of current, marginal and aquatic vegetation as well as gravel, sand and mud biotopes, with a net that is 30 cm square. Various time frames are provided per sampling effort per biotope. The macroinvertebrates collected during each sampling effort are identified to family level and recorded on a SASS scoring data sheet as well as the estimated abundance of each taxa observed. This information was used to calculate the SASS5 score, number of taxa (No. of Taxa) and Average Score per Taxon (ASPT) for each site based on the methods set out by Dickens & Graham (2002). The results of the SASS5 assessment can be interpreted to determine the river water quality and river health, the ecological state of the aquatic ecosystem and the spatial and temporal trends in the ecological state of a river (Dickens & Graham, 2002). The ecological category for each site was determined using the North Eastern Coastal Belt biological band developed by Dallas (2007) as the study area was located within this ecoregion (Figure 3.7).

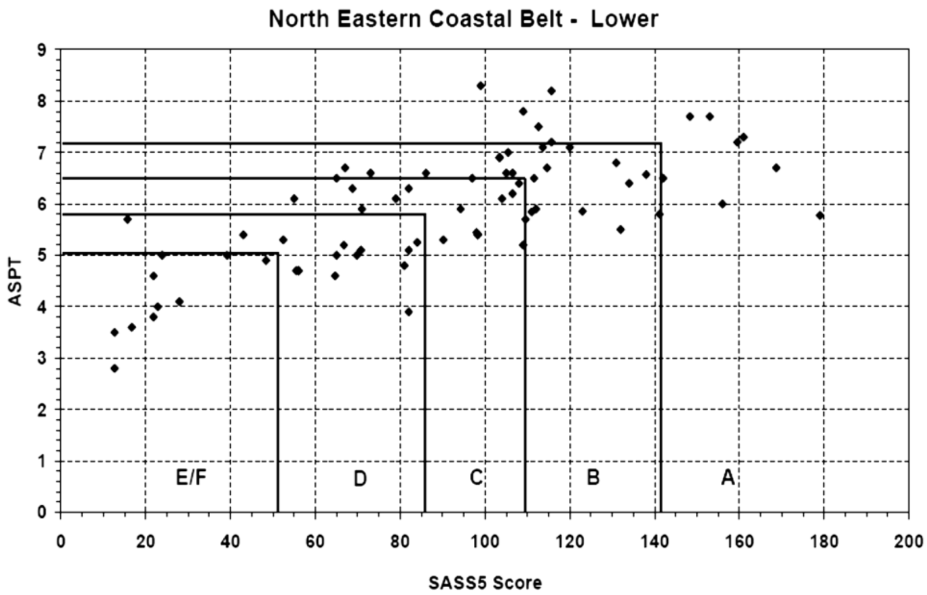

Figure 3.7: Biological Bands for the North Eastern Coastal Belt – Lower zone, calculated using percentiles (Dallas, 2007)

3.3.3.2 Fish

Fish were comprehensively sampled at all sites using both netting techniques and the use of electronarcosis (electroshocking) (Meador *et al.*, 1993; Barbour *et al.*, 1999) methods, where applicable. Netting techniques included the use of a "small" 12 mm meshed 5 m seine net that was hauled through all shallow (less than 1 m) habitats at all sites dominated by sandy bottoms. Additionally, a "medium" sized seine net (22 mm meshed 30 m bagged seine net) was hauled through deep (greater than 1 m) open water habitats at all the sandy bottomed sites. The electroshocking technique was implemented at all freshwater sites where the conductivity allowed for the technique to be used. All riffle and rapid areas were effectively sampled using this technique, as was all shallow marginal vegetated areas and obstructions in the river sites. All the fish specimens were identified in the field and returned unharmed.

The interpretation of the fish data was undertaken using the Fish Response Assessment Index (FRAI) to provide a habitat based cause and effect platform for interpreting the deviation of fish assemblages from reference conditions (Kleynhans, 2007). This index is based on the environmental intolerances and preferences of the reference fish assemblage and the response of the constituent fish species to groups of environmental drivers which are further categorised into metric groups. Changes in environmental conditions are related to fish stress which forms the basis of the ecological response interpretation (Kleynhans, 2007). The resultant index scores are comparable to the six EcoClassification ecological categories (Table 3.2).

3.3.4 EcoStatus

EcoStatus is defined as "The totality of the features and characteristics of the river and its riparian areas that bear upon its ability to support an appropriate natural flora and fauna and its capacity to provide a variety of goods and services" (Kleynhans and Louw, 2007). The EcoStatus approach assesses the driver and response components separately using indices. The driver components are not integrated at the driver level but assist with the interpretation of the response components. The ecological class of each biological response component (fish and macroinvertebrates) are integrated to provide an instream ecological class (Figure 3.8). This instream ecological class is integrated with the riparian vegetation ecological class to determine the overall EcoStatus (Kleynhans and Louw, 2007). The riparian vegetation was not assessed during the field surveys, but the regional KZN River Health Programme; State of the Rivers results were used for the riparian vegetation component of the EcoStatus (DWS, 2017).

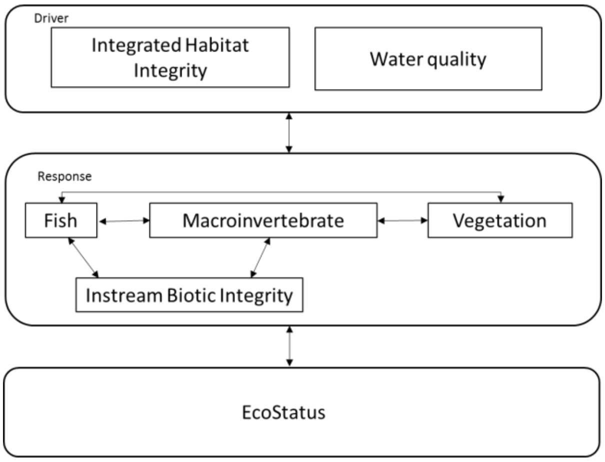

Figure 3.8: Schematic representation of the EcoStatus model based on Kleynhans and Louw (2007).

3.3.5 Temporal trends

The macroinvertebrate, habitat and water quality temporal trend information has been compiled using the unpublished biomonitoring data taken from the reports list in Table 3.4.

Table 3.4: Biomonitoring reports used to compile temporal trends

Year	Report	Reference
2008	Investigation Report: Ecological Integrity Assessment of the lower Umvoti River/Estuary, KwaZulu-Natal: 2008 update of the 2005 Ecological Integrity Assessment of the lower Thukela River/Estuary, KwaZulu-Natal	Ferreira *et al.*, 2008
2010	2010 Update: Ecological state assessment of the lower Thukela River/Estuary. KwaZulu-Natal. Draft Final Survey Report	O'Brien, 2010
2011 2012	An ecological integrity assessment of the lower Amatikulu, Thukela and uMvoti rivers, KwaZulu-Natal, South Africa	Venter, 2013
2013 2014	2014 Update: Ecological State Assessment of the Lower Thukela River/Estuary	INR, 2014a
2015	2015 Update: Ecological State Assessment and dioxin threat analyses of the Lower Thukela River and Estuary, KwaZulu-Natal	Desai *et al.*, 2015
2016	2016 Update: Ecological Assessment of the Lower Thukela River/Estuary.	O'Brien *et al.*, 2016
2017	Holistic ecological risk and environmental water requirement assessment of the lower Thukela River and eMandeni Stream: Appendices Draft Final Report	O'Brien *et al.*, 2017
	2017 Update: Ecological Assessment of the Lower Thukela River/Estuary	Wade *et al.*, 2017

Although due diligence has been applied to include the correct data for the correct sites, the early trends need to be interpreted with caution as certain site names have been used to describe more than one site locality. The biomonitoring was undertaken based on the requirements of the Sappi Tugela mills annual environmental monitoring programme that resulted in some gaps in the water quality data trends when the analysis of certain variables was not required.

3.4 RESULTS AND DISCUSSION

3.4.1 Driver Components

3.4.1.1 Water Quality

The assessment of the water quality included *in situ* measurements and laboratory testing of water samples for a suite of variables that were considered important influencers on ecosystem wellbeing and the results are provided in Table 3.5. The values highlighted in light grey have exceeded the TWQR for domestic use (DWAF 1996b) and those highlighted in dark grey have exceeded the TWQR for aquatic ecosystems (DWAF 1996a) (Table 3.3).

The *in situ* results indicated that the pH for the two sites on the eMandeni Stream was higher than the pH recorded for the sites on the Thukela River, and might be impacting the V5THUK-EWR18 site, as the pH recorded for this site was higher than for the other two Thukela River sites (Table 3.5). The dissolved oxygen concentrations at the downstream V5THUK-EWR18 and V5THUK-ULTM sites where both lower when compared to the V5THUK-EWR17 control site. The dissolved oxygen concentration for the upstream V5MAND-RAILB site was very low with the concentration increasing slightly at the downstream V5MAND-WEIR site. Continuous exposure to low concentrations of dissolved oxygen can be harmful to aquatic biota (DWAF, 1996a). The electrical conductivity results for the two sites on the eMandeni Stream exceeded the TWQR for domestic use and the concentrations were noticeably higher for these sites when compared to the sites on the Thukela River, but did not seem to be impacting on the downstream sites on the Thukela River.

Table 3.5: *In situ* water quality data and water analysis results for the 2018 low flow survey sites on the Thukela River and eMandeni Stream

	Variable	Units	V5THUK-EWR17	V5THUK-EWR18	V5THUK-ULTM	V5MAND-RAILB	V5MAND-WEIR
IN SITU	Temperature	°C	19.84	20.45	21.92	18.0	18.8
	pH		6.96	7.42	6.87	7.51	7.92
	Dissolved oxygen	mg/l	8.17	6.97	6.83	4.00	6.00
	Conductivity	mS/m	27.2	30	31.9	160.6	108
	Salinity	mg/l	0.13	0.14	0.15	18.0	18.8
WATER ANALYSIS	Alkalinity	mg $CaCO_3$/l	83.8	98.3	89.4	348	185
	Calcium	mg Ca/l	18.1	20.3	19.9	30.3	26.3
	Chlorophyll 'a'	µg/l	8.78	13.0	7.23	253	21.8
	Chloride	mg Cl/l	13.1	16.4	15.8	269	197
	Chemical oxygen demand	mg O_2/l	<20.0	<20.0	<20.0	136	90.8
	Conductivity	mS/m	29.7	29.4	27.7	163	120
	Fluoride	µg F/l	β	111	110	283	279
	Sodium	mg Na/l	15.9	25.1	21.3	165	226
	Ammonia	mg N/l	<0.10	<0.10	<0.10	12.9	4.83
	Nitrite	mg N/l	<0.10	<0.10	<0.10	<0.5	1.51
	Nitrate	mg N/l	0.51	0.17	0.18	<0.5	2.32
	Sulphate	mg SO_4/l	18.1	25.5	21.6	26.4	28.1
	Soluble reactive phosphate	µg P/l	<5.00	<5.00	5.10	1745	983
	Phosphate	µg P/l	53.1	146	143	4560	1870
	Turbidity	NTU	30.4	54.1	34.3	25.9	21.5
	E. coli	MPN per 100ml				178200	193500
	Heterotrophic Plate Counts @ 37°C	CFU per ml				>1000	>1000
	Exceeds TWQR for domestic use						
	Exceeds TWQR for aquatic ecosystems						

β: analysis could not be completed due to insufficient sample.

The laboratory results (Table 3.5) of the water analysis for the 2018 low flow survey show that many of the variables for the sites on the eMandeni Stream, have concentrations higher than the TWQR for domestic use (Table 3.3 – DWAF, 1996b). The ammonia concentrations for the two eMandeni Stream sites exceed the TWQR for both domestic use and aquatic ecosystems (Table 3.3 – DWAF, 1996a; DWAF, 1996b). Ammonia is a common pollutant associated with sewerage discharge and industrial waste and is one of the nutrients that contributes to eutrophication but concentrations of un-ionized ammonia can be toxic to aquatic biota (DWAF, 1996a). The upstream V5MAND-RAILB site generally had the highest concentrations for all the variables indicting that the water quality at this site is highly impacted. The concentration of variables at the downstream V5MAND-WEIR site were also high and might be impacting on the V5THUK-EWR18 site as the concentrations of variables at this site were often slightly higher when compared to the upstream V5THUK-EWR17 site. Of concern are the high levels of phosphate at the downstream Thukela River sites, which seem to be due to the high concentrations of phosphate and soluble reactive phosphate in the eMandeni Stream. The high concentrations of *E. coli* and heterotrophic plate counts in the eMandeni Stream are also of concern and are indicative of poor treatment and post-treatment contamination or definite after-growth in the water distribution system and is a health risk to the surrounding community (DWAF, 1996b).

3.4.1.2 Water Quality Temporal Trends

Historical temperature trends are graphically presented in Figure 3.9 for the survey sites on the Thukela and eMandeni Stream. Results indicate general seasonal variations in temperatures between high and low flow surveys which is expected. The trend line for Thukela River sites located upstream and downstream of the Sappi mill discharge suggests that the temperatures of the river below the discharge may be affected by the elevated temperatures from releases, particularly during drought periods, that exceeded the TWQR for aquatic ecosystems (Table 3.3 – DWAF, 1996a). After recovery flows, no considerable difference in temperature was recorded between the two upstream sites (V5THUK-RAILB and V5THUK-EWR17) and the V5THUK-EWR18 downstream site. There is generally a close inverse relationship between temperature and the oxygen saturation potential of water and unnatural changes in temperature can have an effect at the organism, species or community level (DWAF, 1996a) .

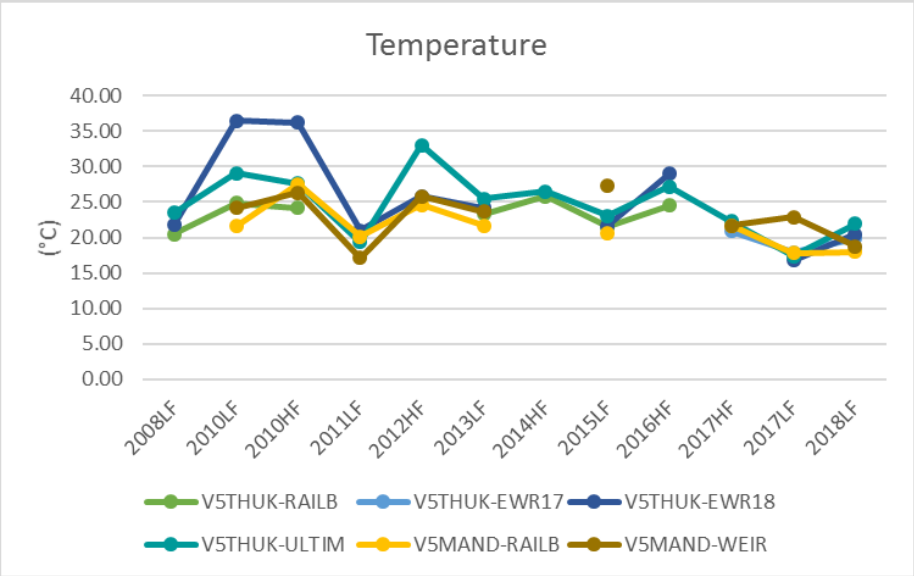

Figure 3.9: Temperature trends for survey sites on the Thukela River and eMandeni Stream

Oxygen concentrations observed in the study area have varied considerably over time (Figure 3.10). Trends in oxygen concentrations below the discharge point of Sappi (V5THUK-EWR18 and V5THUK-ULTIM) include a considerable decreasing trend between 2008 and 2010 which coincides with elevated temperature levels in the region during 2010 and chemical oxygen demand concentrations (Figure 3.13). Historically, the oxygen concentrations at the V5THUK-ULTM site have been low in 2010 and 2012 to 2016. From 2010 to 2015 and again in 2018, unacceptably low oxygen concentrations have been observed in the eMandeni Stream, especially at the V5MAND-RAILB site. Low oxygen concentrations were also observed in the V5MAND-WEIR site from 2010 to 2012. The reduced oxygen concentrations observed in the study area from 2012 to date can be attributed to the combined effects of the water quality stressors associated with the upstream Isithebe Industrial complex, the waste water treatment works, the Sappi mill and the reduced flows during the drought in 2015 and 2016. The effects of reduced oxygen levels depend on the life stages of the aquatic biota and the duration, frequency and timing of the oxygen depletion (DWAF, 1996b). Prolonged exposure to reduced oxygen concentrations can cause extensive changes to community composition as more tolerant species become prevalent (DWAF, 1996ba). During the 2017 season there is a distinctive recovery of the dissolved oxygen concentrations within the system and is possibly due to the increased flows after the drought and the lower water temperature recorded during the same period (Figure 3.9).

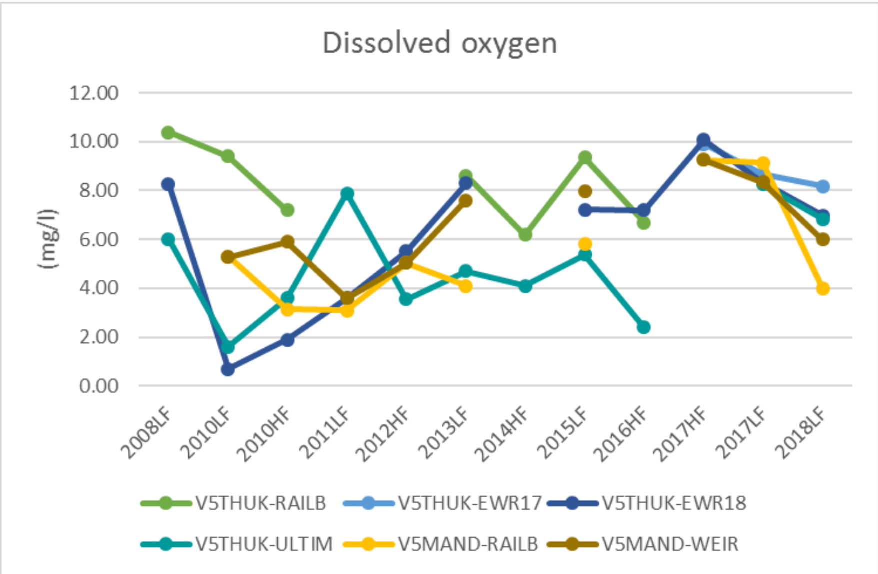

Figure 3.10: Dissolved oxygen trends for survey sites on the Thukela River and eMandeni Stream

The electrical conductivity is used to determine the concentration of total dissolved solids in the water that carry an electrical charge and include carbonate, bicarbonate, chloride, sulphate, nitrate, sodium, potassium, calcium and magnesium (DWAF, 1996b). The electrical conductivity of the two sites on the eMandeni Stream is generally always higher than that recorded for the sites on the Thukela River (Figure 3.11). A distinct increase in the salt load was recorded in the eMandeni Stream during the low flow surveys but did not seem to impact the downstream sites on the Thukela River. The salt loads in the Thukela River have remained relatively consistent over time, except for the V5THUK-EWR18 site in 2010 and the V5THUK-ULTIM site in 2016.

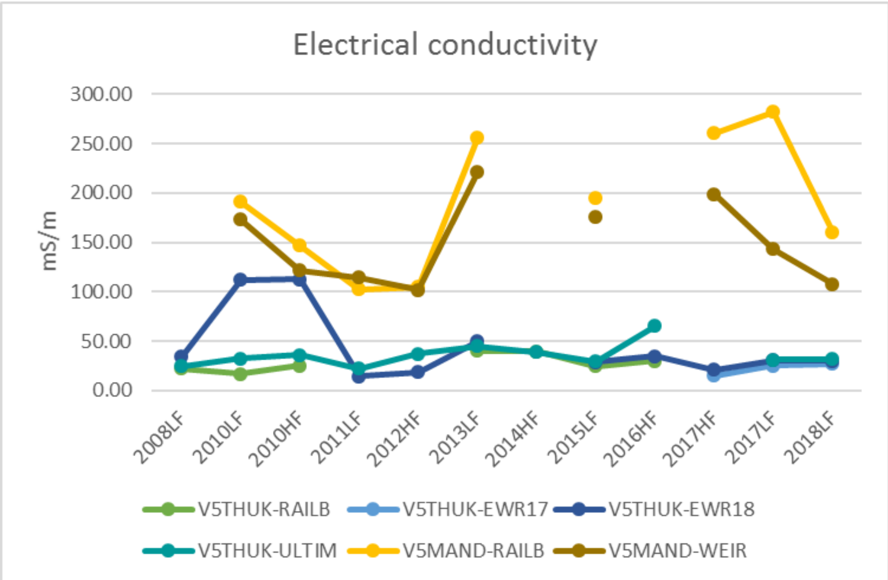

Figure 3.11: Electrical conductivity trends for survey sites on the Thukela River and eMandeni Stream

The pH of water is determined by the concentrations of hydrogen and hydroxyl ions and changes to the pH can affect the ionic and osmotic balance of aquatic organisms (Dallas and Day, 2004). The temporal pH trends (Figure 3.12) for the survey sites indicate that most sites between 2010 and 2012 had elevated pH, above the norm for South African Rivers (between 6 and 8) (DWAF, 1996a). The pH for many of the sites declined from 2013 to 2016 with slight elevations again in 2017. The reduction in pH at the V5THUK-EWR18 site during the 2010 high flow survey could be due to the elevated sulphate concentrations recorded during the same time period (Figure 3.17).

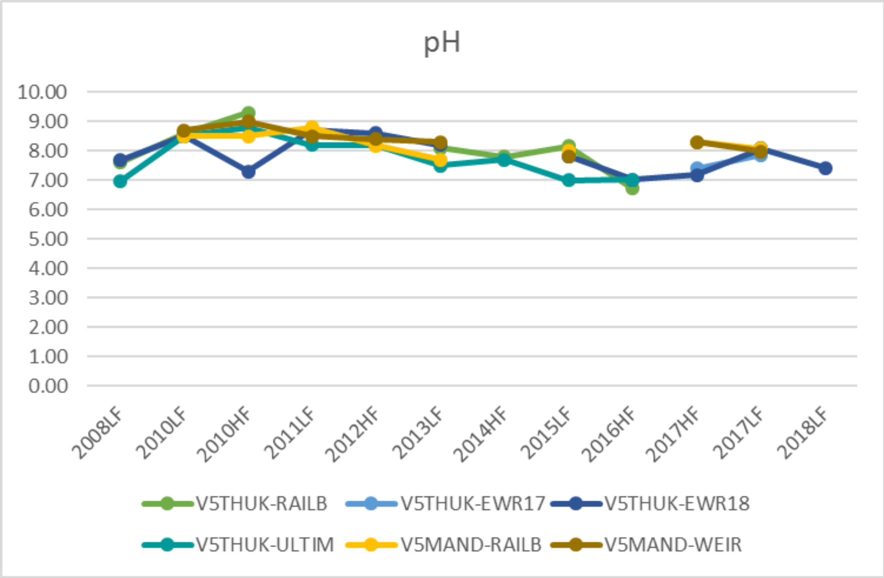

Figure 3.12: pH trends for survey sites on the Thukela River and eMandeni Stream

Chemical oxygen demand (COD) is "*the amount of oxygen consumed by the abiotic fraction of a water sample*" (Dallas and Day, 2004) and the historical trends indicate that the two sites on the eMandeni Stream often have elevated COD when compared to the Thukela River sites (Figure 3.13). A noticeable spike in COD was recorded in 2010 at the V5THUK-EWR18 site which corresponds to low dissolved oxygen levels during the same time period (Figure 3.10). Between 2008 and 2010, the COD was often higher at the downstream V5THUK-EWR18 site when compared to the upstream V5THUK-RAILB site and could possibly be attributed to the high COD in the eMandeni Stream or the Sappi mill effluent. From 2015 to 2018, the COD at theV5THUK-EWR18 site has remained relatively stable and has not been affected by the eMandeni Stream or the Sappi mill effluent.

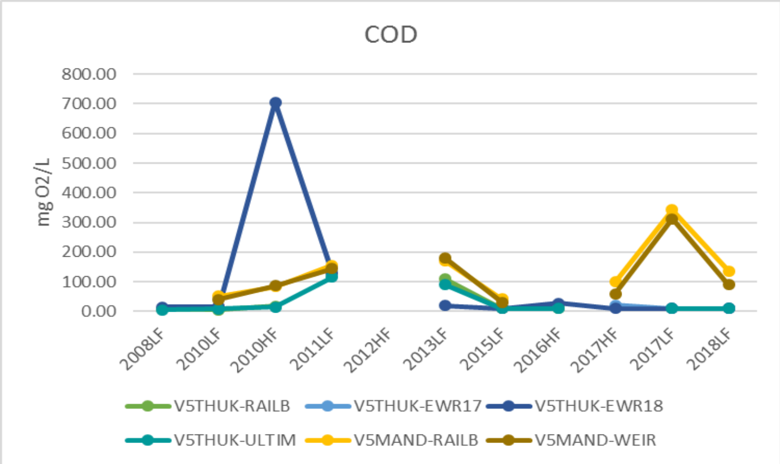

Figure 3.13: Chemical oxygen demand trends for survey sites on the Thukela River and eMandeni Stream

Turbidity decreases the clarity of water and impedes light penetration that can have an impact on primary production and biotic abundance and diversity (Dallas and Day, 2004). Turbidity data is limited for the study area, but a seasonal variation is observed with higher turbidity levels recorded during the high-flow season when compared to the low-flow season (Figure 3.14). A decline in turbidity was recorded for the Thukela River sites during the 2017 and 2018 low flow survey when compared to the 2017 high flow survey. More information is needed to identify possible sources of stressors but charges in land use throughout the catchment as well as altered flows can be impacting the turbidity of the lower Thukela River.

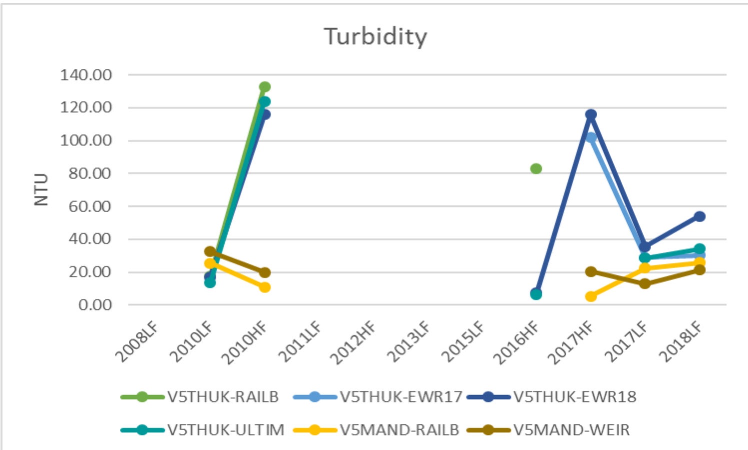

Figure 3.14: Turbidity trends for survey sites on the Thukela River and eMandeni Stream

Nitrates and ammonium are some of the ions that contribute to eutrophication in rivers (Dallas and Day, 2004). High concentrations of nitrates were recorded for the two eMandeni Stream sites and the downstream V5THUK-EWR18 site during the 2012 high flow survey (Figure 3.15). Uncharacteristically high concentrations were also recorded at the V5THUK-WEIR site during the 2017 high flow and 2018 low flow surveys. Temporally, the ammonia concentrations were generally low for the Thukela River sites, with more variation recorded for the eMandeni Stream sites (Figure 3.16). The V5MAND-RAILB site recorded noticeably higher ammonia concentrations during the 2017 and 2018 surveys and seemed to increase the ammonia concentrations at the downstream V5MAND-WEIR site in 2018.

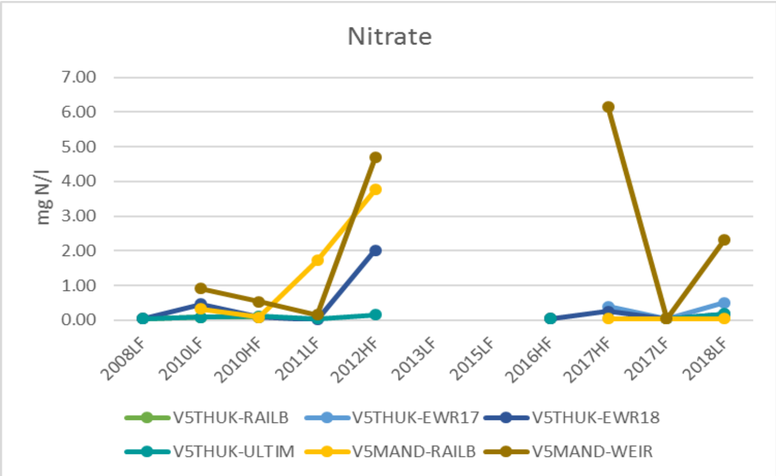

Figure 3.15: Nitrate trends for survey sites on the Thukela River and eMandeni Stream

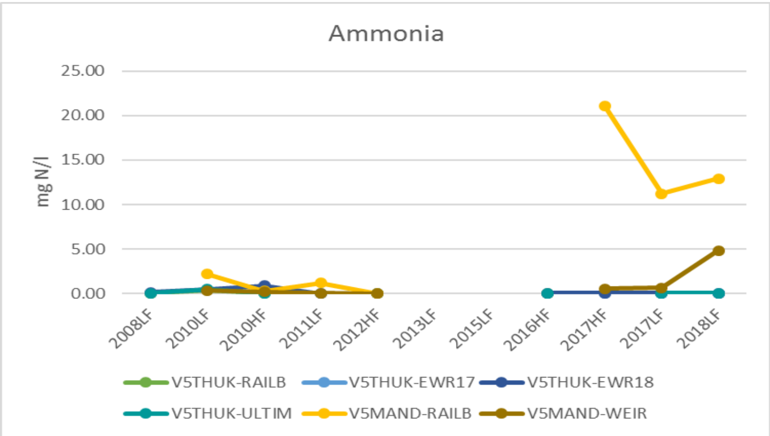

Figure 3.16: Ammonia trends for survey sites on the Thukela River and eMandeni Stream

Sulphur in water largely occurs as sulphate ions which is not toxic but in excess can form sulphuric acid that reduces the pH and can have detrimental effects on the aquatic ecosystem (Dallas and Day, 2004). The temporal trends (Figure 3.17) indicate that the sulphate concentrations were commonly higher at the two eMandeni Stream sites when compared to the results for the Thukela River sites. The high sulphate concentrations recorded during the 2010 HF survey for the V5THUK-EWR18 site resulted in a possible reduction in pH at the site and may have been due to the Sappi mill effluent (Figure 3.12). The higher concentrations of sulphates in the eMandeni Stream appears to be having a slight impact on the V5THUK-EWR18 site, as the sulphate concentrations at this site are commonly higher when compared to the upstream V5THUK-RAILB and V5THUK-EWR17 control sites.

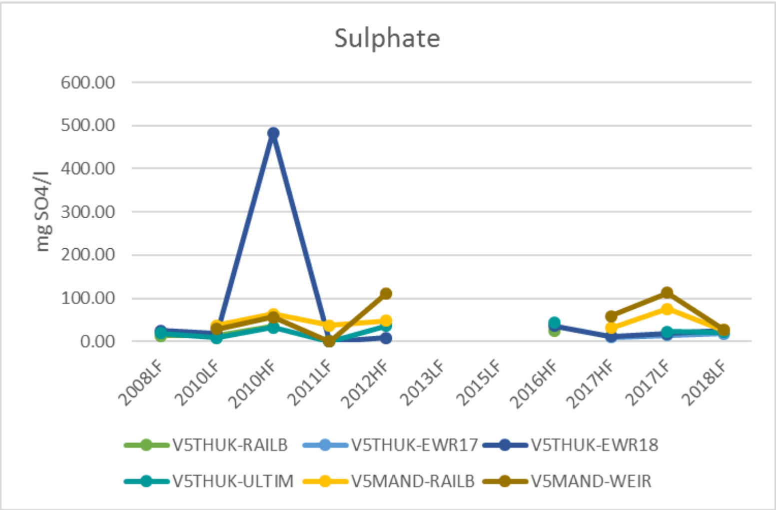

Figure 3.17: Sulphate trends for survey sites on the Thukela River and eMandeni Stream

Chloride is the major anion in sea water and can occur naturally in many South African freshwater systems but concentrations may increase due to irrigation return flows, sewerage effluent discharges and various industrial processes (DWAF, 1996b; Dallas and Day, 2004). Although the South African Water Quality Guidelines only provide TWQR for domestic use (DWAF, 1996b) and not for aquatic ecosystems (DWAF, 1996a), studies have shown that elevated chloride concentrations can negatively impact freshwater organisms (Evans and Frick, 2001; Sadowski, 2002; EPA, 2008). Through osmoregulation, freshwater organisms are able to maintain osmotic pressure in their fluids through the control of water and salt concentrations, but increased chloride concentrations could overwhelm this process, depending on the hardness of the water, with possible toxic effects (EPA, 2008; Elphick *et al.*, 2011). The temporal trends (Figure 3.18) indicate that the chloride concentrations at the eMandeni sites were once again higher than the concentrations for the Thukela River sites, that could in turn be contributing to the higher electrical conductivity in the eMandeni Stream (Figure 3.11). A noticeable increase in the chloride concentration was recorded for the V5MAND-RAILB and V5MAND-WEIR sites during the 2017 high flow surveys and the maximum concentrations were recorded at the V5MAND-RAILB site during the 2017 low flow survey. An increase in chloride concentrations was generally recorded during the high flow surveys for the V5MAND-WEIR site. The high concentrations of chlorides in the eMandeni Stream appears to be having a slight impact on the V5THUK-EWR18 site, as the chlorides concentrations at this site are commonly higher when compared to the upstream V5THUK-RAILB and V5THUK-EWR17 sites.

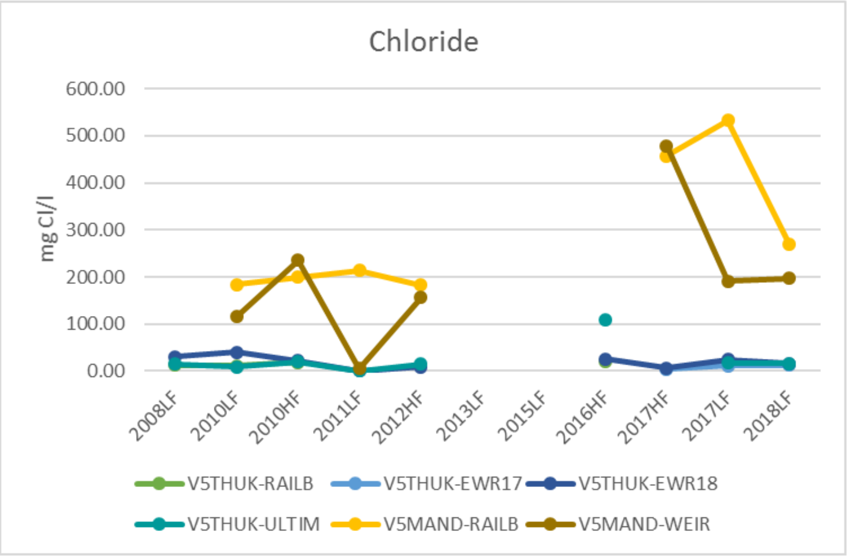

Figure 3.18: Chloride trends for survey sites on the Thukela River and eMandeni Stream

3.4.1.3 Habitat

The results of the habitat integrity assessment for each site during the 2018 low flow survey are provided in Table 3.6, and indicate that most of the survey sites are in a fair state (C category), wherein basic ecosystem functions are predominantly unchanged, but there has been a loss and change of natural habitat and biota. The only exception is the V5THUK-EWR18 site which is in a largely natural state with few modifications. The site V5MAND-WEIR was the most impacted of all the sites surveyed in terms of instream modifications, mainly attributed to the poor water quality at the site and flow modifications and inundation due to the weir. The flow of the eMandeni Stream has been seriously impacted because of urban run-off from Sundumbili, industrial inputs from the Isithebe Industrial complex and discharge from the waste water treatment works, that has also had a severe negative impact on the water quality of this system. Solid waste was most prevalent at these two sites within this urban environment, particularly the V5MAND-RAILB site which is adjacent to the landfill site and dense urban area of Sundumbili. Site V5THUK-EWR18, below the eMandeni-Thukela confluence, was the least impacted of the sites surveyed in terms of instream habitat integrity. Water abstraction, sand mining and erosion were observed at the upstream V5THUK-EWR17 site. The riparian habitat integrity of the V5MAND-RAILB, V5THUK-EWR17 and V5THUK-EWR18 sites were all considered to be good with the remaining two sites rated as fair. The removal of indigenous riparian vegetation, exotic vegetation encroachment and flow modifications were the most apparent and common riparian zone impacts at all sites. This was largely attributed to agricultural land clearing practices ubiquitous in the Thukela catchment, cattle grazing and general disturbance of the riparian zone.

Table 3.6: Index of Habitat Integrity results for the Riparian and Instream Zones of the 2018 survey sites on the eMandeni Stream and Thukela River

	Weight	V5MAND-RAILB	V5MAND-WEIR	V5THUK-EWR17	V5THUK-EWR18	V5THUK-ULTIM
Instream Criteria						
Water abstraction	14	0	0	7	5	5
Inundation	10	0	12	0	0	0
Water quality	14	25	25	5	10	15
Flow modifications	13	12	15	20	15	20
Bed modifications	13	10	10	15	0	0
Channel modifications	13	0	10	0	0	0
Presence of exotic macrophytes	9	0	0	5	10	7
Presence of exotic fauna	8	0	10	0	0	0
Solid waste disposal	6	18	10	5	7	5
Total (100)		**29.8**	**42.6**	**27.9**	**21.5**	**25.3**
Instream Habitat Integrity (%)		**70.2**	**57.4**	**72.1**	**78.5**	**74.7**
Instream Habitat Integrity Class		**C**	**D**	**C**	**C**	**C**
Riparian Zone Criteria						
	Weight	**V5MAND-RAILB**	**V5MAND-WEIR**	**V5THUK-EWR17**	**V5THUK-EWR18**	**V5THUK-ULTIM**
Water abstraction	13	0	0	0	5	5
Inundation	11	0	5	0	0	0
Water quality	13	5	5	0	0	0
Flow modifications	12	5	5	15	10	15
Channel modifications	12	0	10	0	0	0
Removal of indigenous vegetation	13	8	8	10	10	15
Exotic vegetation encroachment	12	8	8	15	8	15
Bank erosion	14	10	8	0	0	2
Total (100)		**18.6**	**24.5**	**19.6**	**16.4**	**25.9**
Riparian Habitat Integrity (%)		**81.4**	**75.5**	**80.4**	**83.6**	**74.1**
Riparian Habitat Integrity Class		**B**	**C**	**B**	**B**	**C**
Total Integrity Score		**75.8**	**66.5**	**76.2**	**81.0**	**74.4**
Total Integrity Class		**C**	**C**	**C**	**B**	**C**

3.4.1.4 Habitat Temporal Trends

The historical IHI and ecological category trends are provided in Figure 3.19 and Figure 3.20 respectively and shows a decrease in the habitat integrity between 2010 and 2015 for most sites and an increasing trend from 2015 to 2018. The decreased habitat integrity around 2015 could be attributed to the drought conditions experience in 2015/2016 where the Thukela River stopped flowing completely. Since then the river started to flow again and the system has recovered resulting in improved habitat integrity. The only site that did not follow this trend is the downstream V5THUK-ULTIM site.

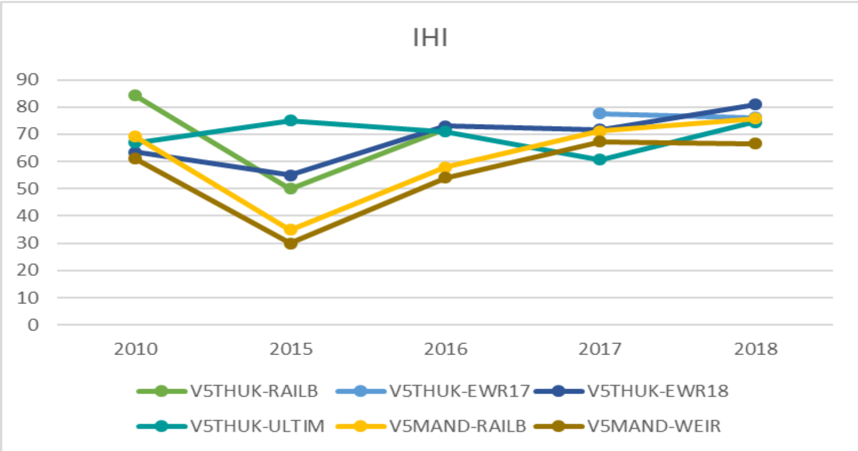

Figure 3.19: Integrated Habitat Integrity trends for survey sites on the Thukela River and eMandeni Stream

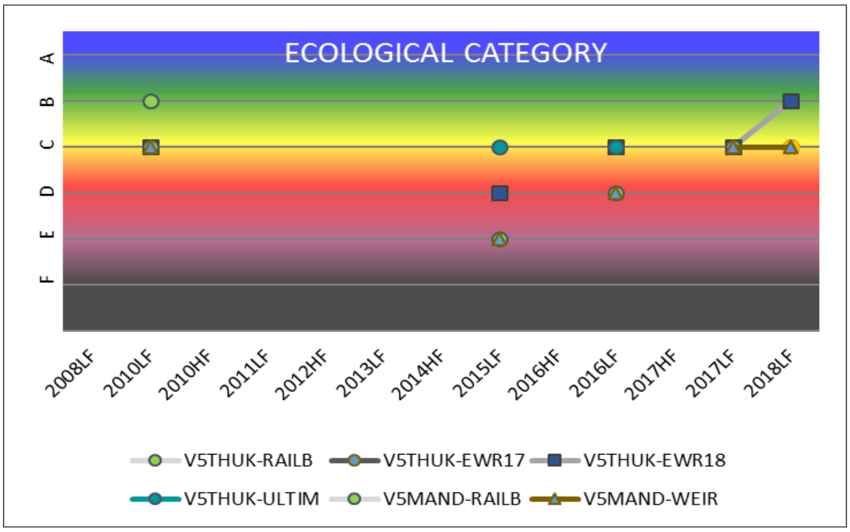

Figure 3.20: Integrated Habitat Integrity ecological category trends for survey sites on the Thukela River and eMandeni Stream

3.4.2 Response Components

3.4.2.1 Aquatic Macroinvertebrates

The interpretation of the SASS results must take into consideration the availability and quality of the habitat, as poor habitat diversity results in less biotic diversity and a lower SASS score (Dickens and Graham, 2002). Table 3.7 provides a summary of the habitat availability at each site during the 2018 low flow assessment and indicates that all the sites on the Thukela River were dominated by mud and some marginal vegetation. The stones biotope was generally lacking at these sites. The two sites on the eMandeni Stream had greater diversity in habitat and included stones, gravel, sand, mud as well as some marginal vegetation at each site.

Table 3.7: SASS habitat scoring for the survey sites on the Thukela River and eMandeni Stream

	V5THUK-EWR17	V5THUK-EWR18	V5THUK-ULTIM	V5MAND-RAILB	V5MAND-WEIR
Stones In Current (SIC)	1	0	0	5	5
Stones Out Of Current (SOOC)	0	0	2	1	3
Bedrock	1	0	0	3	0
Aquatic Vegetation	0	0	0	0	0
MargVegetation In Current	4	2	3	2	1
MargVegetation Out Of Current	3	2	4	5	4
Gravel	4	0	0	5	5
Sand	3	1	3	5	5
Mud	4	4	4	2	5
Hand picking/ Visual observation	3	3	3	4	5

The results of the macroinvertebrate assessment are provided in Table 3.8 and indicate that a total of 30 taxa were recorded in the 2018 low flow survey.

Table 3.8: Aquatic macroinvertebrate results for the 2018 survey sites on the Thukela River and eMandeni Stream

	Sensitivity value	V5THUK-EWR17	V5THUK-EWR18	V5THUK-ULTIM	V5MAND-RAIL	V5MAND-WASTE
Ancylidae	6			1		A
Atyidae	8	C	B	C		
Baetidae 1sp	4		A		A	
Baetidae 2sp	6	B		B		B
*Belostomatidae**	3		1	1		B
Caenidae	6		A	C		
Calopterygidae	10		1			
Chironomidae	2	A		C	D	C
Coenagrionidae	4					A
*Corixidae**	3		1			B
*Dytiscidae**	5			A		
*Gerridae**	5		1			
Gomphidae	6	A	A	A		
Heptageniidae	13	1	1			
Hirudinae	3					1
*Hydraenidae**	8	1				
Hydropsychidae 1sp	4	A		1		
Leptoceridae	6	A				
Leptophlebiidae	9	1		1		
Libellulidae	4	1	1			
*Notonectidae**	3			1		
Oligochaeta	1	B	A			1
Palaemonidae	10	B	1	C		
Perlidae	12	1				
*Physidae**	3					C
*Potamonautidae**	3	A	A	1		
Simuliidae	5	1				D
*Syrphidae**						A
*Thiaridae**	3	1				
*Veliidae**	5	B	B	B		
SASS score		105	81	76	6	37
No of taxa		17	14	14	2	11
ASPT		6.18	5.79	5.43	3	3.4
Ecological category		**C**	**C/D**	**D**	**E/F**	**E/F**

*Airbreathers
#Note: Estimated Abundance where A= 2-10; B=10-100; C=100-1000; D=over 1000

The upstream control site on the Thukela River (V5THUK-EWR17) had the most diverse macroinvertebrate community characterised by species that are moderately tolerant to pollution (Table 3.8). The pollution sensitive taxa, namely Perlidae was exclusively recorded at this site. The site recorded the highest number of taxa and the highest SASS score resulting in the highest ASPT compared to all other sites. The site was classed as being fair (C category), characterised by loss and change to natural habitat and biota but the basic ecosystem functions are predominantly unchanged (Kleynhans and Louw, 2007). Fourteen (14) taxa were sampled at both Thukela River sites (V5THUK-EWR18 and V5THUK-ULTIM) downstream of the SAPPI mill discharge point (Table 3.8). The taxa sampled at the V5THUK-EWR18 site were more sensitive to pollution compared to those sampled at the V5THUK-ULTIM site and resulted in a SASS score of 81 and ASPT of 5.79 compared to the SASS score of 76 and ASPT of 5.43 for the V5THUK-ULTIM site. The V5THUK-EWR18 site was classed as being fair to poor (C/D category) and the V5THUK-ULTIM was in a poor state (D category). The difference in the SASS scores between the two downstream sites and the upstream control site, could be attributed to the greater diversity in habitat at the upstream site (Table 3.7), but the difference in ASPT scores points to water quality stressors at the downstream sites.

The two eMandeni Stream sites both had good habitat for the colonization of macroinvertebrate communities (Table 3.7) yet both sites were classed as being seriously to critically modified (E/F category) (Table 3.8), where the loss of natural habitat, biota and basic ecosystem functions is extensive or complete. This is due to water quality stressors at these sites as only taxa highly tolerant to pollution were sampled. The upstream V5MAND-RAILB site, located downstream of the waste water treat works discharge point, had the lowest diversity, SASS and ASPT scores of all the sites assessed. More taxa were sampled at the downstream V5MAND-WEIR site, resulting in a SASS score of 37 and ASPT of 34. The V5MAND-WEIR site was dominated by *Chironomidae* and *Simuliidae,* and the V5THUK-RAILB site by *Chironomidae*.

These species are regarded as pollution tolerant taxa, with *Chironomidae* being one of the only macroinvertebrates that can survive in polluted water (Davies and Day, 1998). The V5MAND-RAILB is the most impacted site when compared to V5MAND-WEIR, and the Thukela River sites.

Based on the 2018 low flow survey SASS scores and the ASPT, the health of the macroinvertebrate communities of the Thukela and eMandeni Stream ranged from fair (C category) to seriously/critically modified (E/F category) (Table 3.8). Overall, the SASS results indicated that the ecological integrity of macroinvertebrate communities is poorest in the eMandeni Stream and in the Thukela River downstream of the eMandeni-Thukela River confluence and the Sappi mill discharge point. It results suggest that the poor water quality emanating in the eMandeni Stream catchment and possibly the effluent from the Sappi mill, exert a notable negative effect on the ecology of the receiving river systems, with the poorest conditions occurring nearest the source of impact and immediately downstream of the confluence. This can be attributed to water quality impacts relating to major industrial activities associated with Isithebe industrial complex, the Sundumbili waste water treatment works and Sappi mill effluent discharge, as well as other anthropogenic activities that reduce water quality (e.g. agricultural runoff, solid waste disposal and leachate from the local landfill site).

3.4.2.2 Aquatic Macroinvertebrate Temporal Trends

A macroinvertebrate assessment results of the various survey sites (Figure 3.1) from 2008 to 2018 are provided in Table 3.9 and Table 3.10 with the temporal SASS and ASPT trends represented in Figure 3.21 and Figure 3.22 respectively. Generally, lower SASS scores were recorded for most sites in 2008 and 2012 but a noticeable improvement is seen in 2013 for all sites (Figure 3.21). The SASS scores decline again in 2014 and 2015 and this could be due to the drought conditions experienced. Improved SASS scores were recorded for 2016HF but then another downward trend is recorded to the 2017HF survey with an improvement in the SASS score for some sites since then to 2018. Some seasonal variation is also noted at most sites, as the highest diversity of taxa sampled was often during the low flow surveys. The upstream V5THUK-RAIL site has generally had the highest SASS and ASPT scores (Figure 3.22) for each survey. This is expected as the site has more stones habitat for macroinvertebrates to colonise and is upstream of the eMandeni Stream and SAPPI discharge point. The SASS and ASPT scores for the downstream V5THUK-EWR18 site has varied but an increasing trend is seen from the 2017HF scores to the 2018LF scores. The V5THUK-ULTIM site often shows similar or higher SASS scores compared to the V5THUK-EWR18 site but lower ASPT scores. The upstream V5MAND-RAIL site has displayed a decreasing trend in both the SASS and ASPT scores from 2015 to 2018. The SASS and ASPT scores for the downstream V5MAND-WEIR site have varied but have often been higher than those of the upstream V5MAND-RAIL site.

Table 3.9: The number of taxa, SASS scores, ASPT and ecological classes for the survey sites on the Thukela River from 2008 to 2018

	V5THUK-RAILB								V5THUK-EWR17			V5THUK-EWR18											V5THUK-ULTIM									
Taxa	2008LF	2010LF	2010HF	2013LF	2014HF	2015LF	2016HF	2016LF	2017HF	2017LF	2018LF	2008LF	2010LF	2010HF	2011LF	2012HF	2013LF	2015LF	2016HF	2017HF	2017LF	2018LF	2008LF	2010LF	2010HF	2011LF	2012HF	2013LF	2014HF	2016HF	2017LF	2018LF
Aeshnidae	-	-	-	-	A	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-
Ancylidae	-	-	-	-	-	-	-	-	-	-	-	-	-	A	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	A	B	1
Atyidae	1	B	C	B	A	B	B	B	-	B	C	-	B	C	1	1	B	-	B	A	A	B	1	B	C	-	1	B	C	B	B	C
Baetidae	1	B	B	B	B	B	A	B	B	B	B	-	A	B	1	1	B	-	A	A	C	A	1	B	B	1	1	B	B	B	C	B
Belostomatidae	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	1	1	-	-	-	-	-	1
Caenidae	-	-	-	A	A	-	-	-	-	A	-	-	-	-	-	-	B	-	A	-	A	A	-	-	1	-	-	B	A	-	-	C
Calopterygidae ST,T	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Ceratopogonidae	-	-	1	-	1	-	-	1	-	A	-	-	-	-	-	-	1	A	1	-	-	-	-	-	-	-	-	1	A	A	-	-
Chironomidae	1	-	-	B	A	B	B	A	-	B	A	1	B	-	1	-	B	B	B	-	C	-	1	D	B	1	-	B	A	C	C	C
Chlorocyphidae	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coenagrionidae	1	A	1	-	A	A	-	A	1	1	-	-	A	B	1	-	-	-	1	A	B	-	-	-	B	1	1	A	A	1	A	-
Corbiculidae	-	1	B	A	-	1	-	B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	-	-	-	-
Corixidae	-	-	A	-	-	-	A	A	-	-	-	-	-	-	1	-	-	-	1	-	1	1	1	-	-	-	-	A	-	B	C	-
Culicidae	-	-	-	-	1	-	-	1	-	A	-	-	-	-	-	-	-	A	-	-	-	-	1	B	-	1	-	B	1	-	-	-
Dytiscidae	-	-	-	1	-	1	-	-	-	1	-	-	-	B	1	-	-	-	A	-	-	-	-	1	B	-	-	1	-	A	-	A
Ecnomidae	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Elmidae	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ephydridae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	-	-	-	-
Gerridae	1	-	B	-	A	B	-	-	-	-	-	-	A	A	-	-	-	-	-	-	-	1	-	A	-	-	1	-	A	B	1	-
Gomphidae	1	A	1	A	A	1	-	-	-	B	A	-	1	B	1	-	A	B	A	-	B	A	1	-	A	1	1	A	A	A	B	A
Gyrinidae	-	-	B	1	A	-	-	-	-	A	-	-	-	A	1	-	1	-	-	-	B	-	1	B	B	1	-	B	A	-	A	-
Heptageniidae	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Hydraenidae	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydrophilidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	A	-	-	-	-	-	-	-	-	-	-	A	-	-
Hydropsychidae	-	1	-	A	1	-	1	-	-	A	A	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	B	-	-	-	1
Leptoceridae	-	-	1	A	1	-	-	-	-	1	A	-	1	A	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Leptophlebidae	-	A	-	A	-	-	1	-	-	-	1	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Libellulidae	-	1	1	A	A	B	1	A	-	-	1	-	-	-	-	1	-	-	-	-	-	1	-	-	-	1	1	A	B	1	-	-
Muscidae	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Naucoridae	-	1	-	A	A	A	-	-	-	-	-	-	-	B	-	-	-	-	-	-	-	-	-	-	A	-	-	A	B	-	1	-
Nepidae	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	-	-
Notonectidae	-	A	B	A	A	1	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	-	-	-	1	-	-	1	1
Oligochaeta	1	B	-	B	B	A	-	B	-	-	B	-	-	-	-	-	A	-	A	-	A	A	-	-	-	-	-	A	-	1	B	-
Palaemonidae	1	C	B	-	-	-	-	A	-	-	B	-	B	B	-	-	-	-	-	-	-	1	-	-	C	-	-	-	-	-	-	C
Perlidae	-	A	-	A	-	-	A	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Physidae	-	-	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	-	-	B	-
Porifera	-	-	-	-	-	B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Potamonautidae	1	A	B	B	B	-	1	-	A	-	A	-	A	B	-	-	A	-	A	-	1	A	-	A	B	-	1	A	B	-	1	1
Prosopistomatidae	-	A	-	A	1	-	B	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Psephenidae	-	-	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Psychomyiidae	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Simuliidae	1	1	B	B	B	B	A	A	-	A	1	-	-	-	-	-	A	-	-	-	B	-	-	-	-	-	-	B	B	-	C	-
Thiaridea	1	D	D	C	C	C	C	B	1	1	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	C	-	-	-
Tipulidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbellaria	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-
Veliidae	1	B	B	A	B	B	A	A	-	B	B	-	-	C	-	-	B	-	B	B	B	B	-	A	B	-	-	B	-	-	B	B
No. of Taxa	**13**	**19**	**18**	**22**	**24**	**17**	**14**	**17**	**4**	**16**	**17**	**1**	**11**	**13**	**12**	**4**	**17**	**4**	**13**	**4**	**13**	**14**	**7**	**11**	**14**	**10**	**8**	**25**	**15**	**14**	**16**	**14**
SASS Score	**72**	**114**	**100**	**130**	**123**	**75**	**84**	**81**	**14**	**89**	**105**	**2**	**59**	**82**	**66**	**21**	**101**	**14**	**57**	**23**	**66**	**81**	**31**	**44**	**78**	**50**	**39**	**121**	**70**	**63**	**78**	**76**
ASPT	**5.54**	**6.00**	**5.56**	**5.91**	**5.13**	**4.41**	**6.00**	**4.76**	**3.50**	**5.56**	**6.18**	**2.00**	**5.36**	**6.31**	**5.50**	**5.25**	**5.94**	**3.50**	**4.38**	**5.75**	**5.08**	**5.79**	**4.43**	**4.00**	**5.57**	**5.00**	**4.88**	**4.84**	**4.67**	**4.50**	**4.88**	**5.43**
Ecological Category	**B**	**B**	**C**	**B**	**B**	**D**	**C**	**D**	**E/F**	**C**	**C**	**E/F**	**D**	**C**	**D**	**D**	**C**	**E/F**	**D**	**C**	**D**	**C/D**	**E/F**	**E/F**	**C/D**	**D/E**	**E/F**	**B**	**C**	**D**	**D**	**D**

#Note: Estimated Abundance where A= 2-10; B=10-100; C=100-1000; D=over 1000

Table 3.10: The number of taxa, SASS scores, ASPT and ecological classes for the survey sites on the eMandeni Stream from 2008 to 2018

	V5MAND-RAILB											V1MAND-WEIR										
Taxa	2008LF	2010LF	2011LF	2012HF	2013LF	2015LF	2016HF	2016LF	2017HF	2017LF	2018LF	2010LF	2010HF	2011LF	2012HF	2013LF	2015LF	2016HF	2016LF	2017HF	2017LF	2018LF
Aeshnidae	-	-	1	1	-	-	-	A	-	-	-	-	1	-	1	1	-	-	-	A	-	-
Ancylidae	-	-	-	-	A	B	A	-	-	-	-	-	-	-	-	A	-	A	B	A	A	A
Atyidae	-	-	-	1	B	A	A	-	-	-	-	-	-	-	1	A	-	B	-	-	1	-
Baetidae	-	-	1	1	B	B	A	B	A	-	A	B	A	1	1	A	B	B	C	-	B	B
Belostomatidae	-	1	1	1	A	A	A	B	A	1	-	A	C	-	-	A	-	-	A	A	-	B
Caenidae	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	1	1	-	-	-	1	-
Ceratopogonidae	-	-	-	-	-	-	1	-	-	-	-	A	-	1	-	-	1	1	-	-	A	-
Chironomidae	1	D	1	1	C	B	B	D	C	D	D	B	D	1	-	B	B	B	B	B	D	C
Chlorolestidae	-	-	-	-	B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coenagrionidae	1	-	1	1	-	B	B	C	A	B	-	B	-	1	1	B	A	A	B	-	B	A
Corixidae	-	-	-	-	-	A	A	-	-	-	-	A	-	-	-	A	-	-	B	-	1	B
Culicidae	-	B	1	-	A	-	-	C	-	-	-	-	C	1	-	1	A	-	A	-	-	-
Dytiscidae	-	-	1	1	B	-	-	-	-	1	-	A	A	1	-	A	-	-	-	-	-	-
Ecnomidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	-	-	-
Elmidae	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gerridae	-	-	-	-	A	-	-	-	-	1	-	-	1	-	1	-	-	A	-	-	A	-
Gomphidae	-	-	-	1	A	-	1	-	-	-	-	-	-	-	-	-	1	A	-	A	-	-
Gyrinidae	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Heptageniidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Hirudinea	-	-	1	1	-	B	A	-	-	-	-	D	-	1	1	-	-	1	B	1	B	1
Hydracarina	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydrometridae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-
Hydrophilidae	-	-	-	-	1	-	-	-	-	A	-	-	A	-	-	1	-	-	-	-	A	-
Hydropsychidae	-	-	-	1	1	-	B	-	-	-	-	-	-	-	1	A	A	A	-	1	B	-
Libellulidae	-	-	1	-	A	1	-	-	A	A	-	-	-	1	-	A	-	-	-	A	A	-
Lymnaeidae	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Muscidae	-	-	-	-	-	-	-	-	-	1	-	-	A	-	-	A	-	-	-	-	-	-
Naucoridae	-	-	-	-	1	-	-	-	A	-	-	A	B	-	-	-	-	A	-	-	1	-
Nepidae	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	A	-	-	-	-	-	-
Notonectidae	-	-	-	-	A	-	-	-	-	-	-	A	-	-	-	A	-	A	-	-	-	-
Oligochaeta	1	-	1	1	B	B	B	A	-	A	-	C	-	1	1	B	A	B	B	-	B	1
Palaemonidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Physidae	-	-	-	-	-	-	-	-	-	-	-	B	-	-	-	-	-	-	C	-	B	C
Planorbidae	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Potamonautidae	-	-	1	1	-	C	B	A	1	-	-	A	A	1	1	1	A	-	A	1	A	-
Psephenidae	-	-	-	-	-	-	-	-	-	A	-	-	-	-	-	-	-	-	C	-	-	-
Simuliidae	1	-	-	-	A	C	B	D	-	-	-	D	-	1	-	B	B	B	-	-	C	D
Syrphidae	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A
Tabanidae	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thiaridea	-	-	-	-	-	-	B	-	-	-	-	-	-	-	1	-	-	B	-	B	1	-
Tipulidae	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	B	-	A	-
Turbellaria	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Veliidae	1	1	-	-	-	-	A	-	-	-	-	A	-	-	-	A	-	-	-	-	A	-
No. of Taxa	**5**	**4**	**13**	**12**	**22**	**15**	**16**	**9**	**7**	**11**	**2**	**17**	**12**	**14**	**12**	**22**	**12**	**17**	**15**	**10**	**22**	**11**
SASS Score	**15**	**11**	**48**	**51**	**107**	**67**	**65**	**39**	**27**	**37**	**6**	**62**	**49**	**48**	**58**	**92**	**56**	**74**	**58**	**39**	**101**	**37**
ASPT	**3.00**	**2.75**	**3.69**	**4.25**	**4.86**	**4.47**	**4.06**	**4.33**	**3.86**	**3.36**	**3.00**	**3.65**	**4.08**	**3.43**	**4.83**	**4.18**	**4.67**	**4.35**	**3.87**	**3.90**	**4.59**	**3.36**
Ecological Category	E/F	E/F	D/E	D/E	C	D	D	E/F	E/F	E/F	E/F	D	D/E	D/E	D/E	C	D	D	D	E/F	C	E/F

#Note: Estimated Abundance where A= 2-10; B=10-100; C=100-1000; D=over 1000

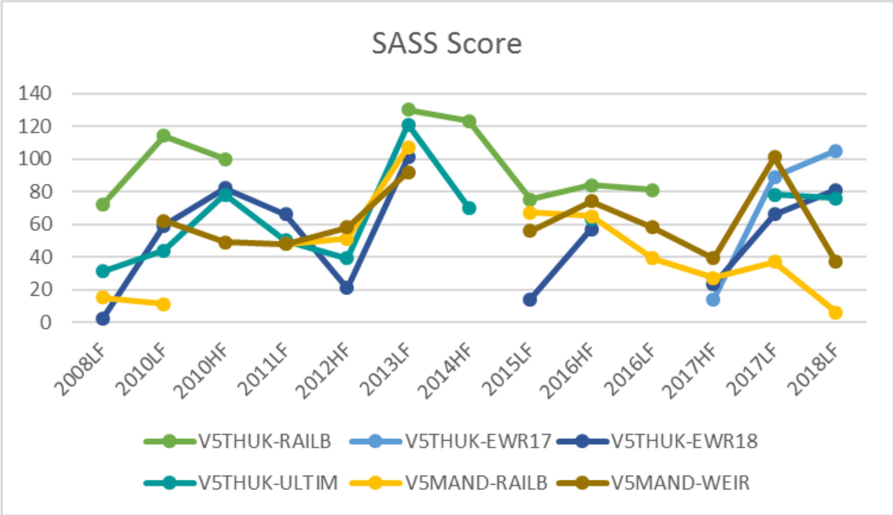

Figure 3.21: SASS score trends for survey sites on the Thukela River and eMandeni Stream

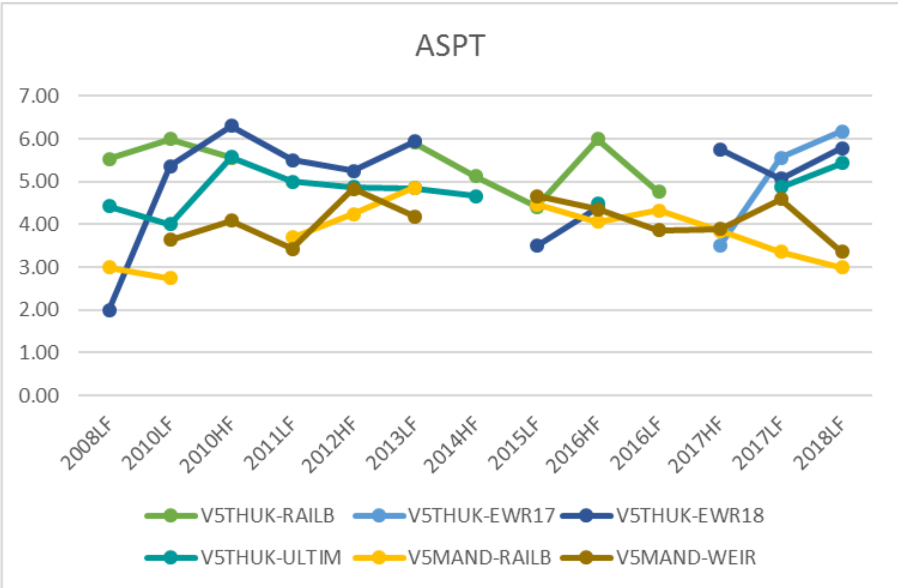

Figure 3.22: ASPT trends for survey sites on the Thukela River and eMandeni Stream

The temporal trends in the ecological category of the macroinvertebrates is varied (Figure 3.23). Generally, the ecological category for the upstream V5THUK-RAILB and V5THUK-EWR17 sites has been higher than for the downstream sites and have ranged between a poor D category (2015 and 2016 low flows assessments) and a good B category, except for the 2017 high flow survey where the V5THUK-EWR17 site was in a seriously to critically modified state (E/F category). The ecological category for the upstream V5MAND-RAILB site has generally been the lowest of all the sites, often in a seriously to critically modified state (E/F category) indicating the critical loss of natural habitat, biota and basic functions. The downstream V5MAND-WEIR has most commonly been in a poor or seriously modified state (D or D/E ecological category). The ecological category for the V5THUK-EWR18 site, downstream of the Sappi mill discharge point, has mostly ranged between a C and D category (fair to poor), with a general improvement recorded during the high flow assessments. The V5THUK-ULTIM site was often in a seriously to critically modified state (E/F category) between 2008 and 2012 but improved in 2013 and 2014 and has been in a poor state (D category) from 2016 to 2018.

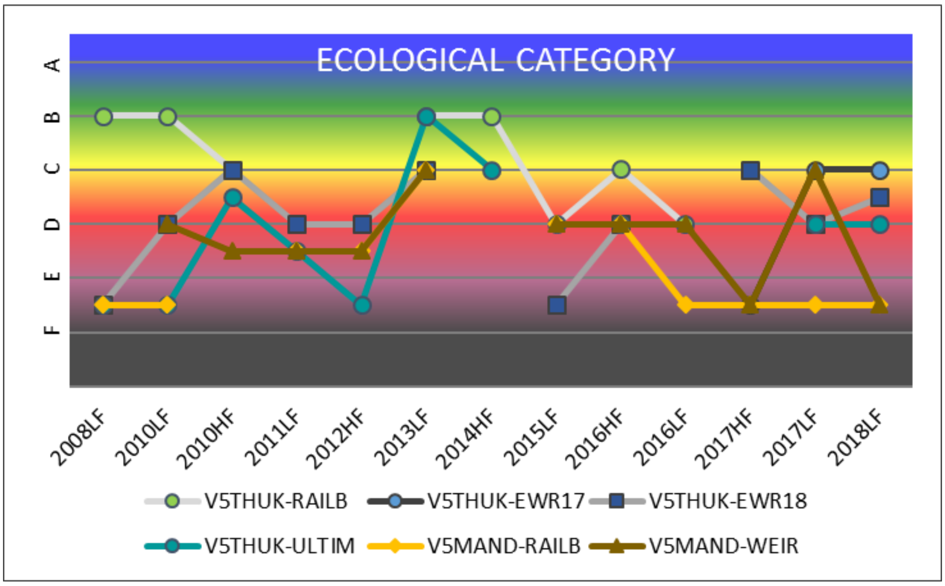

Figure 3.23: Macroinvertebrate ecological category trends for survey sites on the Thukela River and eMandeni Stream

3.4.2.3 Fish

Approximately 36 species of fish occur within the survey area, with the majority of these regarded as ‘Least Concern’ or ‘Data Deficient’ under IUCN guidelines (IUCN, 2018) (Table 3.11). The only two species of conservation concern are *Oreochromis mossambicus*, currently classified as ‘Near Threatened” (Cambray and Swartz, 2007) and *Labeo rubromaculatus* classified as ‘Vulnerable’ (Chakona and Bills, 2018) under IUCN guidelines. The major threat that *O. mossambicus* is facing in the Zambezi and Limpopo systems is the invasion of the Nile tilapia (*Oreochromis niloticus*) into these systems that may result in the extirpation of *O. mossambicus* due to competition and hybridisation (Cambray and Swartz, 2007). As *O. niloticus* does not occur in the Thukela system, the system possibly provides an important area of protection for *O. mossambicus*. Threats to *L. rubromaculatus* include hydrological modification through the construction of dams which also form barriers to fish movement, as well as potential hybridisation with other Labeo species introduced through interbasin water transfer schemes (Chakona and Bills, 2018). Mugilidae (Mullet species) are abundant within the survey area with four species recorded, namely *Chelon macrolepis*, *Liza dumerili*, *Mugil cephalus* and *Myxus capensis* (Table 3.11). *M. capensis* is of particular concern as it is a catadromous species restricted to southern Africa and is currently threatened by migration barriers (Swartz *et al.*, 2007). Additional catadromous species requiring catchment connectivity are the Anguillid eels. Three of the four species occurring within KwaZulu-Natal have been recorded within the system (Table 3.11). Three invasive species have been recorded within the system, namely *Cyprinus carpio*, *Micropterus salmoides* and *Poecilia reticulata* (Table 3.11). Each species negatively impacts on the wellbeing of indigenous fish communities in different ways due to the ecological niche each species occupies and/or behaviour.

Table 3.11: The fishes expected in the study area including abbreviations used for species and conservation status. (CS): LC = Least Concern, DD = Data Deficient, NT = Near Threatened, VU = Vulnerable, NA = Not Applicable. X = Invasive alien species (IUCN 2018)

Species	Common Name	Abbreviation	CS
Acanthopagrus berda (Forsskål, 1775)	Estuarine Bream	ABER	LC
Ambassis natalensis (Gilchrist & Thompson, 1908)	Slender Glassy	ANAT	LC
Anguilla bengalensis labiata (Peters, 1852)	African Mottled Eel	ABEN	DD
Anguilla marmorata	Marbled Eel	AMAR	LC
Anguilla mossambica (Peters, 1852)	Longfin Eel	AMOS	LC

Table 3.11 cont.: The fishes expected in the study area including abbreviations used for species and conservation status. (CS): LC = Least Concern, DD = Data Deficient, NT = Near Threatened, VU = Vulnerable, NA = Not Applicable. X = Invasive alien species (IUCN 2018)

Species	Common Name	Abbreviation	CS
Anguilla sp.	Unidentified Anguillid Eel	ANG	NA
Argyrosomus sp.	Unidentified kob	ARG	NA
Awaous aeneofuscus (Peters, 1852)	Freshwater Goby	AAEN	LC
Chelon macrolepis (Smith, 1846)	Large-scale Mullet	CMAC	LC
Clarias gariepinus (Burchell, 1822)	Sharptooth Catfish	CGAR	LC
Coptodon rendalli (Boulenger, 1897)	Redbreast Tilapia	CREN	DD
Cyprinus carpio (Linnaeus, 1758)[X]	Common Carp	CCAR	NA
Eleotris fusca (Forster, 1801)	Brown Spinecheek Gudgeon	EFUS	LC
Enteromius paludinosus (Peters, 1852)	Straightfin Barb	EPAU	LC
Enteromius trimaculatus (Peters, 1852)	Threespot Barb	ETRI	LC
Enteromius viviparus (Weber, 1897)	Bowstripe Barb	EVIV	LC
Glossogobius callidus (Smith, 1937)	River Goby	GCAL	LC
Glossogobius giuris (Hamilton & Buchanan, 1822)	Tank Goby	GGIU	LC
Hypseleotris cyprinoides (Valenciennes, 1837)	Golden Sleeper	HCYP	DD
Labeo molybdinus (du Plessis, 1963)	Leadan Labeo	LMOL	LC
Labeo rubromaculatus (Gilchrist & Thompson, 1913)	Tugela Labeo	LRUB	VU
Labeobarbus natalensis (Castelnau, 1861)	KwaZulu-Natal Yellowfish	LNAT	LC
Liza dumerili (Steindachner, 1870)	Grooved Mullet	LDUM	LC
Megalops cyprinoides (Broussonet, 1782)	Indo-Pacific Tarpon	MCYP	DD
Microphis brachyurus (Bleeker, 1854)	Short-tail Pipefish	MBRA	LC
Microphis fluviatilis (Peters, 1852)	Freshwater Pipefish	MFLU	DD
Micropterus salmoides (Lacepède, 1802) [X]	Largemouth Bass	MSAL	NA
Monodactylus argenteus (Linnaeus, 1758)	Round Moony	MARG	LC
Monodactylus falciformis (Lacepède, 1801)	Full Moony	MFAL	LC
Mugil cephalus (Linnaeus, 1758)	Flathead Mullet	MCEP	LC
Mullet fry	Mullet fry	MUL	NA
Myxus capensis (Valenciennes, 1836)	Freshwater Mullet	MCAP	LC
Oreochromis mossambicus (Peters, 1852)	Mozambique Tilapia	OMOS	NT
Poecilia reticulata (Peters, 1859) [X]	Guppy	PRET	NA
Pseudocrenilabrus philander (Weber, 1897)	Southern Mouthbrooder	PPHI	DD

Table 3.11 cont: The fishes expected in the study area including abbreviations used for species and conservation status. (CS): LC = Least Concern, DD = Data Deficient, NT = Near Threatened, VU = Vulnerable, NA = Not Applicable. X = Invasive alien species (IUCN 2018)

Species	Common Name	Abbreviation	CS
Redigobius dewaali (Weber, 1897)	Checked Goby	RDEW	LC
Rhabdosargus holubi (Steindachner, 1881)	Cape Stumpnose	RHOL	LC
Rhabdosargus sarba (Forsskål, 1775)	Tropical Stumpnose	RSAR	LC
Invasive species			

The results of the 2018 fish assessment are provided in Table 3.12. The downstream V5THUK-ULTIM site had the greatest species richness followed by the upstream V5THUK-EWR17 site. Six and two species were recorded at the V5THUK-EWR17 and V5THUK-EWR18 sites respectively and the difference between the two sites denoted deteriorated conditions downstream of the eMandeni confluence. Although the V5MAND-RAIL site had the greatest abundance of fish caught, the majority of those were *Poecilia reticulata* which is an invasive species that competes for food resources with indigenous species and possibly feeds on eggs of species that exhibit no parental care. Therefore, it is likely to negatively influence indigenous species populations. The resulting ecological class for this site was a F category (critically modified state). The V5MAND-WEIR site had the second largest abundance of fish but 12 of the fish caught were juveniles *C. carpio* which are a habitat modifying species that disturb the substrate, effecting the water quality and impacting indigenous fish health. Historically, the species has never been recorded in substantial abundance (Table 3.13), but the juveniles caught during the 2018 assessment is evidence of recruitment of the species in the eMandeni system. The close proximity of this site to the confluence with the Thukela River is concerning, as this may potentially lead to exacerbated degraded water quality within the Thukela system. The FRAI scores for the upstream V5THUK-EWR17 site and the downstream V5THUK-EWR18 site were very similar resulting in a D category for the upstream site and a D/E category for the downstream site. The integrity of the fish community at the V5THUK-ULTIM site was fair (C category).

Table 3.12: Fish results for the 2018 survey sites on the Thukela River and eMandeni Stream

Taxa	V5THUK-EWR17	V5THUK-EWR18	V5THUK-ULTIM	V5MAND-RAILB	V5MAND-WEIR
Acanthopagrus berda (Forsskål, 1775)	1	-	2	-	-
Argyrosomus sp.	1	-	-	-	-
Clarias gariepinus (Burchell, 1822)	-	-	3	2	4
Cyprinus carpio(Linnaeus, 1758)	-	-	-	-	12
Eleotris fusca (Forster, 1801)	1	-	1	-	-
Enteromius paludinousus Peters, 1852	-	-	1	-	-
Enteromius trimaculatus Peters, 1852	-	4	-	-	-
Glossogobius callidus (Smith, 1937)	-	-	5	-	-
Hypseleotris cyprinoides (Valenciennes, 1837)	-	-	1	-	-
Labeobarbus natalensis (Castelnau, 1861)	-	1	-	-	-
Microphis fluviatilis(Peters, 1852)	1	-	-	-	-
Mullet fry	1	-	3	-	-
Oreochromis mossambicus (Peters, 1852)	2	-	4	-	10
Poecilia reticulata Peters, 1859	-	-	-	40	7
Species richness	**6**	**2**	**8**	**2**	**4**
Total abundance	**7**	**5**	**20**	**42**	**33**
FRAI Score	**58**	**59**	**64**	**18**	**48**
Ecological category	**D**	**C/D**	**C**	**F**	**D**
Invasive species					

3.4.2.4 Fish Temporal Trends

The fish assessment results of the various survey sites from 2008 to 2018 are provided in Table 3.13 with the temporal species richness and abundance trends represented in Figure 3.24 and Figure 3.25 respectively. The results indicate that the “Vulnerable” *L. rubromaculatus* have not been sampled in the study area since 2015 while *O. mossambicus* have been sampled in varying abundances at all the survey sites.

Species richness varies spatially and temporally within the survey area with distinctive fluctuations (Figure 3.24). The noticeable decreasing trend in the species richness is observed for the V5THUK-EWR18 site from 2010 to 2012 with a slight increase in 2013 and 2015. A vast improvement in the species richness was observed from the 2016 high flow assessment to the 2017 low flow assessment but then another decreasing trend to the 2018 low flow assessment. The species richness results for the V5THUK-RAILB and V5THUK-ULTIM sites showed fluctuating trends with the V5THUK-EWR17 site showing a decreasing trend from 2017 low flow to 2018 low flow. The eMandeni Stream is particularly depauperate with regards to species richness with the lowest recorded value of zero at V5MAND-RAILB during the 2011 low-flow season. Species richness increased to six during the 2015 low-flow period, but the site has shown a decreasing trend since then. The V5MAND-WEIR site has shown an increase in species richness from 2011 to 2013. The species richness for this site then remained fairly stable from 2015 to 2017 high flow only to decrease during the 2018 low flow assessment. Similar habitat features are present at the upstream V5MAND-RAILB and downstream V5MAND-WEIR sites, and the higher species richness at the downstream site could be due to its close proximity to the confluence with the Thukela River. The presence of the weir at the V5MAND-WEIR site also obstructs migration of fish from the Thukela River further up into the eMandeni Stream.

Table 3.13: The species richness, abundance and ecological classes for the survey sites from 2008 to 2018

Taxa	V5THUK-RAILB					V5THUK-EWR17			V5THUK-EWR18									V5THUK-ULTIM							V5MAND-RAILB									V5MAND-WEIR								
	2010HF	2013LF	2015LF	2016LF	2016HF	2017LF	2017HF	2018LF	2010HF	2011LF	2012HF	2013LF	2015LF	2016HF	2017LF	2017HF	2018LF	2010HF	2011LF	2012HF	2013LF	2016HF	2017LF	2018LF	2011LF	2012HF	2013LF	2015LF	2016LF	2016H	2017LF	2017H	2018LF	2011LF	2012HF	2013LF	2015LF	2016LF	2016HF	2017LF	2017HF	2018LF
Acanthopagrus berda (Forsskål, 1775)	-	-	-	-	1	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ambassis natalensis (Gilchrist & Thompson, 1908)	-	-	1	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ambassis sp.	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Anguilla bengalensis labiata (Peters, 1852)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Anguilla marmorata	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Anguilla mossambica (Peters, 1852)	5	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	-	-	2	1	-	-
Anguilla sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	6	-	-
Argyrosomus sp.			-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Awaous aeneofuscus (Peters, 1852)	51	3	-	6	1	6	1	-	11	-	-	-	-	3	1	-	-	7	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	3	2	-	-	-	-	-
Awaous sp.	-	-	-	-	-	-	-	-	-	50	11	-	-	-	-	-	-	-	-	36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Captodon rendalli (Boulenger, 1897)	-	-	14	-	-	-	-	-	-	-	-	-	-	64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chelon macrolepis (Smith, 1846)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clarias gariepinus (Burchell, 1822)		-	1	-	1	-	-	-	-	-	-	-	-	4	2	1	-	1	-	7	1	7	5	3	-	3	1	2	-	-	3	2	2	-	-	-	2	-	-	1	-	4
Coptodon rendalli (Boulenger, 1897)											-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cyprinus carpio (Linnaeus, 1758)	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12
Eleotris fusca (Forster, 1801)	-	-	1	-	2	2	-	1	3	-	-	-	-	5	3	3	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	3	2	11	5	3	1	-
Enteromius paludinousus Peters, 1852	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	5	-	-	-	-	-	-	-	1	2	-	-	3	-	-
Enteromius trimaculatus Peters, 1852	11	-	-	8	-	-	2	-	4	-	-	-	7	1	3	-	4	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	-	3	-
Enteromius viviparus Weber, 1897	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	2	-	-	-	-
Gambusia affinis (Baird & Girard, 1853)	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	8	-	13	-	-	-	-	-	21	3	-	-	-	-	-	-
Glossogobius callidus (Smith, 1937)	-	-	2	-	-	2	-	-	9	50	-	-	-	1	2	2	-	29	-	-	1	-	4	5	-	-	-	-	-	-	-	-	-	-	-	-	-	9	-	-	-	-
Glossogobius giuris (Hamilton & Buchanan, 1822)	-	-	-	-	-	1	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Glossogobius sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hypseleotris cyprinoides (Valenciennes, 1837)			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Hypseleotris dayi Smith, 1950		-	-	-	-	-	-	-	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Labeo rubromaculatus Gilchrist & Thompson, 1913	25	6	6	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	1	-	-	-	-	-	-
Labeo molybdinus (DU Plessis, 1963)	-	-	-	23	16	23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	6	-
Labeobarbus natalensis (Castelnau, 1861)	62	7	24	2	2	-	4	-	2	-	-	-	11	7	5	1	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	6	1	2	-	-	-
Liza dumerilii (Steindachner, 1870)	-	-	-	-	-	25	-	-	-	-	-	-	-	-	25	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Megalops cyprincides (Broussonet, 1782)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Microphis brachyurus (Bleeker, 1854)		-	-	-	-	-	-	-	-	-	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Microphis fluviatilis (Peters, 1852)	-	-	-	-	-	16	4	1	-	-	-	6	-	-	12	2	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Monodactylus argenteus (Linnaeus, 1758)		-	-	-	-	1	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Monodactylus falciformis (Lacepède, 1801)	-	-	-	-	-	-	-	-	-	-	-	24	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mugil cephalus Linnaeus, 1758	-	-	-	-	-	15	-	-	-	-	-	-	-	-	39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mullet fry	39	-	-	-	-	-	-	1	345	50	-	139	-	-	-	-	-	65	350	60	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	17	-	-	-	-
Mycropterus salmoides (Lacepède, 1802)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Myxus capensis (Valenciennes, 1836)	-	-	-	-	1	1	1	-	3	1	-	-	-	-	7	-	-	1	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Oreochromis mossambicus (Peters, 1852)	-	-	-	30	-	18	22	2	165	7	13	-	7	14	42	37	-	15	3	23	-	13	18	4	-	23	3	4	5	22	2	22	-	-	5	4	12	20	15	11	13	10
Poecilia reticulata Peters, 1859	-	-	-	-	-	-	-	-	4	-	-	-	-	-	26	-	-	-	-	-	-	-	1	-	-	115	-	74	5	83	120	57	40	-	-	-	85	-	2	41	7	7
Pseudocrenilabrus philander (Weber, 1897)	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	3	7	4	-	9	-	-	-	-	-	1	-	-	-	18	-	-
Redigobius dewaali (Weber, 1897)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhabdosargus holubi (Steindachner, 1881)	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhabdosargus sarba (Forsskål, 1775)	-	-	-	-	-	-	-	-	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tilapia rendalli (Boulenger, 1897)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Species richness	6	4	7	5	8	14	6	6	15	5	2	3	3	9	17	8	2	8	2	6	5	3	6	8	0	4	5	6	3	3	3	3	2	1	3	10	7	7	8	8	8	4
Total abundance	169	17	49	69	25	115	34	7	582	128	28	169	24	100	173	80	5	123	353	103	8	21	33	20	0	144	20	90	23	114	125	81	42	1	32	19	111	70	45	84	33	33
FRAI Score	79.5	38.7	70.5	48	57.5	69.9	57.5	58	71.9	66.4	60.2	38	67.6	67.2	68.6	58	59	60.9	57.1	71.2	38	36	65.2	64	43.4	61.1	40.8	57.1	21	36	47.7	47.7	18	52.7	61.3	59	43.4	44.7	57	48.1	48.1	48
Integrity category	B	D/E	C	D	C/D	C	C/D	D	C	C	C/D	E	C	C	C	C/D	C/D	C	D	C	D/E	D/E	C	C	D	C/D	D	D	E/F	E	D	D	F	D	C/D	C/D	D	D	C/D	D	D	D

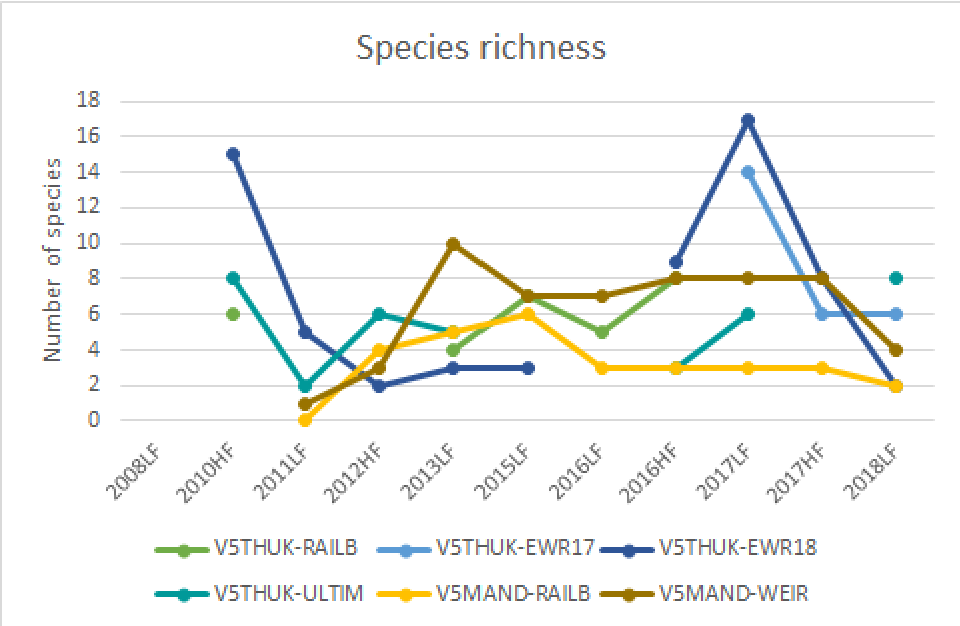

Figure 3.24: Trends in fish species richness for survey sites on the Thukela River and eMandeni Stream

The trends in the abundance of fish sample at each site shows varying trends temporally and spatially (Figure 3.25). The abundance of fish sampled during the 2018 assessment was the lowest amount sampled at the V5THUK-EWR17 and V5THUK-EWR18 sites to date and the second lowest sampled for the V5THUK-ULTIM site. Low abundances were also recorded for the V5THUK-EWR18 site during 2012 and 2015. A decreasing trend in fish abundance at the V5THUK-ULTIM site is recorded from 2011 and is of concern. The largest contribution to total abundance within the eMandeni Stream is the alien invasive species *P. reticulata* (Table 3.13). The species is tolerant to poor water quality and therefore can thrive in the system due to the lack of competitors and a reduced diversity of predators. During the 2018 low flow assessment, most of the fish sampled at the two eMandeni sites were alien invasive species. The general decline in the fish abundances for the two eMandeni sites is observed from the 2017 low flow survey to the 2018 low flow survey.

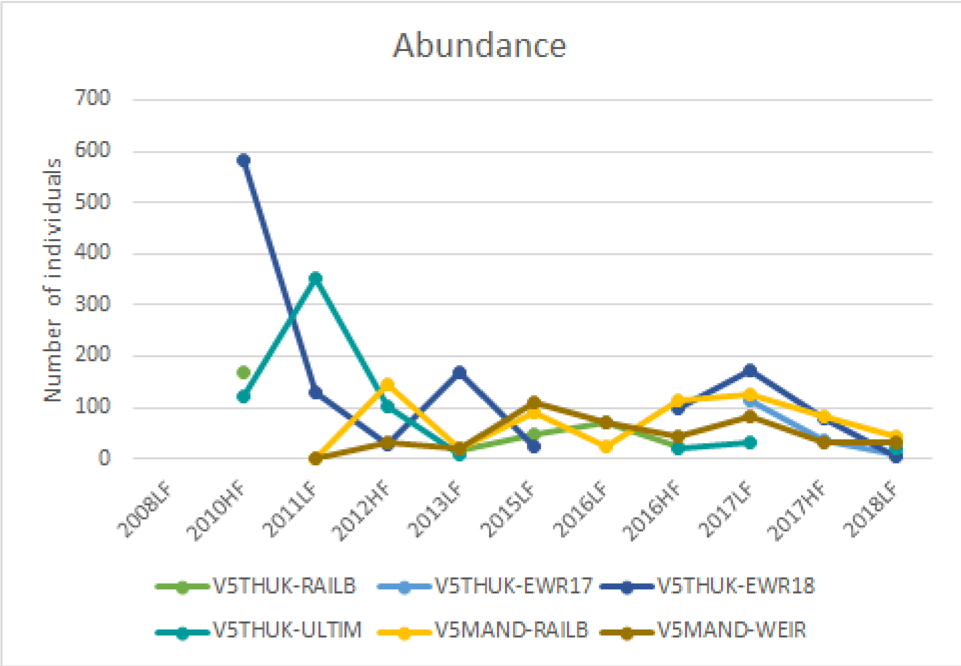

Figure 3.25: Trends in fish species abundance for survey sites on the Thukela River and eMandeni Stream

The trends projected in Figure 3.26 indicate a general decline in the ecological categories of all the sites in 2013. The V5THUK-RAILB and V5THUK-EWR18 site both improved to a C category in 2015 and the V5THUK-EWR18 has remained stable till the 2017 high flow assessment, where the ecological category deteriorated to a D/C category where it has remained. The V5THUK-ULTIM site improved from a D/E category in 2013 and 2016 to a C category in 2017 and 2018. The V5THUK-EWR17 site has displayed a decreasing trend from a C category in 2017 low flow to a D category in 2018. The upstream V5MAND-RAILB site displayed a noticeable decreasing trend from a C/D category in 2012 to an E/F category during the 2016 low flow assessment. The ecological integrity of the site improved to a D category in 2017 only to decline to a F category (critically modified) in 2018. This is the lowest recorded result to date and indicates that the fish community at the site has been modified completely with an almost complete loss of natural biota. The V5MAND-WEIR site has remained the most stable of all the sites, often being categorised in a D category.

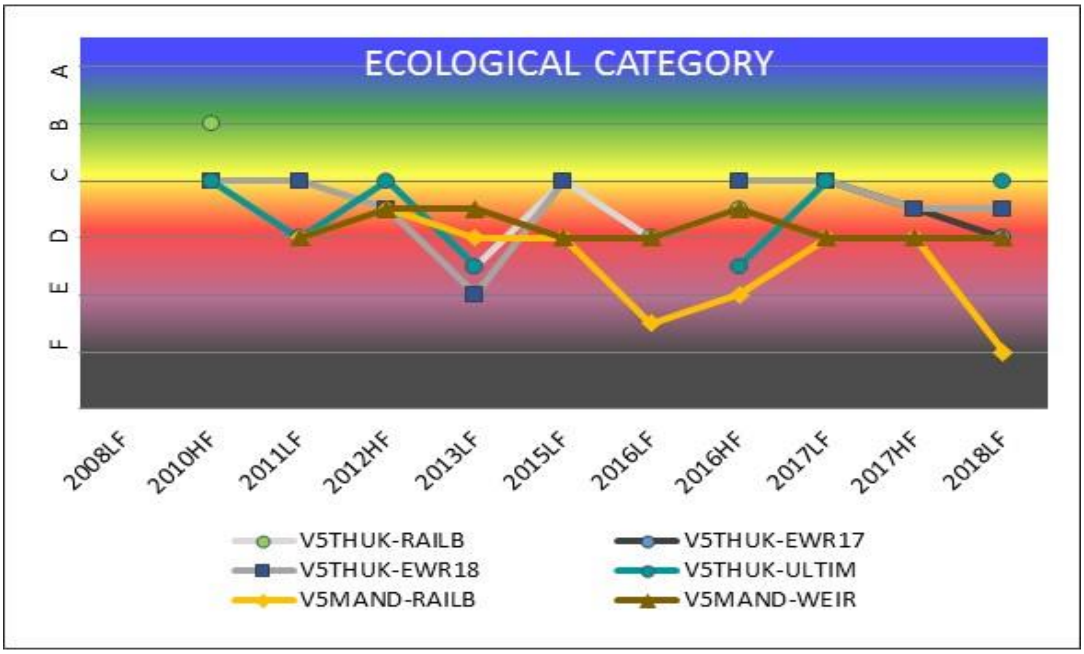

Figure 3.26: Fish trends in the ecological category for survey sites on the Thukela River and eMandeni Stream

3.4.3 EcoStatus

The EcoStatus results for all the sites are provided in Table 3.14 and indicate that all three sites on the Thukela River are in a fair state (C category) compared to the sites on the eMandeni Stream that are in a poor to seriously modified state (D/E and D category). Even though the EcoStatus for all the Thukela River sites was a C category, the ecological category percentage indicates that the integrity of the two downstream sites were similar but less than that for the upstream V5THUK-EWR17 site.

Table 3.14: EcoStatus results of the 2018 assessment of survey sites on the Thukela River and eMandeni Stream

	V5THUK-EWR17		V5THUK-EWR18		V5THUK-ULTIM		V5MAND-RAILB		V5MAND-WEIR	
	%	EC	%	EC	%	EC	%	EC	%	EC
Fish	58	C/D	59	C/D	64	C	18	E/F	48	D
Macroinvertebrates	70	C	59	C/D	50	D	19	E/F	19	E/F
Instream ecological category	**64**	**C**	**59**	**C/D**	**57**	**D**	**18.6**	**E/F**	**31.5**	**E**
Riparian vegetation	70	C	70	C	70	C	70	C	70	C
EcoStatus	**71.7**	**C**	**68.9**	**C**	**67.7**	**C**	**39.7**	**D/E**	**53.1**	**D**

3.4.4 EcoStatus Temporal Trends

The temporal trends in the EcoStatus are provided in Figure 3.27 and indicate that the upstream sites have remained in a fair state (C category) but decreasing to a poor state (D category) in 2016. The downstream V5THUK-EWR18 site remained in a poor state from 2010 to 2016 high flow survey but during the 2016 low flow survey, the ecological integrity increased to a fair state, where it has remained. A similar trend was observed for the V5THUK-ULTIM site that was in a fair state in 2010, decreased to a poor state in 2011 where it remained till 2016. In 2017 and 2018, the ecological integrity of the site increased to a fair state again. The two sites on the eMandeni Stream have shown more variation in their EcoStatus results. The upstream V5MAND-RAILB site has fluctuated between a poor to a seriously/critically modified state (E/F category). The ecological integrity of the downstream V5MAND-WEIR site has generally been healthier than that of the V5MAND-RAILB site, ranging between a fair and poor state (E category).

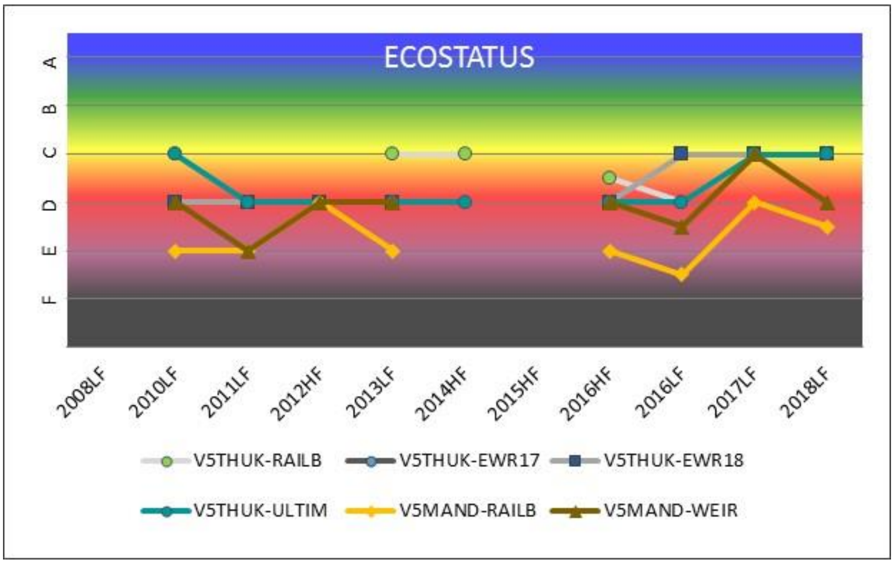

Figure 3.27: Trend assessment of the EcoStatus of survey sites on the Thukela River and eMandeni Stream

3.5 CONCLUSION

The aim of this chapter was to update the current ecological state assessment of the lower reach of the Thukela River and the eMandeni Stream and to identify the trend of the ecological state of the system over time. The 2018 low flow survey assessed the driver and response components of three sites on the lower reach of the Thukela River and two sites on the eMandeni Stream. It is evident from the 2018 and historical results that the water quality of the eMandeni Stream is being greatly impacted by stressors like the upstream Isithebe Industrial complex, the waste water treatment works and the landfill site. Fortunately, the poor water quality from the eMandeni Stream and the Sappi mill effluent discharge only seems to be having a slight impact on the receiving waters of the Thukela River due to the dilution effect of the quantity of water in the Thukela River. Reduction in flow in the Thukela River will reduce this dilution effect and impacts from the eMandeni Stream and the Sappi mill effluent to the downstream water quality of the Thukela River will increase; as was documented in the past, where releases from the Spioenkop Dam was occasionally required to dilute the effluent discharge from the Sappi mill (DWAF, 2004a).

The trends in the habitat integrity assessment indicate that there was a decline for most sites in 2015 that is attributed to the 2015/2016 drought but since then the habitat integrity has improved. The response components indicate that the biota of the two sites on the eMandeni Stream are responding negatively to the poor conditions of the driver components, mainly the water quality, as the macroinvertebrate communities of both sites were in a seriously to critically modified state in 2018. The ecological integrity of the macroinvertebrates for the upstream V5MAND-RAILB site has generally been the lowest of all the sites, often in a seriously to critically modified state indicating the critical loss of natural habitat, biota and basic functions. The fish community at the upstream V5MAND-RAILB site was in a critically modified state in 2018, the lowest recorded result to date and indicates that the fish community at the site has been modified completely with an almost complete loss of natural biota. The ecological integrity of the macroinvertebrates at the V5MAND-WEIR site has most commonly been in a poor or seriously modified state and the fish in a poor state.

Generally, the macroinvertebrate ecological category for the upstream V5THUK-RAILB and V5THUK-EWR17 sites have been higher than for the downstream sites and have ranged between a poor and good state except for the 2017 high flow survey where the V5THUK-EWR17 site was in a seriously to critically modified state. The integrity of the fish community has varied for the upstream sites but from the 2017 low flow to the 2018 low flow assessment, there has been a decreasing trend from a fair state to a poor state. The macroinvertebrate and fish communities at the V5THUK-EWR18 site were classed as being in a fair to poor state in 2018. Historically, the ecological integrity of the macroinvertebrates for the V5THUK-EWR18 site has mostly ranged between a fair to poor state with a general improvement recorded during the high flow assessments. The fish community for this site was in a fair state in 2015, 2016 and 2017 low flow assessment but since the 2017 high flow assessment has declined to a poor state. The macroinvertebrate community of the V5THUK-ULTIM site was in a poor state from 2016 to 2018, with varying results before then. The integrity of the fish community has remained in a fair state for 2017 and 2018 which is an improvement on the poor to seriously modified state recorded in 2013 and 2016.

The overall EcoStatus results for 2018 indicate that all three sites on the Thukela River are in a fair state compared to the sites on the eMandeni Stream that are in a poor to seriously modified state. Even though the EcoStatus for all the Thukela River sites was a C category, the ecological category percentage indicates that the integrity of the two downstream sites were similar but less than that for the upstream V5THUK-RAILB site. The upstream V5THUK-RAILB site remained in a fair state in 2013 and 2014 but decreased to a poor state in 2016. The upstream V5THUK-EWR17 site has remained in a fair state in 2017 and 2018. The downstream V5THUK-EWR18 site remained in a poor state from 2010 to 2016 high flow survey but during the 2016 low flow survey, the ecological integrity increased to a fair state, where it has remained. A similar trend was observed for the V5THUK-ULTIM site that was in a fair state in 2010, decreased to a poor state in 2011 where it remained till 2016. In 2017 and 2018, the ecological integrity of the site increased to a fair state again. The two sites on the eMandeni Stream have shown more variation in their EcoStatus results. The upstream V5MAND-RAILB site has fluctuated between a poor to a seriously/critically modified state. The ecological integrity of the downstream V5MAND-WEIR site has generally been healthier than that of the V5MAND-RAILB site, ranging between a fair and seriously modified state.

It is clear from the results that the Thukela River and eMandeni Stream have both been impacted by stressors, and the eMandeni Stream more so than the Thukela River. The comparison of results between the upstream reference sites (V5THUK-RAILB and V5THUK-EWR17) and the downstream V5THUK-EWR18 site indicates that the downstream site is being impacted on marginally by the eMandeni Stream and possibly the Sappi mill discharge, although the full impacts are being mitigated by the size and dilution capacity of the Thukela River. This dilution capacity may decrease with reductions in flow due to the completion in December 2016 of the UBTS upstream of the V5THUK-EWR17 site as well as other water requirements further upstream in the catchment. The effects to changes in flow regimes is often difficult to observe due to the potential lag effect in the biological responses (Bunn and Arthington, 2002). Research has highlighted that alterations in flow regimes can be the most serious and continuing threat to the sustainability of aquatic ecosystems and should be taken into account in future biomonitoring assessment (Bunn and Arthington, 2002). Another consideration is the impact of reduced flows on the Thukela Estuary and the offshore Thukela Banks and KZN Bight. The Thukela River is important for the ecology and biology of the Thukela Banks and the Bight, and reductions in freshwater outflows and sediment loads could have an impact on the estuarine system and the marine ecosystem and ultimately on the people who are depending on these resources for subsistence, recreational and commercial fishing (De Lecea and Cooper, 2016).

To sustainably maintain a suitable balance between the use and protection of the Thukela River and estuary, it is recommended that an updated Ecological Reserve determination be completed for the Thukela River and Resource Quality Objective sets to enable decision makers to make informed decisions on the management of the Thukela system, taking into account the impacts on the Thukela Estuary. The functionality of the UBTS fishways should also be investigated as well as the impacts of the weir as a barrier for fish migration especially considering that the "Vulnerable" *L. rubromaculatus* species has not been sampled in the study area since 2015. Threats to *L. rubromaculatus* include hydrological modification that form barriers to fish movement.

CHAPTER 4

4 RELATIVE ECOLOGICAL RISK ASSESSMENT OF MULTIPLE STRESSORS TO A RANGE OF SOCIAL AND ECOLOGICAL ENDPOINTS IN THE LOWER REACH OF THE THUKELA RIVER

4.1 INTRODUCTION

South Africa does not only face problems with regards to the security of supply of water but also with environmental degradation and resource pollution (DEA, 2012; DWA, 2013). South Africa is a water stressed country with rainfall amounts varying annually and large geographic differences in rain. This results in water resources that are extremely varied and highly stressed in certain areas. This problem is aggravated by human activities like mines, industries and waste water treatment works that negatively impact on the quality of our water resources (DEA, 2012). The National Water Act of South Africa (NWA; Act 36 of 1998) tries to appease this situation by ensuring that water resources are protected, used, developed, controlled, conserved and managed in a sustainable and equitable manner, for the benefit of all (DWAF, 1999). Chapter 3 of the NWA provides the measures that need to be taken to comprehensively protect all water resources and these Resource Directed Measures (RDMs) include the classification of water resources, establishing Resource Quality Objectives (RQOs) and determining the Reserve. Unfortunately, utilising these RDMs to achieve a balance between the use and protection of water resources is not an easy task as achieving the one is normally to the detriment of the other.

The Thukela River in the KwaZulu-Natal province of South Africa is the second largest river in the country with a total catchment area of 29 042 km^2 representing 31.8% of KwaZulu-Natals total surface area (DWAF, 2003a, DWAF, 2004b). The river rises in the Drakensberg mountains, meanders through central KwaZulu-Natal and discharges through the Thukela Estuary into the Indian Ocean. The Thukela river catchment is divided into eight major catchments, including; the Upper Thukela, the Little Thukela, the Klip, the Bushmans, the

Sundays, the Mooi, the Buffalo and the Lower Thukela (Oliff, 1960a). The Thukela River is extensively utilised for water transfers, including transfer so the Vaal river system, transfer to the Mhlathuze River system, the Mooi-Mgeni transfer scheme and the Lower Thukela Bulk Water Supply Scheme (DWAF, 2013; Umgeni Water, 2017a). Within the catchment, the river also supplies water to the Newcastle and Ladysmith complexes, SAPPI Tugela paper and pulp mill near Mandeni and for power generation, mining and irrigation (DWAF, 2003a; DWAF, 2013). The use of the ecosystem services provide by the Thukela River system, including; water abstraction, waste dilution, waste assimilation, recreational activities and subsistence fishing all results in various water quality, quantity and habitat impacts (DWAF, 2004a).

The Thukela River is considered to be ecological important for the offshore marine environment (De Lecea and Cooper, 2016). The Thukela Estuary enters the ocean at the broadest point of a continental shelf called the Bight that extents from St Lucia to an area just south of Durban. The Thukela River accounts for more than 35% of the freshwater entering the Bight and its river-dominated estuary forms a large organic matter plume and the Thukela Banks. This large mud bank is extremely important for fisheries and it is the only near-shore area on the east coast of South Africa where prawn trawling is possible. The riverine nutrient input from the Thukela River is vital for the ecology and biology of the Thukela Banks and the Bight, but reductions in freshwater outflow and sediment loads can have negative impacts on the estuarine system as well as for the marine ecosystems (De Lecea and Cooper, 2016). The state of the lower reach of the Thukela River and estuary have both recently been established as moderately modified from 2005 to 2014 (Ferreira *et al.*, 2008; O'Brien, 2010; O'Brien and Venter, 2012; INR, 2014a) and now largely modified from 2015 which can largely be attributed to the synergistic effects of land use and the severe drought the region has endured. This suggests that although key ecosystem processes are occurring, some structure and function aspects of the ecosystem may be negatively impacted on as a result of altered state of water quality, and or quantity or habitat driver states.

The area upstream of the Thukela Estuary includes the town of Mandeni, the Sundumbili settlement, the Isithebe industrial area, the SAPPI Tugela paper and pulp mill and sugar cane farming (DWAF, 2003b) . The SAPPI Tugela mill was erected in 1953 in Mandeni and has both extraction and discharge points in the lower reach of the Thukela River (DWAF, 2003b; Macdonald, 2004). An underground pipe system releases effluent from the SAPPI mill into the Thukela River approximately 500m below the confluence of the Thukela River with the eMandeni Stream. This pipeline is deteriorating resulting in breakages and associated short-term releases of effluent into the eMandeni Stream.

The ecological impacts from these water resource users include a drop in oxygen levels along with rise in chemical oxygen demand, ammonia and conductivity (DWAF, 2004a; Ferreira *et al.*, 2008; Stryftombolas, 2008). Oxygen levels in the eMandeni Stream have been reported to be lower than those in the Thukela River (Stryftombolas, 2008). A risk assessment previously conducted in the Thukela system revealed that the lower reach of the Thukela River together with the eMandeni Stream are the areas at the greatest threat of stressors affecting the ecosystem health (O'Brien and Venter, 2012). As such, the impacts of the sources of stressors in the Thukela River may persist into the Thukela Estuary. As indicated, the region has also faced one of the worst droughts in modern history with flows ceasing in the river entirely during 2015 and 2016. These reduced flows exacerbate the stress associated with the anthropogenic use of the system. These combined stressors may result in irreversible changes to the wellbeing of the system.

Ecosystems are a complex system of ecological organization that is difficult to manage (Ayre and Landis, 2012). Ecological risk assessments were developed to provide the context and protocol for predicting environmental impacts of various stressors, both natural and anthropogenic. Originally, ecological risk assessments were developed to determine the risk on organisms from the release of environmental pollutants into isolated areas but the need to evaluate the ecological consequences across large spatial scales with multiple disturbances let to the development of the relative risk model (RRM) (Ayre and Landis, 2012). This model is a conceptual framework that is used to identify sources of stressors, the stressors themselves, the effects of these stressors on receptors and the resulting impacts on the endpoints at a regional scale (Landis, Ayre, *et al.*, 2017). Spatially distinct risk regions are selected to organise the information into cause and effect pathways and ranking schemes are used to combine variables with different units. The relative-risk scores are calculated for assessment endpoints and are compared across risk regions and between endpoints (Landis, Ayre, *et al.*, 2017). This approach has been used internationally at different spatial scales and on various stressors and combinations of stressors (Walker *et al.*, 2001; Hayes and Landis, 2004; Colnar and Landis, 2007; O'Brien and Wepener, 2012; Hines and Landis, 2014). To describe the relationships between the model's variables in a more transparent and graphic way, Bayesian networks (BN) were included as a conditional probability distribution model. This reduces the uncertainty in a model due to the lack of knowledge as combinations of different types of information and expert knowledge can be used (Ayre and Landis, 2012; Landis, Ayre, *et al.*, 2017). The inclusion of the BN into RMM was formalised into an integrated BN-RRM approach as the causal framework of the RRM can be directly rendered into the node structure of the BN. This approached has been used on a variety of assessments (Ayre and Landis, 2012; Hines and Landis, 2014; Herring *et al.*, 2015; Landis, Markiewicz, *et al.*, 2017) and is a useful tool not just for ecological risk assessments and ecosystem management but also for environmental flow (E-flow) assessments (O'Brien *et al.*, 2018).

A BN-RRM based E-flow approach was developed between 2013 and 2016, call PROBFLO (O'Brien *et al.*, 2018). This approach is a scenario-based E-flow assessment tool that according to O'Brien *et al.* (2018) is; "*a transparent and adaptable, evidence based probabilistic modelling approach that can also incorporate expert solicitations and explicitly address uncertainty*". The approach allows for the evaluation of both social and ecological consequences of altered flows and takes into consideration the impacts of non-flow drivers of ecosystem loss (O'Brien *et al.*, 2018).

The aim of this chapter is to implement the BN-RRM approach to evaluate the socio-ecological consequences, in term of ecological risk, of altered water resource use scenarios to a range of endpoints for risk regions in the study area during low and high flow periods. This included the evaluation of a range of water resource use options for the Sappi Tugela Paper and Pulp mill to consider the cost-benefits of alternative water resource opportunities before the existing deteriorating effluent pipeline is replaced.

4.2 STUDY AREA

The study area was the lower reach of the Thukela River, from the confluence of the Nembe River to the Thukela Estuary, as well as the eMandeni Stream that flows into the Thukela River (Figure 4.1). Adjacent to the eMandeni Stream is the town of Mandeni, the Sundumbili settlement, the Isithebe industrial area, and the SAPPI Tugela paper and Pulp mill (DWAF, 2003b). The Sundumbili wastewater treatment works, a textile and a vegetable oil factory, Tugela Rail, SAPPI and irrigation for sugar farmers downstream, all impact on the eMandeni Stream or Thukela River through abstraction, discharge or both (DWAF, 2003b). Upstream of the confluence with the eMandeni Stream, is the Lower Thukela Bulk Water Supply Scheme which was completed in 2017 (Umgeni Water, 2017a). This scheme initially abstracts 55Ml of water per day from a weir that has been constructed in the Thukela River but Phase 2 of the scheme will double the abstraction to 110 Ml per day (Umgeni Water, 2017b). Downstream of the study area is the river dominated Thukela Estuary which flows into the Indian Ocean. To provide up to date ecological and hydrological data for the case study, field studies were undertaken to revise the Ecological Reserve for the Thukela River at sites EWR16, EWR17 and EWR18 and two sites on the eMandeni Stream (EMAN1 and EMAN2) (Figure 4.1).

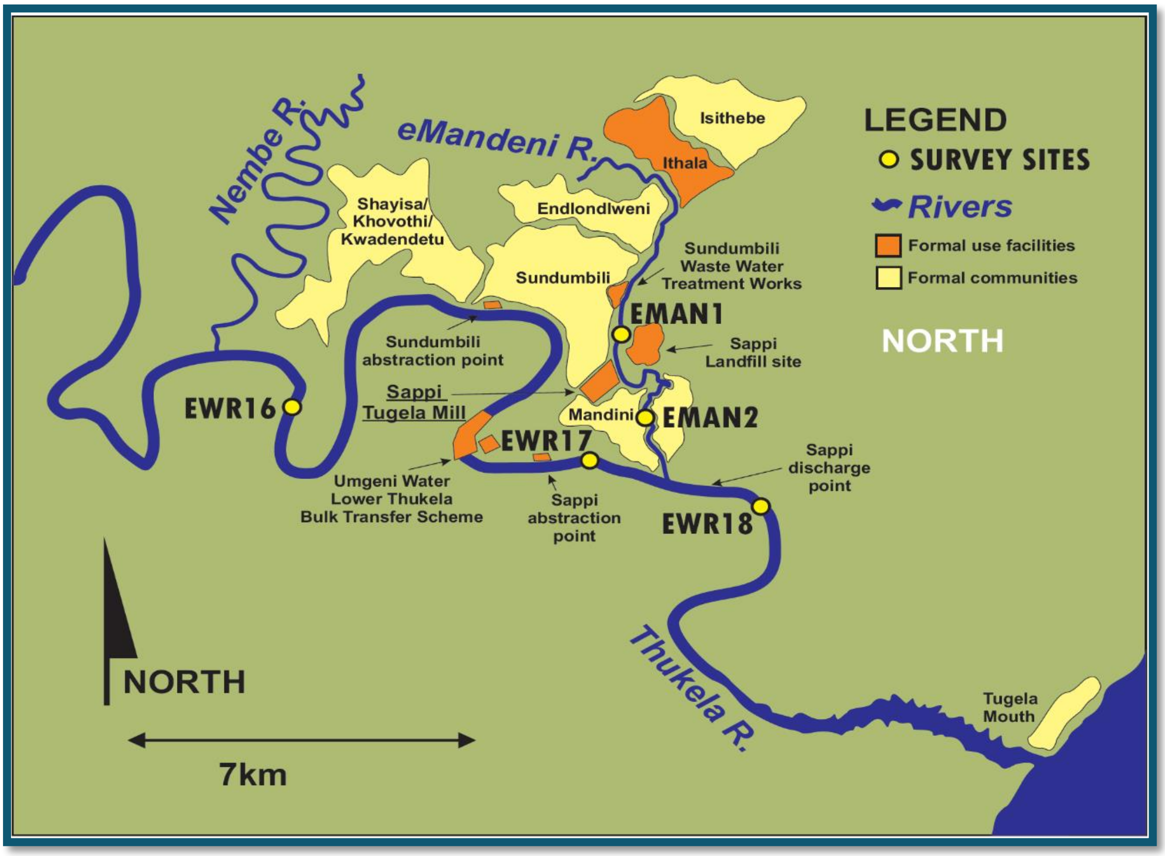

Figure 4.1: Map of the study area including sampling sites, formal facilities and communities.

4.3 APPLICATION OF THE PROBFLO APPROACH

The ten procedural steps of PROBFLO were followed according to the methods presented in O'Brien *et al.* (2018) (Figure 4.2) to evaluate and present the risk of various scenarios related to the replacement or relocation of the deteriorating SAPPI Tugela mill effluent pipeline.

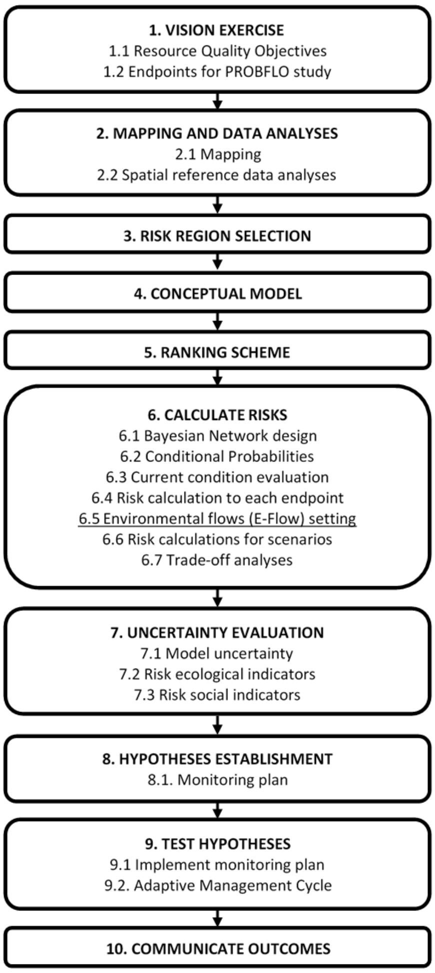

Figure 4.2: The ten procedural steps of PROBFLO (O'Brien *et al.*, 2018)

4.3.1 Step 1: Vision exercise

The importance of having clear water resource management objectives for a regional scale risk assessment is imperative as it directs all components of the assessment. Although the purpose of the risk assessment is to evaluate endpoints that are exposed to relatively different risks from sources and stressors in different regions of the study area, in the context of risk pathways, an understanding is needed of what managers or stakeholders deem important in the region and what should be tested in an assessment. To achieve this, it is considered good practice by Integrated Water Resource Management strategies, regional management plans and frameworks, national legislation and E-flow assessment tools to establish clear goals or visions for the study area that will direct the use and protection of water resources (Poff *et al.*, 2010; King and Pienaar, 2011). This vision should be established within a legislative context so the RQO determination procedure (DWA, 2011) was implemented to provide a narrative and numerical description of various ecosystem features required to achieve the balance between the use and protection of the water resources in the study area and provide a documented vision. However, in the absence of a catchment scale Water Classification Study for the Thukela River and Estuary, the vision established for the lower reach of the Thukela River has only been used in the development of endpoints for this assessment. These endpoints would be useful for the future RDMs required for the comprehensive protection of the water resources in the whole catchment but in the interim would facilitate the sustainable use and protection of water resources for the region.

A summary of the procedural steps followed for this case study to establish the vision and develop the endpoints are provided below.

- **Delineate the Integrated Units of Analysis (IUAs) and Resource Units (RUs):** In this case, the region was divided into two IUAs. The first being the freshwater part of the lower reach of the Thukela River and the second, the Thukela Estuary. Three spatial levels for resources were considered for RQO determination in this case study:
    - Regional (IUA) scale assessments for the rivers in the study area.
    - Resource Unit scale assessments that were aligned to sub-quaternary catchments and existing Reserve determination sampling sites were considered for the rivers and estuary in the study area.

  The RU delineation procedure initially involved the identification of sub-quaternary reaches of rivers in the study area. The sub-quaternary reach of V50D-03903 for the Thukela River was the only applicable sub-quaternary for the assessment (DWS, 2014).

This included the Thukela River and estuary from the upstream edge of the study area to the mouth of the Thukela River. Unfortunately, available data did not include the delineation of the socio-ecologically important eMandeni Stream that is a focus of the assessment and represents a location where the quality and associated use of water resources in the study area changes. As such, the eMandeni Stream and its associated catchment was delineated and used to separate RUs in the assessment (Figure 4.3). The number and spatial extent of RUs selected for the assessment can be associated with the biophysical nodes that can inform a future formal Water Resource Classification study for the region. The delineation procedure involved the use of Geographical Information System (GIS) spatial ecosystem data.

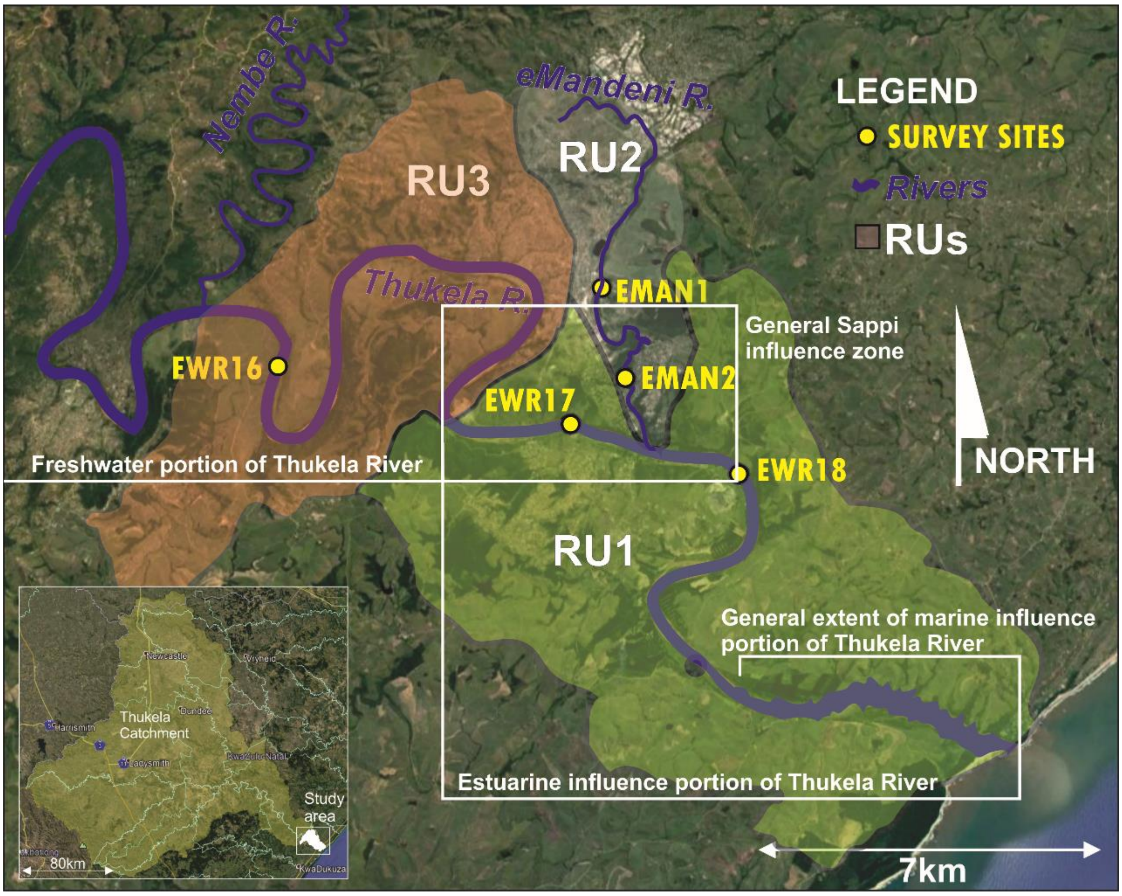

Figure 4.3: Map of the Resource Units determined for the study area

- **Establish a vision for the catchment and key elements for the IUAs:** In this phase, existing preliminary RQOs from a Draft Thukela River Estuary Management Plan (INR, 2014b) and available water resource use and protection information were considered. Stakeholder workshops were also held, that highlighted the importance of flows in the Thukela River and estuary to maintain the wellbeing of the Thukela Bight. The vision selected to direct this assessment is adaptable and based on local and regional applicable legislation and policies. The vision for the assessment simply states:
  - *Maintain the current (2017) ecological wellbeing of the structure and function of the ecosystem, which includes biodiversity and key ecosystem process maintenance.*
  - *Maintain a sustainable balance between the use and protection of water resources, including an environment that is safe and clean and promotes sustainable use for the benefit of all stakeholders.*
- **Prioritise and select RUs and ecosystems for RQO determination:** In this step, RU's in the study area were prioritised and sites within each RU that have previously been used as Ecological Water Requirement (EWR) sites or sites for routine monitoring were selected to represent the study area (Figure 4.3).
- **Prioritise sub-components for RQO determination, select indicators for monitoring and propose the direction of change:** Sub-components prioritised for RQO development in this assessment included water quality, quantity and habitat components and a series of biological components. They were used to establish the endpoints for the assessment, that represent the current balance between the use and protection of water resources that should be "maintained or improved".
- **Develop draft endpoints for the assessment:** The endpoints selected for the assessment include a range of use and protection ecosystem indicators including:

Resource protection indicators:

- Maintain riparian vegetation wellbeing: this ecological endpoint represents an important component of the ecological wellbeing of the aquatic ecosystems of the Thukela River and eMandeni Stream. Risk to the maintenance of the wellbeing of the riparian ecosystem will inform the components of the vision to maintain the biodiversity and ecosystem processes of the study area.
- Maintain fish community wellbeing: similarly, this ecological endpoint represents an important component of the ecological wellbeing of the aquatic ecosystems of the Thukela River and eMandeni Stream. Risk to the maintenance of the wellbeing of the fish communities will inform the components of the vision to maintain the biodiversity and ecosystem processes of the study area.
- Maintain macroinvertebrate community wellbeing: similarly, this ecological endpoint represents an important component of the ecological wellbeing of the aquatic ecosystems of the Thukela River and eMandeni Stream. Risk to the maintenance of the wellbeing of the invertebrate communities will inform the components of the vision to maintain the biodiversity and ecosystem processes of the study area.

Resource use indicators:

- Maintain supply of natural products: in the study area the supply and maintenance of the existing quality of fish from the river and vegetation from the riparian zone for food and materials, as well as sand were selected to represent the natural product supply for the assessment. These endpoints must be maintained for the benefit of local communities to achieve the sustainable use and protection vision of the rivers in the study area.

- Maintain opportunities and environmental quality for recreational activities: the maintenance of the quality of the ecosystem to limit threats to human health and access and opportunities for recreation in the study area must be maintained. This will contribute to the achievement of the vision of the study area, namely; to promote the use of and access to the study area as well as sustainably use the environment.
- Maintain water for abstractors: the socio-economic value of the rivers in the study area, associated with the abstraction of water for urban and peri-urban communities, agriculture and industry must be maintained. This will contribute to achievement of the sustainable use of water resources in the study area for the equitable benefit of all users.
- Maintain effluent assimilative capacity of the environment: the water borne waste removal service of the rivers in the study area is of great value to the users and regulators of the rivers in the study area. To achieve the vision of the assessment that includes, "*sustainable use for the benefit of all stakeholders*" the assimilative capacity of the rivers is a suitable ecosystem indicator for the assessment that must be carefully managed.

4.3.2 Step 2: Mapping and data analysis

In this step, the spatial extent of the study area needs to be defined and described so that the location of potential sources, habitats and impacts are identified and spatially referenced (O'Brien *et al.*, 2018). This information is used as part of the BN-RRM approach to PROBFLO, that includes the relative evaluation of multiple sources of stressors to endpoints on a regional scale, that are spatially and temporally referenced for regional comparison (O'Brien *et al.*, 2018). To achieve this, a comprehensive literature review of the lower reach of the Thukela River and estuary was carried out. In addition to this spatial data pertaining to water resource use was reviewed and specialist input obtained to evaluate the data

4.3.3 Step 3: Risk region selection

This step requires the establishment of geographical risk regions that can be assessed in a relative manner through the evaluation of management objectives, source information and habitat data (O'Brien *et al.*, 2018). It is important in this step to consider the spatial connectivity of multiple variables within the study area so that the risk regions incorporate appropriate sources, stressors, habitats and endpoints (O'Brien *et al.*, 2018). In the case study, available sub-quaternary catchment information, the extent of the estuary and water resource use and protection scenarios were considered to delineate risk regions that were used in the risk assessment. Particular consideration was afforded to knowledge of:

- the general Sappi influence zone,
- the freshwater portion of the Thukela River,
- the estuarine influence portion of the Thukela River and
- the general extent of marine influence zone.

These data were used to establish the three risk regions considered in the assessment and in addition five sites were used to evaluate risk associated with the activities of the Sappi Tugela Pulp and Paper mill (Figure 4.3).

4.3.4 Step 4: Conceptual model

The development of a conceptual model is a critical step in the risk assessment process as it describes the cause-effect linkages for all the risk components, namely; the sources, stressors, habitats and impacts to endpoints selected for the case study (Wiegers *et al.*, 1998; Ayre and Landis, 2012; Landis, Ayre, *et al.*, 2017). The PROBFLO conceptual model also includes the consideration of flow and non-flow related variables in a spatial-temporal context to conform to a regional-scale E-flow framework procedure (Poff *et al.*, 2010; O'Brien *et al.*, 2018). This includes: (1) the selection of socio-ecological endpoints that direct the hydrologic foundations for the case study, (2) classifying ecosystem types based on geomorphic, water quality, quantity and ecoregion considerations and, (3) incorporating evidence based flow-ecosystem relationships and flow-ecosystem service relationships, with relevant non-flow variable relationships upon which the assessment is based (O'Brien *et al.*, 2018).

The conceptual models for the case study were constructed through an expert stakeholder workshop after the completion of the literature review. The workshop included hydrologists, geomorphologists, ecologists and ecosystem services scientists. These experts are familiar with the socio-ecological system of the lower Thukela River and eMandeni Stream and were able to generate hypotheses that represent the socio-ecological processes of the system being evaluated, and probable cause and effect relationships of: (1) sources to stressors to (2) multiple receptors in relation to (3) their impacts on the endpoints, selected for the case study (Figure 4.4).

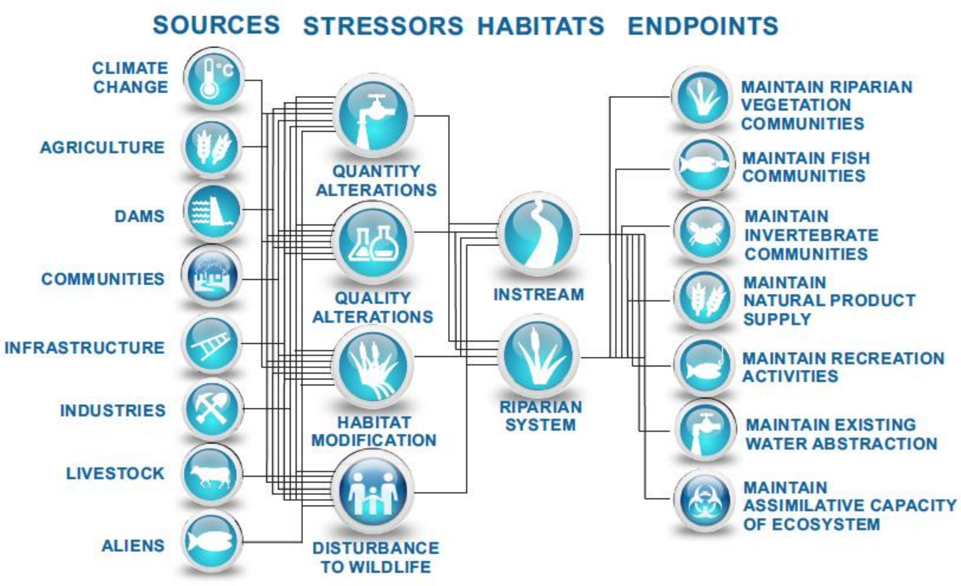

Figure 4.4: Conceptual model of the relevant sources, stressors, habitats and endpoints considered for the lower reach of the Thukela River

Conceptual models that consider all relevant sources, stressors, habitats, effects and impact relationships with spatial and temporal considerations for the assessment included four models namely:

- Macroinvertebrate endpoint model (Figure 4.5).
- Fish endpoint model (Figure 4.6).
- Riparian vegetation endpoint model (Figure 4.7).
- Social endpoint model including sub-component models for natural products, recreation, water abstraction and assimilative capacity of the ecosystem (Figure 4.8).

The models represented here in the format of the BN used in the assessment include exposure relationships with socio-ecological system structure and function variables (green nodes) which contribute to the exposure pathway of the model (yellow nodes). The exposure component of the system is then combined with the effects (pink) component where they contribute to the overall risk to the endpoints of the assessment (blue nodes).

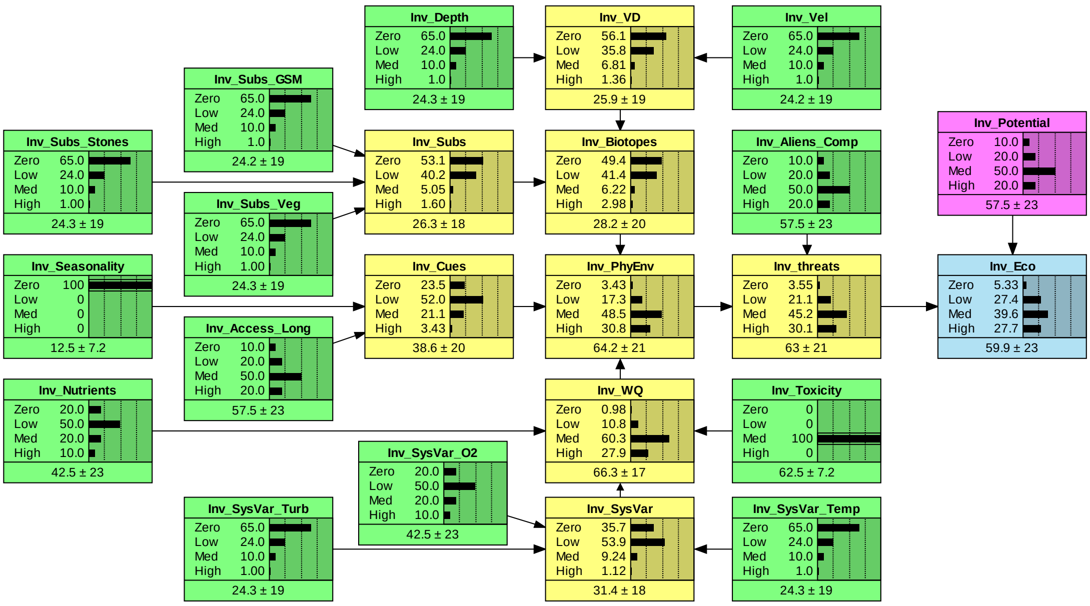

Figure 4.5: Bayesian network of the conceptual model representing the macroinvertebrate endpoint selected for the assessment. Networks include input exposure variables (green nodes), daughter exposure variables (yellow nodes), the effects (pink) variable and endpoints node/variable (blue nodes)

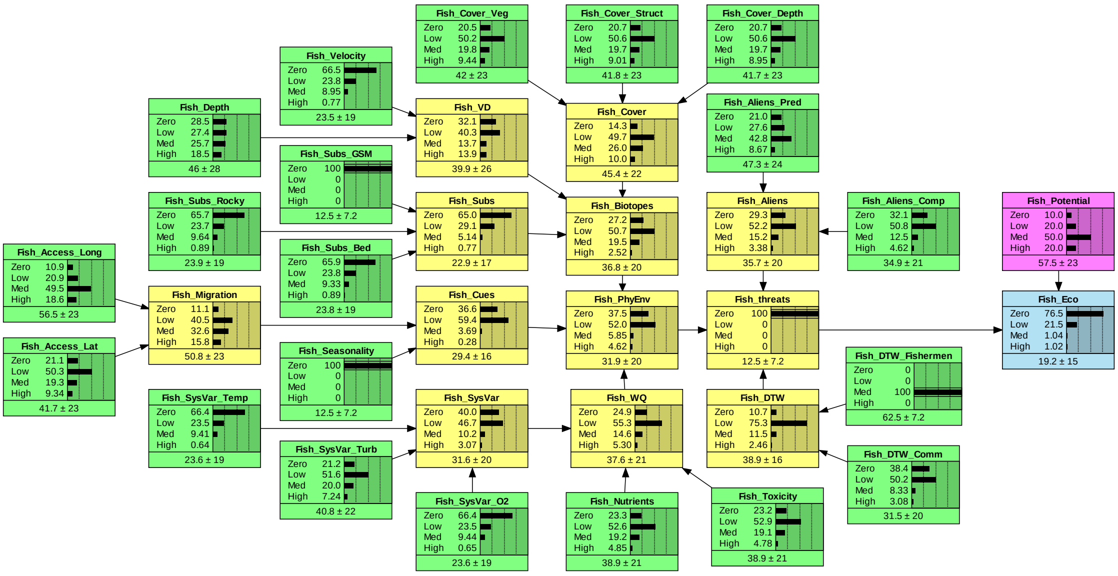

Figure 4.6: Bayesian network of the conceptual model representing the fish endpoint selected for the assessment. Networks include input exposure variables (green nodes), daughter exposure variables (yellow nodes), and the effects (pink) variable and endpoints node/variable (blue nodes)

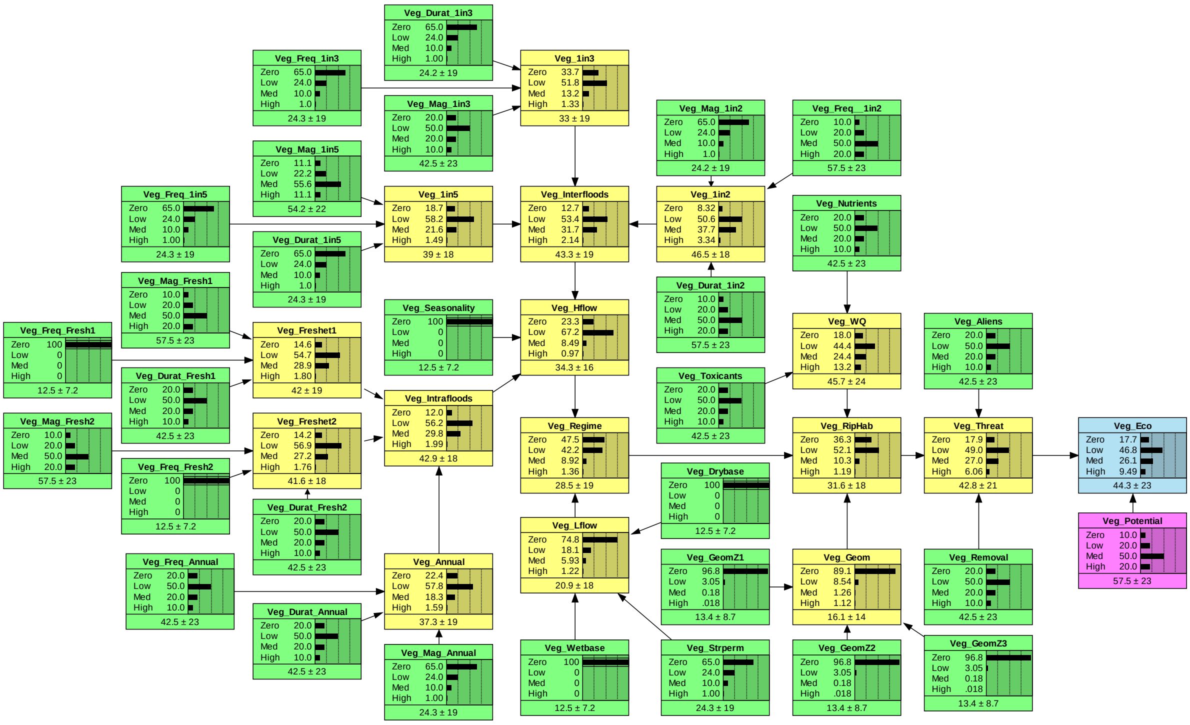

Figure 4.7: Bayesian network of the conceptual model representing the Riparian vegetation endpoint selected for the assessment. Networks include input exposure variables (green nodes), daughter exposure variables (yellow nodes), and the effects (pink) variable and endpoints node/variable (blue nodes)

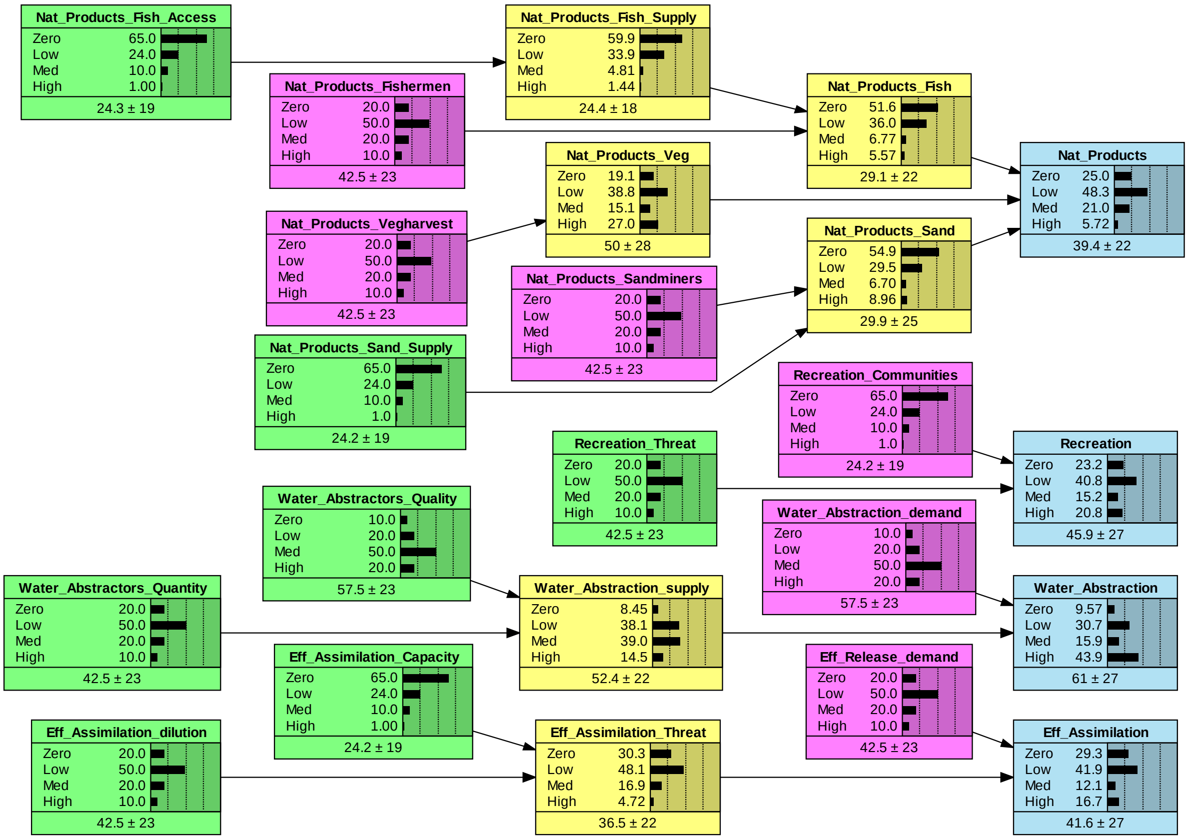

Figure 4.8: Bayesian network of the conceptual model representing the social endpoints selected for the assessment. Networks include input exposure variables (green nodes), daughter exposure variables (yellow nodes), and the effects (pink) variable and endpoints node/variable (blue nodes)

4.3.5 Step 5: Ranking scheme

Ranking schemes allows for the calculation of relative risks to each selected endpoint in the case study (O'Brien and Wepener, 2012) by representing the state of variables, with unique measures and units to be comparable as non-dimensional ranks and combining them in BN-RRMs (Landis, 2004; Landis, Ayre, *et al.*, 2017; O'Brien *et al.*, 2018). The four states that are commonly used in RRMs, namely zero, low, moderate and high (Colnar and Landis, 2007; O'Brien and Wepener, 2012; Hines and Landis, 2014; Landis, Ayre, *et al.*, 2017), have also been incorporated into the PROBFLO process. The states represent the range of wellbeing conditions, levels of impacts and management ideals as defined in O'Brien *et al.* (2018) as follows:

- Zero: pristine state, no impact/risk, comparable to pre-anthropogenic source establishment, baseline or reference state,
- Low: largely natural state/low impact/risk, ideal range for sustainable ecosystem use,
- Moderate: moderate use or modified state, moderate impact/risk representing threshold of potential concern or alert range, and
- High: significantly altered or impaired state, unacceptably high impact/risk.

This ranking scheme represents the full range of potential risk to the ecosystem and ecosystem services with management options, for example, low risk states usually represent management targets with little impact while moderate risk states represent partially suitable ecosystem conditions that usually warrant management/mitigation measures to avoid high-risk conditions (O'Brien *et al.*, 2018). By incorporating BN modelling into PROBFLO, the variability between ranks for each model variable can be represented as a percentage for each rank and are assigned scores along a percentage continuum representing the state of the variables using natural breaks of 0.25 (zero), 0.5 (low), 0.75 (moderate) and 1 (high) in the calculation (O'Brien *et al.*, 2018).

4.3.6 Step 6: Calculate risks

This step uses the BN model to calculate the relative risk and incorporate management options by including indicators of the socio-ecological system being evaluated. Measures and interactions of variables are initially set up, justified, tested and then applied. These models can be analysed individually or integrated using a range of BN modelling tools by using nodes representing variables that share the same indicators and measures. The graphic BN models make use of conditional probability distributions to graphically represent the relationships between the variables in the model (Ayre and Landis, 2012) . The model consists of parent or input nodes that provide the input parameters and child or conditional nodes that receive inputs from one or more parent nodes (Harris *et al.*, 2017). The interactions between the parent nodes that result in the child node and the probability of all potential outputs based on different combinations of input variables are described in Conditional Probability Tables (CPTs) within the BN (Herring *et al.*, 2015). In this case study we made use of the Netica^{TM} BN software by Norsys Software (http://www.norsys.com/) to perform the assessments.

The BNs were used in this assessment to represent risks to current or present scenarios based on available data, field surveys and expert opinion and then used to model future use and protection scenarios. A socio-economic model representing risk pathways from stressors such as users, alien species and natural ecosystem drivers to ecosystem receptors representing the structure and function of the systems was developed. The model was calibrated using known historical socio-ecological ecosystem wellbeing characteristics compared with current or present-day conditions and then used to model future scenarios. For this case study, 10 hydrological and or ecotoxicological water resource use scenarios were selected for the evaluation (Table 4.1). These scenarios will allow for the consideration of the socio-ecological consequences of alternative water resource use options. With the updated Ecological Reserve for the study area, the outcomes could be considered in a legislative National Water Act (No 36 of 1998) context.

Table 4.1: The ten water resource use scenarios selected for this risk assessment. Including descriptions, hydrology and ecotoxicology implications

Scenario	Title	Description	Hydrology	Ecotoxicology
SC1	Natural	Pre-anthropogenic scenario that represent 1900 conditions with limited water resource use.	Natural (Natural *Hydro.* Based on available data prior to major dam development).	Pre-anthropogenic development conditions with no "unnatural" potential for water quality threats occurring.
SC2	Present	Scenario representing present observable conditions, including observed water resource use and protection scenarios (*2015-2017*).	Present (Present *Hydro.* 1990 to current).	Observed (present) water quality alteration potential based on water quality monitoring of region from 2006 to date.
SC3	Present + EWR	Present scenario including observed water resource use (SC2) and protection scenarios with assurance that EWR will be achieved (*modelled scenario*).	Current (Current *Hydro.* + *EWR*).	Observed (current) water quality alteration potential (SC2).
SC4	Alternative (Alt.) Management (Man.) Options (Opt.) I: 100% eMandeni release at Sappi	Alternative water resource use Option I: Scenario based on; (1) current water resource use scenarios (SC2) and (2) observed ecosystem structure and function, with (3) an amended release scenario of existing effluent from the Sappi Tugela Mill into the eMandeni Stream directly adjacent to the Tugela Mill between sites EMAN1 and EMAN2.	Change in release location of current Sappi effluent *flows* into the eMandeni Stream between EMAN1 and EMAN2.	Change in release location of Sappi effluent with its water quality alteration potential into the eMandeni Stream between EMAN1 and EMAN2.
SC5	Alt. Man. Opt. II: 100% eMandeni release at weir	Alternative water resource use Option II: Scenario based on; (1) current water resource use scenarios (SC2) and (2) observed ecosystem structure and function with (3) an amended release scenario of existing effluent from the Sappi Tugela Mill into the eMandeni Stream at the lower eMandeni Stream weir below site EMAN2.	Change in release location of current Sappi effluent *flows* into the eMandeni Stream below EMAN2.	Change in release location of Sappi effluent with its water quality alteration potential into the eMandeni Stream below EMAN2.

Table 4.1 cont.: The ten water resource use scenarios selected for this risk assessment. Including descriptions, hydrology and ecotoxicology implications

Scenario	Title	Description	Hydrology	Ecotoxicology
SC6	Alt. Man. Opt. III: 50% reduction in flow of effluent and eMandeni release at Sappi.	Alternative water resource use Option III: Scenario based on; (1) current water resource use scenarios (SC2) and (2) observed ecosystem structure and function with (3) an amended release scenario of 50% of effluent volume from the Sappi Tugela Mill into the eMandeni Stream between sites EMAN1 and EMAN2.	Change in release location with 50% reduction of Sappi effluent flows into the eMandeni Stream between EMAN1 and EMAN2.	Change in release location of Sappi effluent into the eMandeni Stream between EMAN1 and EMAN2. With 50% reduction of Sappi effluent volume with existing water quality alteration potential.
SC7	Alt. Man. Opt. IV: 100% eMandeni release at Sappi with 50% reduction in water quality alteration potential.	Alternative water resource use Option IV: Scenario based on; (1) current water resource use scenarios (SC2) and (2) observed ecosystem structure and function with (3) an amended release scenario of existing volume (SC4) of effluent from the Sappi Tugela Mill. With a 50% reduction in water quality alteration potential into the eMandeni Stream, released directly adjacent to the Tugela Mill between sites EMAN1 and EMAN2.	Change in release location of current Sappi effluent *flows* into the eMandeni Stream below EMAN2..	Change in release location of Sappi effluent *with a 50% reduction in water quality alteration potential of effluent* into the eMandeni Stream between EMAN1 and EMAN2
SC8	Alt. Man. Opt. V: 100% eMandeni release at Sappi with 75% reduction in water quality alteration potential.	Alternative water resource use Option IV: Scenario based on; (1) current water resource use scenarios (SC2) and (2) observed ecosystem structure and function with (3) an amended release scenario of existing volume (SC4) of effluent from the Sappi Tugela Mill. With a 75% reduction in water quality alteration potential into the eMandeni Stream, released directly adjacent to the Tugela Mill between sites EMAN1 and EMAN2.	Change in release location of current Sappi effluent *flows* into the eMandeni Stream below EMAN2.	Change in release location of Sappi effluent *with a 50% reduction in water quality alteration potential of effluent* into the eMandeni Stream between EMAN1 and EMAN2

Table 4.1 cont.: The ten water resource use scenarios selected for this risk assessment. Including descriptions, hydrology and ecotoxicology implications

Scenario	Title	Description	Hydrology	Ecotoxicology
SC9	Alt. Man. Opt. VI: 100% eMandeni release at Sappi with 50% reduction in water quality alteration potential of Sappi and other eMandeni effluents.	Alternative water resource use Option IV: Scenario based on; (1) current water resource use scenarios (SC2) and (2) observed ecosystem structure and function with (3) an amended release scenario of existing volume (SC4) of effluent from the Sappi Tugela Mill. With a 50% reduction in water quality alteration potential of Sappi and other upstream effluents on the eMandeni stream into the eMandeni Stream, released directly adjacent to the Tugela Mill between sites EMAN1 and EMAN2.	Change in release location of current Sappi effluent *flows* into the eMandeni Stream below EMAN2.	Change in release location of Sappi effluent *with a 50% reduction in water quality alteration potential of Sappi and upstream effluents* into the eMandeni Stream between EMAN1 and EMAN2
SC10	Alt. Man. Opt. VII: 100% eMandeni release at Sappi with 100% reduction in water quality alteration potential of Sappi and other eMandeni effluents.	Alternative water resource use Option IV: Scenario based on; (1) current water resource use scenarios (SC2) and (2) observed ecosystem structure and function with (3) an amended release scenario of existing volume (SC4) of effluent from the Sappi Tugela Mill. With a 100% reduction in water quality alteration potential of Sappi and other upstream effluents on the eMandeni stream into the eMandeni Stream, released directly adjacent to the Tugela Mill between sites EMAN1 and EMAN2.	Change in release location of current Sappi effluent *flows* into the eMandeni Stream below EMAN2.	Change in release location of Sappi effluent *with a 100% reduction in water quality alteration potential of Sappi and upstream effluents* into the eMandeni Stream between EMAN1 and EMAN2

4.3.7 Step 7: Uncertainty evaluation

The PROBFLO approach includes the evaluation of uncertainty so as to identify key drivers in the model and sources of uncertainty that may be impacting on the overall uncertainty of the model (Ayre and Landis, 2012). The results of this evaluation provide context to the stakeholders and contribute to the decision-making process in E-flow assessment studies. For this case study, the "Sensitivity to Findings" tool of Netica was used to evaluate input variables. The important areas of uncertainty observed in the assessment include:

- Cause and effect risk pathways are dependent on the understanding of the relationships between flows and non-flow driver variables and ecosystem processes and functions. Knowledge of these relationships are relatively limited resulting in inherent uncertainty. The generation and testing of hypotheses to reduce uncertainty should be considered. Especially if outcomes are used to change water resource use scenarios.
- The case study addressed the socio-ecological consequence of alternative water use scenarios to the wellbeing of the ecosystem (based on endpoints) and associated availability and conditions of ecosystem services. The assessment did not address the social impacts associated with any visual and or aesthetic impacts of the developments.
- The wellbeing of the near shore marine biodiversity hotspot off the mouth of the Thukela River and the Thukela Bight has repeatedly been linked to existing reductions in flows and associated sediment transport from the Thukela River. The water resources of the lower reaches of the Thukela River are currently being managed with consideration of the marine ecosystem and or requirements of the Thukela River for these associated marine ecosystems. It is speculated that future water resource developments are being considered without thought of the connectivity of the Thukela River to regional marine ecosystems. The direct effect of existing water resource

development and possible future developments to the wellbeing of the marine ecosystems should be addressed.

- In this case study a simplified RQO method was implemented to establish endpoints for the assessment. These endpoints were established independently of catchment scale water classification processes where use and protection scenarios for Integrated Units of Analyses for the catchment will be considered. For these endpoints to be accepted by regional stakeholders as suitable objectives to achieve the balance between the use and protection of the ecosystem, the formal Water Resource Classification and RQO process for the Thukela River catchment should be undertaken.
- The effect of increased flows to the eMandeni Stream is poorly understood and this affects the risk estimates.

4.3.8 Step 8: Hypotheses establishment

The purpose of this step is to establish suitable experiments to test flow-ecosystem and flow-ecosystem service relationships so as to better understand the socio-ecological risk relationships (O'Brien *et al.*, 2018). Often, uncertainties regarding outcomes need to be eliminated or mitigated before they can be used to inform decision making and to do this assumptions must be tested (O'Brien *et al.*, 2018). In this case study, the hypothesis is related to Scenario 2 (Present) (Table 4.2); that the water resources in the study area have deteriorated due to current water use practices.

Table 4.2: Hypotheses for Scenarios 1 to 10

Scenario	Title	Hypothesis
SC1	Natural	The Thukela River in its natural state is the ideal state to be in.
SC2	Present	The present observable conditions of the Thukela and eMandeni Rivers indicates that the balance between the use and protection of the system is not being achieved.

Table 4.3 cont.: Hypotheses for Scenarios 1 to 10

Scenario	Title	Hypothesis
SC3	Present + EWR	The assurance that EWR will be achieved will improve the balance between the use and protection of the Thukela and eMandeni systems.
SC4	Alternative (Alt.) Management (Man.) Options (Opt.) I: 100% eMandeni release at Sappi	The release of existing effluent from the Sappi Tugela Mill into the eMandeni Stream directly adjacent to the Tugela Mill between sites EMAN1 and EMAN2 will improve the balance between the use and protection of the Thukela River.
SC5	Alt. Man. Opt. II: 100% eMandeni release at weir	The release of existing effluent from the Sappi Tugela Mill into the eMandeni Stream at the lower eMandeni Stream weir below site EMAN2 will improve the balance between the use and protection of the Thukela River.
SC6	Alt. Man. Opt. III: 50% reduction in flow of effluent and eMandeni release at Sappi.	An amended release of 50% of effluent volume from the Sappi Tugela Mill into the eMandeni Stream between sites EMAN1 and EMAN2 will improve the balance between the use and protection of the Thukela River.
SC7	Alt. Man. Opt. IV: 100% eMandeni release at Sappi with 50% reduction in water quality alteration potential.	An amended release scenario of existing volume (SC4) of effluent from the Sappi Tugela Mill with a 50% reduction in water quality alteration potential into the eMandeni Stream, released directly adjacent to the Tugela Mill between sites EMAN1 and EMAN2 will improve the balance between the use and protection of the Thukela River.
SC8	Alt. Man. Opt. V: 100% eMandeni release at Sappi with 75% reduction in water quality alteration potential.	An amended release scenario of existing volume (SC4) of effluent from the Sappi Tugela Mill with a 75% reduction in water quality alteration potential into the eMandeni Stream, released directly adjacent to the Tugela Mill between sites EMAN1 and EMAN2 will improve the balance between the use and protection of the Thukela River.
SC9	Alt. Man. Opt. VI: 100% eMandeni release at Sappi with 50% reduction in water quality alteration potential of Sappi and other eMandeni effluents.	An amended release scenario of existing volume (SC4) of effluent from the Sappi Tugela Mill with a 50% reduction in water quality alteration potential of Sappi and other upstream effluents on the eMandeni stream into the eMandeni Stream, released directly adjacent to the Tugela Mill between sites EMAN1 and EMAN2 will improve the balance between the use and protection of the Thukela River.
SC10	Alt. Man. Opt. VII: 100% eMandeni release at Sappi with 100% reduction in water quality alteration potential of Sappi and other eMandeni effluents.	An amended release scenario of existing volume (SC4) of effluent from the Sappi Tugela Mill with a 100% reduction in water quality alteration potential of Sappi and other upstream effluents on the eMandeni stream into the eMandeni Stream, released directly adjacent to the Tugela Mill between sites EMAN1 and EMAN2 will improve the balance between the use and protection of the Thukela River.

4.3.9 Step 9: Test hypotheses

The water quality and aquatic ecosystem of the lower reach of the Thukela River and the eMandeni Stream have been monitored since 2008 and the data was used to illustrate trends in the state of the two rivers. A field survey was also undertaken in conjunction with this assessment to provide data on the current state of the aquatic ecosystem. This information was used to test the hypothesis.

4.3.10 Step 10: Communicate outcomes

It is important that the outcomes of a PROBFLO assessment are presented to stakeholders in a clear and concise format, to evaluate the socio-ecological consequences of water resource use options and this forms the final step of the PROBFLO method (O'Brien *et al.*, 2018). This case study was undertaken on behalf of the Sappi Tugela mill, to determine the best way forward with regards to the deteriorating effluent pipeline. The results of the assessment were presented to the Simunye Forum, a local environmental committee in June 2017, to the Mandeni Municipality in November 2017 and to the Mandeni Municipality executive community retreat and EXCO meeting in January 2018, to discuss the outcomes and associated socio-ecological consequences of the study.

4.4 RESULTS AND DISCUSSION

The PROBFLO model was applied in the assessment through the;

- selection of indicators to represent the socio-ecological system being evaluated in the assessment,
- validation of the indicators for use, including characterisation of relationships between variables,

- selection of measures for the assessment focusing on hydrology and ecotoxicology statistics for future scenario analyses,
- set-up of the BNs and testing with current and historical socio-ecological system information,
- generation of input environmental variable conditions to represent the scenarios in the assessment,
- application of the scenarios to run the model and generate risk profiles for each site for high and low flow periods and for each scenario and
- integration of the social and ecological outcomes for relative comparison using a Monte-Carlo randomisation tool.

Outcomes of an initial set up and calibration analyses was undertaken considering scenarios SC1 to SC4 only where changes in hydrology were required. Thereafter the additional relative socio-ecological risk to the endpoints associated with alternative management options for water resource use by the Sappi Tugela mill were evaluated which pertained primarily to water quality modelling.

The initial assessment included a graphical summary of average relative risk to each ecological endpoint for Scenario 1 to Scenario 4 (Figure 4.9) which modelled:

- Natural (SC1),
- Present conditions (SC2),
- Present with EWR (SC3) and
- Alternative management option I. (SC4) of releasing effluent into the eMandeni Stream adjacent to the Sappi Tugela mill.

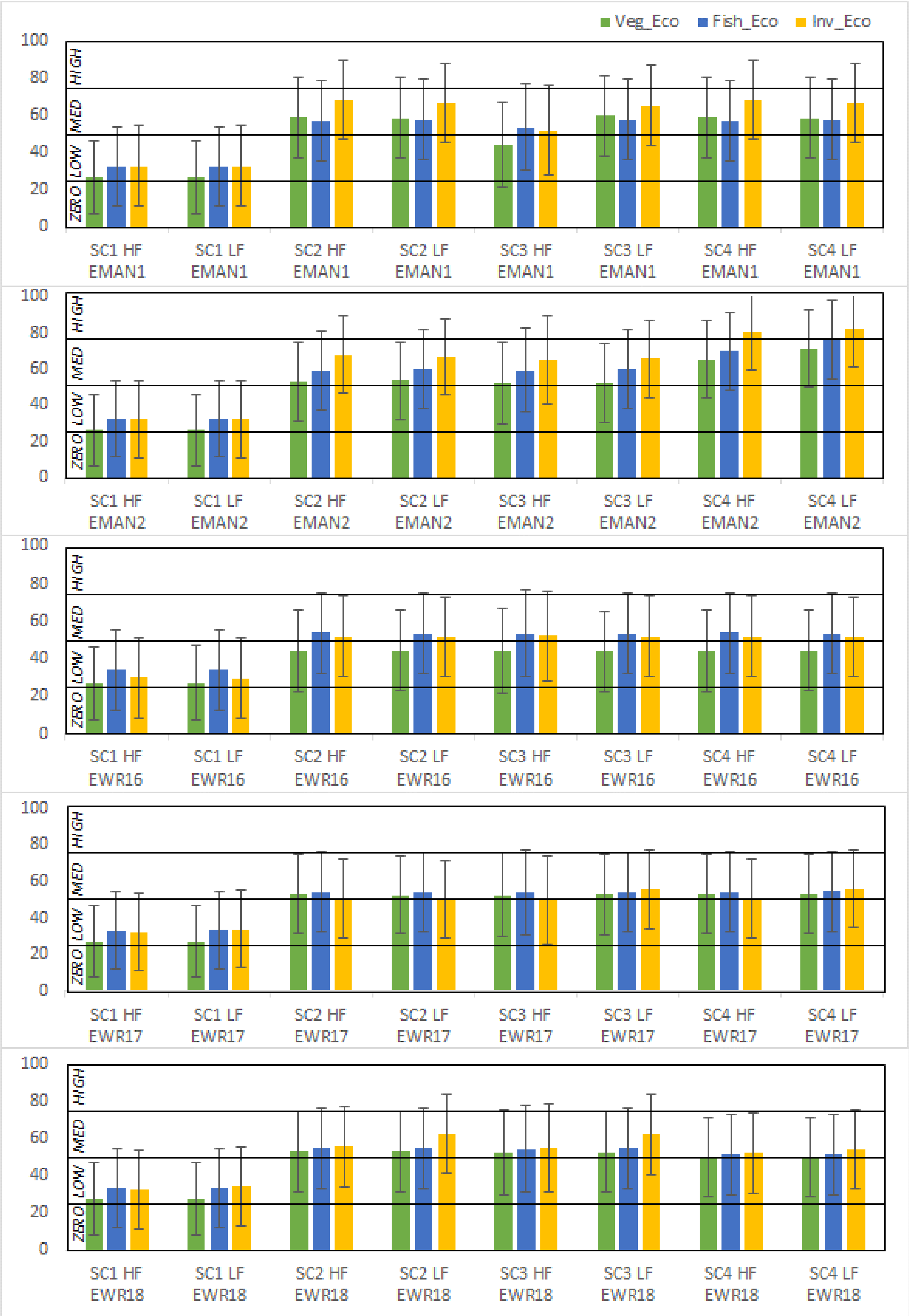

Figure 4.9: Average relative risk scores to the ecological endpoints including the vegetation, fish and macroinvertebrate components for each risk region assessed with error bars representing standard deviation

Risk to the ecological endpoints were generally comparable with a slight vulnerability observed to macroinvertebrates in the eMandeni Stream in particular at EMAN2. This could be attributed to the limited diversity and general tolerance of fish that naturally occurred in the stream. Interestingly, at EMAN1 during scenario 3 (HF) fish were relatively more vulnerable. It should be taken into consideration though, that the risk to EMAN1 during this scenario represents the EWR requirement where flow would be provided to meet the requirement of the fish at this site, but water quality issues associated with upstream Waste Water Treatment Works would still pose a risk to the wellbeing of the endpoint.

Temporal trends include an increase in risk to all endpoints at all sites associated with the scenarios during low flow conditions compared to high flow conditions. This is attributed to the natural seasonality of the rivers including a reduction in flows during low flow conditions. Interestingly, in the eMandeni Stream, when seasonality of the stream is affected through the augmentation of the stream due to WWTW releases, the temporal variability of risk is reduced. Results also include a noticeable increase in risk to the ecological endpoints from SC1 “Natural” to SC2 “Present” as expected. Although recent bio-physical monitoring of the stream demonstrates an improvement from the mid 2000’s the wellbeing of the eMandeni Stream ecosystem is significantly poorer compared with modelled natural conditions. Comparisons between sites includes a considerably greater risk to the ecological endpoints in the eMandeni Stream relative to the Thukela River. The latter can be considered to have a relatively greater resilience. The risk to the ecological endpoints during SC4 in the eMandeni Stream will increase considerably if the effluent scenario is altered and effluent is released into the stream. Although the Thukela River is relatively more tolerant/resilient to change compared with the smaller eMandeni Stream, if the effluent produced by the Sappi Tugela Mill is diverted to the eMandeni Stream, a reduction in risk to the endpoints has been modelled to occur.

The average risk associated with SC4 (diversion of Sappi effluent to the eMandeni Stream) is largely attributed to a reduction in habitat diversity and sensitivity of the macroinvertebrate community, that will indirectly be affected by the high chemical oxygen demand (COD) in the effluent. This 4 km reach between the alternative release point and the confluence with the Thukela River is hypothesised to be exposed to high risk, which will result in the biodiversity maintenance and ecosystem process part of the vision not being achieved. If this reach is considered a sacrificial zone, the benefit to the wellbeing of the Thukela River will be observable. From the model outcomes, we hypothesise that the risk of the Thukela River exceeding the moderate/high risk threshold will be reduced to zero. This will be beneficial to the Thukela River. If additional water quality treatment is incorporated to the water resource scenarios, the risk profile will change favourably as reviewed in Scenarios 6 to Scenario 10.

As expected, the risk posed to the wellbeing of the Thukela River ecosystem upstream of the confluence of the eMandeni Stream and upstream of the discharge site into the eMandeni Stream will not be affected by any alternative water resource use options. Findings of the assessment include an averaged “moderate” risk to the ecological endpoints in the Thukela River. This can be attributed to upstream water quantity and quality stressors and local threats. It should be considered that the water quality and hydrology statistics used to model the alternative water resource use options did not include the drought observed during 2015 and 2016. This is due to the hydrological period used for the current and future scenarios that ends prior to the drought. With this data, we hypothesise that the system will recover if base flows associated with the EWR are provided.

The results of the risk outcomes to the social endpoints for SC 1 to SC 4 (Figure 4.10) are highly variable. The results include a moderate to high risk in the eMandeni Stream under the natural scenario (1) to the supply of natural products and the assimilative capacity of the stream to waste. This can be attributed to the relatively small size and associated provision of services of the eMandeni Stream. With the increase in use of the stream, the risk to many of the social endpoints has increased. On occasion, some endpoints benefit from resource use. This includes the relationship between the WWTW located on the eMandeni Stream, which has augmented the stream and reduced the risk to the water abstraction endpoint of the stream. In contrast, due to the releases the risk to the assimilative capacity of the system has increases. The risk to recreation and effluent assimilation endpoints were observed to be relatively larger in the eMandeni Stream compared to the Thukela River. Increases in water resource use options will result in additional risk to the endpoint. The eMandeni Stream has naturally been a very small tributary of the Thukela River. It has not been considered for delineation through the national Present Ecological State: Ecological Importance and Sensitivity (PES:EIS) study (DWS, 2014). The change in risk to sites EWR 17 and EWR18 in the Thukela River compared with site EWR16 on the Thukela River can be attributed to local water resource use activities that increase in the lower reach of the Thukela River study area.

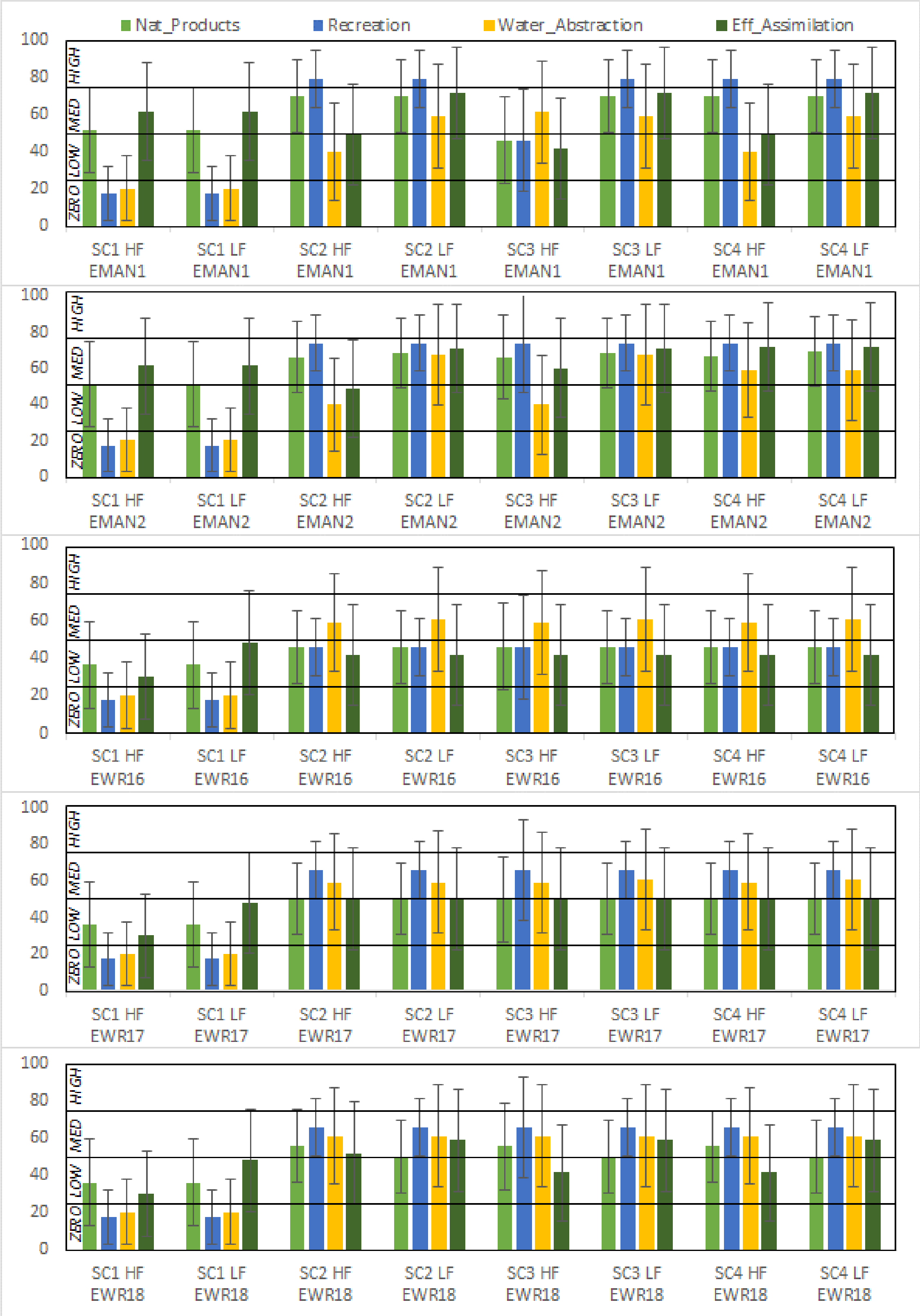

Figure 4.10: Average relative risk scores to the social endpoints including natural products, recreation, water abstraction and effluent assimilation components for each risk region assessed with error bars representing standard deviation

In Figure 4.11 the risk to the wellbeing of the ecological endpoints to the lower reach of the Thukela River during high flow (Figure 4.11A) and low flow (Figure 4.11B) for all of the scenarios 1-10 are included. Results include a slight relative increase in risk to the ecological endpoints during the low flow period, compared with the high flow or “recovery” period as expected. Scenario 5 risk results are comparable with SC2 (present state) due to the location of the sites considered in the assessment as the release point is just upstream of the confluence with the Thukela River and has been modelled as the same as the present scenario. Of importance is the reduction in risk to the wellbeing of the Thukela River at EWR18 observed for SC4 during both high and low flow conditions. In addition, the reduction in risk to the wellbeing of the Thukela River at EWR18 during low flow conditions for scenarios 6 to 10. These outcomes demonstrate the positive benefit of releasing the Sappi mill effluent into the eMandeni Stream compared to releasing the effluent into the Thukela River. Moreover, that additional treatment of the Sappi mill effluent and the combined effluent from the Sappi mill and the WWTW will contribute to the wellbeing of the system. The key determinant in these scenarios is the indirect effect of the CODs on the wellbeing of the Thukela River, which is hypothesised to reduce through assimilation of the waste in the 4km reach of the eMandeni Stream. In consideration of the cost benefit of the alternative management options, the SC7 appears to have the best results. This includes treating 50% of the water quality alteration potential of the Sappi mill effluent that includes reduction in 50% of the COD from the mill. This will result in increases in oxygen to the Thukela River, which in turn results in risk reduction to the ecological endpoints.

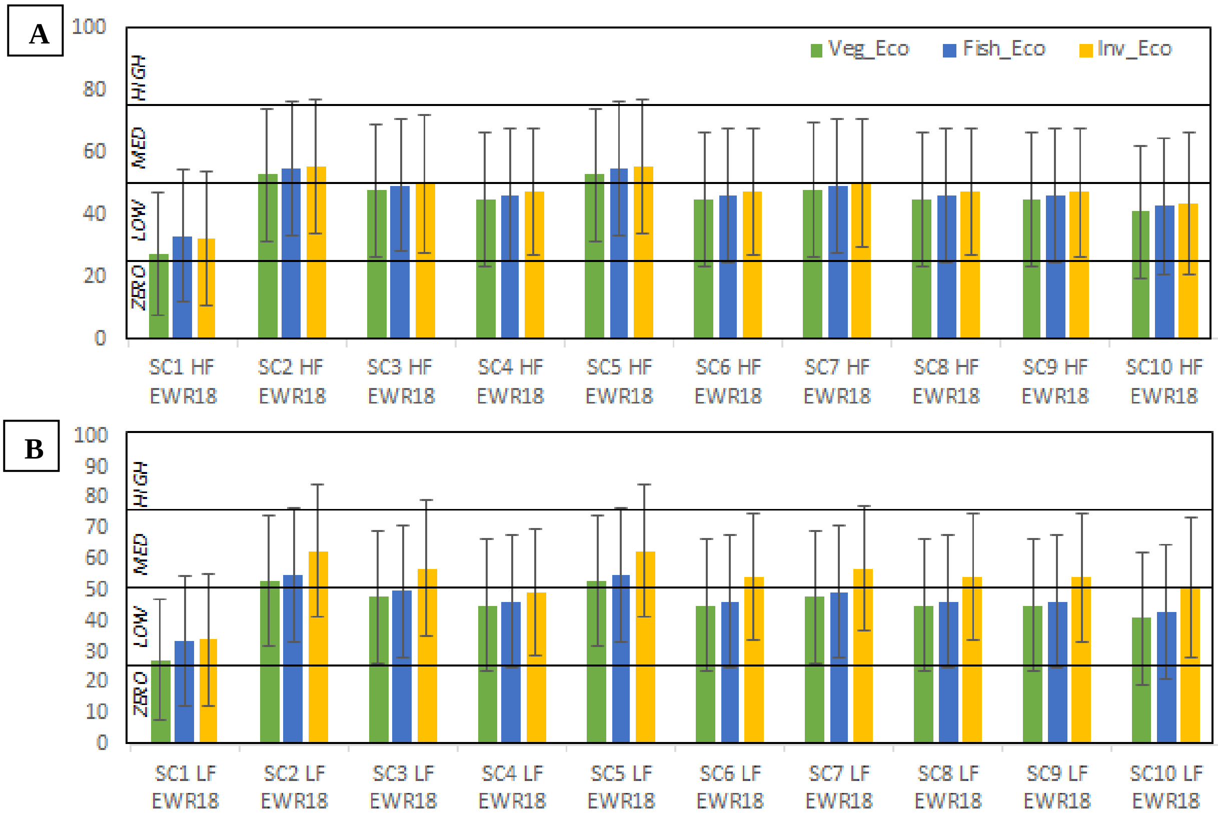

Figure 4.11: Average relative risk scores to the ecological endpoints including the vegetation, fish and macroinvertebrate components for EWR18 during the high flow (A) and low flow (B) periods with error bars representing standard deviation

In the eMandeni Stream (Figure 4.12), the effect of the Sappi mills alternative wastewater release strategy (SC4) will result in a significant increase in risk to the ecological and social endpoints of the ecosystem. Although the eMandeni Stream is relatively unimportant compared to the Thukela River in the context of the vision of the assessment and consideration of the natural state of the stream, it will be beneficial to the endpoints of the assessment if the effluent released from the Sappi mill is treated to reduce the risk to the wellbeing of the eMandeni Stream. Although the outcomes demonstrate that none of the scenarios will result in an ideal balance between the use and protection of the stream, due to the water quality and significantly increased flow into the stream, the wellbeing of the endpoint will improve considerably if all of the effluent from the Sappi mill and the WWTW is treated. Without complete treatment of the effluent, all the other mitigation scenarios are hypothesised to result in similar, comparable risk profiles to the ecological endpoints considered in the assessment. The wellbeing of the eMandeni Stream will only return to a healthy state if the effluent from the Sappi mill and the WWTW is piped into a treatment works and then released into the Thukela River at a desirable quality. The uncertainty associated with wastewater releases from the Ithala Industrial complex into the eMandeni Stream will influence this outcome. During the late 2000s the quality of the eMandeni Stream had reduced to critically modified conditions, which were partially attributed to the operations of textile factories in the Ithala industrial complex that has closed which resulted in an improvement in the quality of the river.

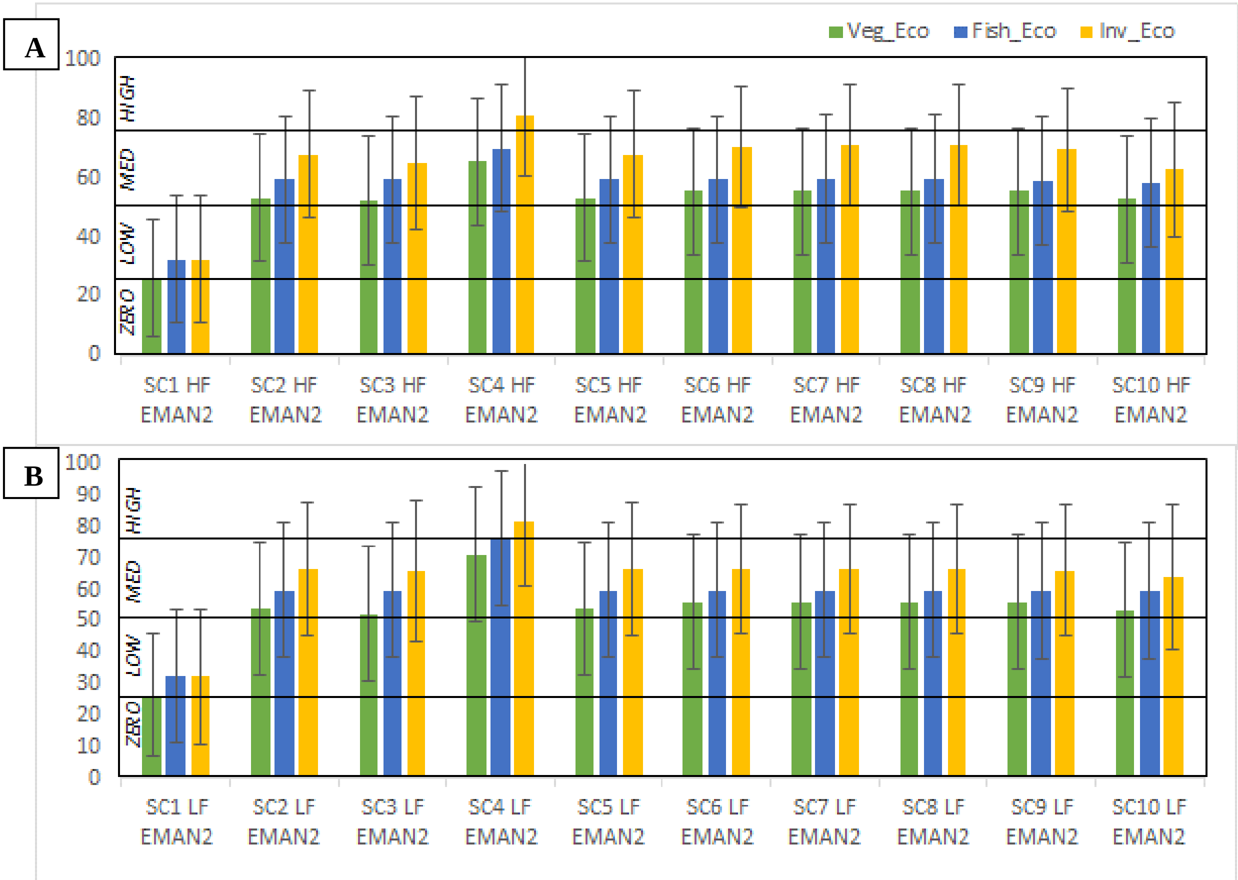

Figure 4.12: Average relative risk scores to the ecological endpoints including the vegetation, fish and macroinvertebrate components for EMAN2 during the high flow (A) and low flow (B) periods with error bars representing standard deviation

The application of the Monte Carlo permutation test with 5000 random iterations for the integration of all the ecological endpoints to the site EWR18 on the Thukela River conforms to the BN outcomes (Figure 4.14). In this randomisation assessment the probability of approximately 10% exists to the failure of the ecological endpoints for SC2 (present day) and SC5 (alternative management option II where the Sappi mill effluent will be released in to the eMandeni Stream at the weir on the lower section of the river (200m upstream of the confluence)). This can partially be attributed to the current condition of the instream habitat of the Thukela River with the synergistic effects of reduced flows and the existence of high CODs and temperatures that will affect the wellbeing of the river. The results demonstrate that the wellbeing of the Thukela River can probably be achieved by diverting the Sappi mill effluent into the eMandeni Stream alone but the value of implementing scenarios 6 and 7 will potentially result in a more sustainable state to the wellbeing of the lower reach of the Thukela River. These outcomes are based on current flows in the Thukela River from upstream of the study area. Should upstream flows be reduced the wellbeing of the lower reach of the Thukela River ecosystem will respond. This assessment did not consider the relationship between flows in the Thukela River and the wellbeing of the near shore marine biodiversity hotspot and associated Thukela Bight. These requirements are potentially greater than the flows proposed in this assessment and should be considered as a matter of urgency. If the subsequent EWR of the lower reach of the Thukela River increases, it will be beneficial to the wellbeing of the Thukela River ecosystem.

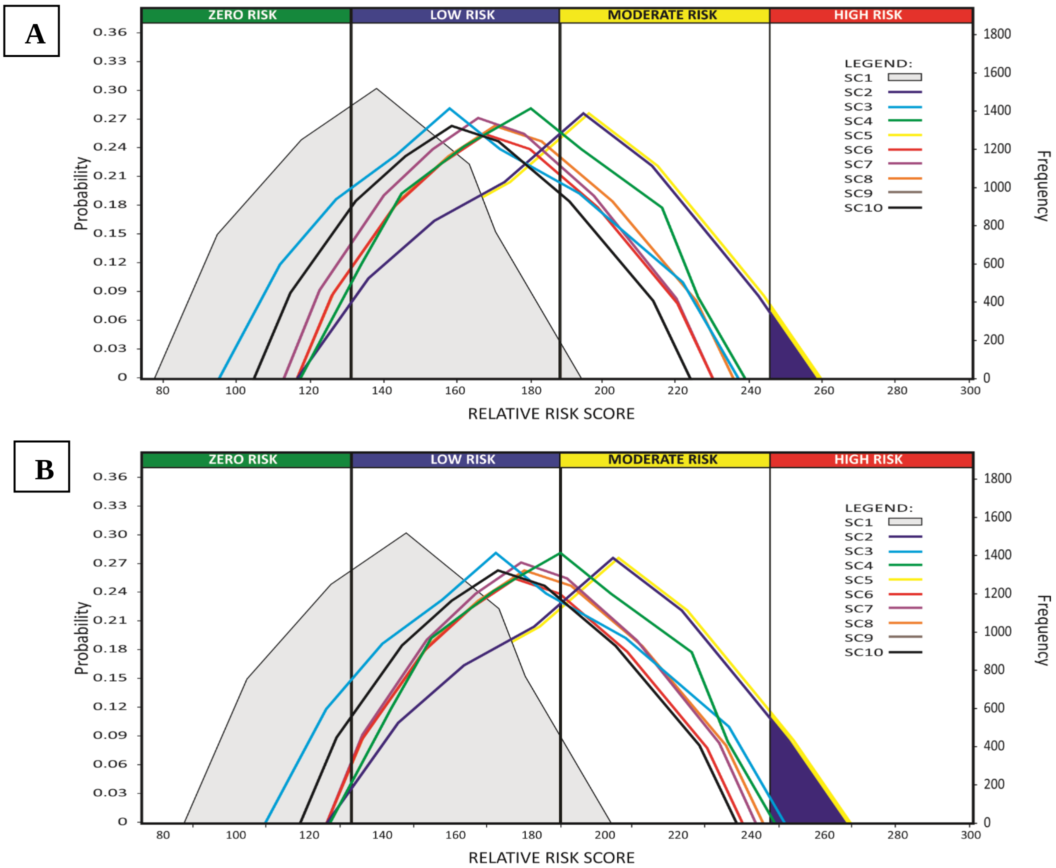

Figure 4.13: Integrated Risk projections (simulated using Crystal Ball (Oracle) – 5000 trials) to site EWR18. Risk posed to: ecological endpoints during high flow period (A) and low flow period (B). Risk rank categories: zero (blue), low (green), moderate (yellow) and high (red) superimposed. Integrated Risk projects to RR1

In Figure 4.15, the results of the integration exercise includes an increase from current 15% probability of failure to the wellbeing of the ecological endpoints that is excessive, to a 20% to 25% probability if SC 4 is implemented without any mitigation measures. Only the present and EWR (SC3) scenario and scenario 10 will result in a probable suitable balance between with the use and protection of the ecosystem endpoints. These results suggest that the desired wellbeing of the eMandeni Stream cannot be attained unless the WWTW effluent is removed from the system or if the WWTW and Sappi mill effluent is treated to achieve a 100% reduction in water quality alteration potential to the stream. Thereafter, scenarios 6, 7 and 8 were considered which all result in a likelihood of high risk of 12%, 15% and 12% respectively. A summary of the outcomes for the risk assessment for all the scenarios is provided in the APPENDIX.

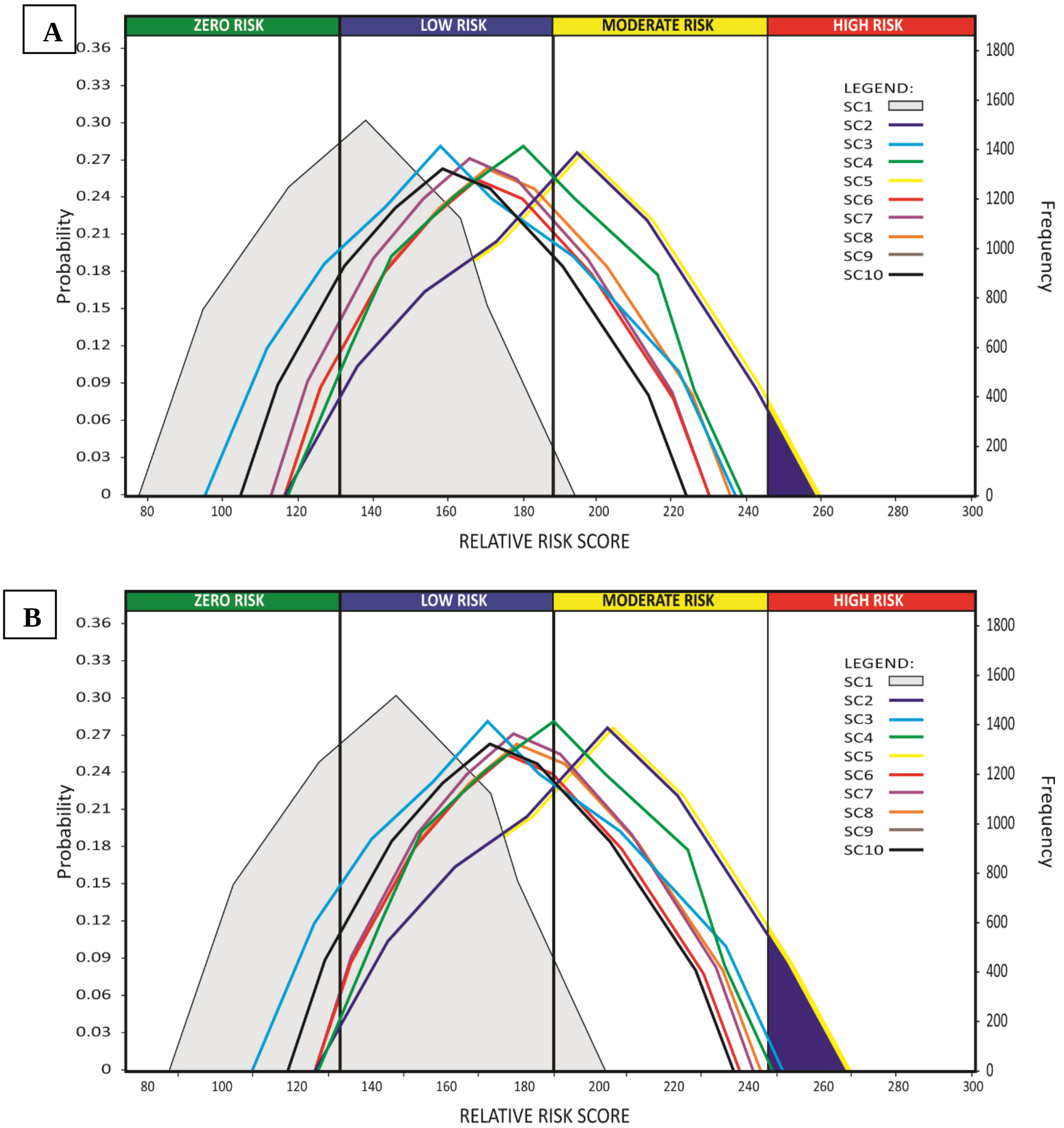

Figure 4.14: Integrated Risk projections (simulated using Crystal Ball (Oracle) – 5000 trials) to site EWR18. Risk posed to: ecological endpoints during high flow period (A) and low flow period (B). Risk rank categories: zero (blue), low (green), moderate (yellow) and high (red) superimposed. Integrated Risk projects to RR1

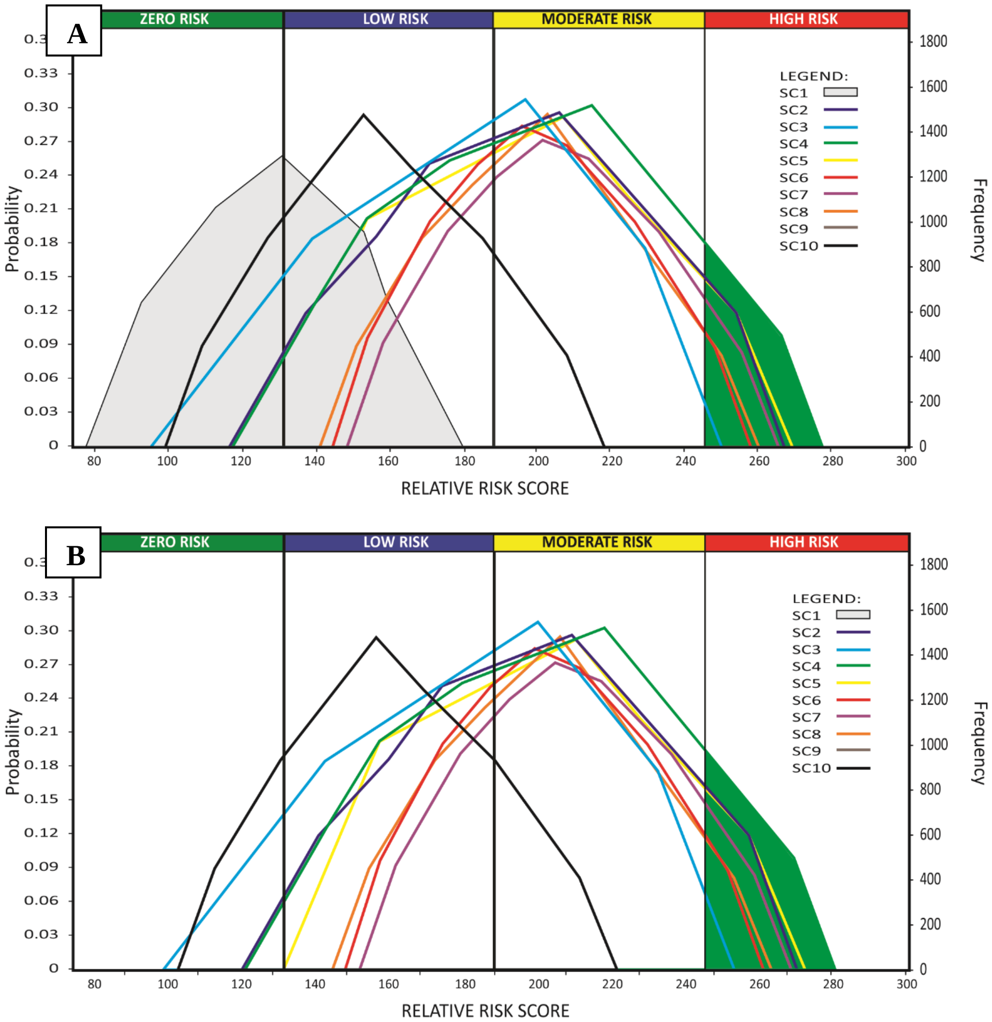

Figure 4.15: Integrated Risk projections (simulated using Crystal Ball (Oracle) – 5000 trials) to site EMAN2. Risk posed to: ecological endpoints during high flow period (A) and low flow period (B). Risk rank categories: zero (blue), low (green), moderate (yellow) and high (red) are superimposed onto the graphs to represent the probability of risk rank occurring in the assessment.

4.5 CONCLUSION

Application of the PROBFLO regional scale ecological risk assessment in the case study resulted in a range of risk projections from zero risk, ideal state dominated projections to all sites during the "natural" scenario, as expected, to increases in risk to suitable low/moderate states for the Thukela River main stem for current conditions and moderate/high risk profiles for the eMandeni Stream. These results reflect the observed change in the wellbeing of the rivers in the study area due to existing upstream stressors and local water quality, quantity and habitat stressors.

Currently the Thukela River has been affected by reduced flows, alterations in sedimentation processes and increases in water borne wastes that includes the effect of the Sappi mill effluent on the wellbeing of the lower reach of the Thukela River. The eMandeni Stream has also been altered through increased water volume and effluent being released into this small stream. The risk assessment included the consideration of the relative effect of releasing the Sappi Tugela mill effluent into the eMandeni Stream at Sappi, compared to the current situation were the effluent is released directly into the Thukela River. Results from this scenario assessment include probable benefits to the Thukela River but a considerable increase in the risk to the eMandeni Stream. This will primarily affect the habitat quality, and a deterioration in water quality that will influence the ecosystem wellbeing.

Another scenario considered the benefit of releasing partially (50%) treated effluent from the Sappi mill into the eMandeni Stream. This treatment of the effluent will reduce the COD of the effluent which will result in increases in oxygen to the Thukela River and improve the wellbeing of the lower reach of the Thukela River, and possibly the Thukela Estuary. Although the risk to the eMandeni Stream will still increase, in consideration of the cost benefit of the alternative management options, this scenario appeared to provide the best results.

To reduce uncertainty associated with the outcomes of the risk assessment it is recommend that existing monitoring programs be expanded to; (a) validate the flow-ecosystem and non-flow-ecosystem variable interactions established in this assessment, (b) validate the hypothesised ecosystem structure and function used to represent the socio-ecological system considered in this assessment and (c) verify the probable response of the socio-ecological system to change in flow and other variables if the recommendations are or are not implemented. It is projected that a better regional balance between the use and protection of the water resources in the region can be obtained if these recommendations are implemented.

4.6 APPENDIX

Table 4.4: Summary of the outcomes of the risk assessment of sources to endpoints and the rivers considered in the assessment.

Scenarios	Ecological endpoints	Social endpoints	Thukela River	eMandeni Stream
SC1: Natural	The risk assessment demonstrated that under "historical" conditions threats to the wellbeing of the ecological endpoints selected for the assessment are negligible. These results demonstrate the model has been well calibrated for the assessment.	Prior to the "modern" development of water resources in the lower reach of the Thukela River, supply of ecosystem services either exceeded demand or lack of development resulted in moderate hypothesised risk to endpoints demonstrating that they would not be achieved. These results are expected.	The wellbeing of the Thukela River represents "natural" un-impacted conditions. The ecological importance and associated resilience of the ecosystem, its biodiversity and processes would have been high.	Under natural conditions the eMandeni Stream was a very small tributary of the lower Thukela River with a small catchment. The rocky ridge on the lower reach of the Thukela River would have been periodically inundated during large floods which would have maintained connectivity of aquatic species with the main stem Thukela River. The river would have provided ideal habitats for some rare aquatic species such as the stargazer fish *Amphilius natalensis* which has been observed in the river in the 1960s.
SC2: Present	The current risk to the ecological endpoints considered in the assessment ranges between low, moderate and high-risk states. There is currently between a 12% and 18% probability of some or all of the endpoints being in a high risk or unsustainable state. These results suggest that while the overall risk to these endpoints is acceptable the probable synergistic effect of water resource use	Currently the supply of ecosystem services exceeds demand. New developments which include increased flow reductions in the Thukela River and waste water releases in the eMandeni Stream have reduced the availability and quality of services. Of concern is the potential effect of reduced flows and associated sediment transportation from the Thukela River on the near shore marine	The current wellbeing of the Thukela River is acceptable with moderate changes, and low to moderate risk to both the fish and macroinvertebrate communities of the river. The riparian vegetation appears to be in a stable relatively healthy (largely natural) state with low risk to this ecosystem component. Water quality, flow and habitat (particularly geomorphological changes) have	Following the establishment of the Waste Water Treatment Works on the eMandeni Stream the river has been considerably augmented. This increase in the size of the stream has resulted in changes in instream and riparian habitats. Current water quality conditions and associated habitat changes have resulted in considerable (large) changes to the wellbeing of the eMandeni Stream ecosystem.

Scenarios	Ecological endpoints	Social endpoints	Thukela River	eMandeni Stream
	including water abstraction and quality changes with the effect of the drought may result in long term or permanent effects to the wellbeing of the ecosystem.	biodiversity hotspot and the larger Thukela Bight. Observed, published impacts on these marine ecosystems may be associated with long term (many years) flow patterns with reduced large floods rather than water abstraction.	been observed in the Thukela River. These changes and the synergistic effect of the drought result in moderate risk to the ecosystem of the river.	The current moderate to high (17% probability) risk of the ecological endpoints of this stream not being achieved is an improvement from recent (2008 to 2012) conditions of the ecosystem.
SC3: Present + EWR	Implementation of the E-flows established in the assessment are considered to result in a slight reduction in the risk to the ecological endpoints of the assessment, particularly in the eMandeni Stream. In the Thukela River in particular the revised E-flows should result in a reduction to the stressed state of ecosystem components during low flows and especially during drought flows.	The reduced risk to the ecological endpoints of the assessment will result in an associated increase in the resilience of the ecosystem services and a slight reduction in risk to the social endpoints in the Thukela River. No change in the wellbeing of the social endpoints to the eMandeni Stream which is already augmented would be observed if the E-flows were implemented. This demonstrates that the drivers of impairment of the eMandeni Stream is primarily quality driven and not quantity.	The wellbeing of the Thukela River is expected to increase with a reduction in risk to the fish, macroinvertebrates and riparian vegetation as well as the positive impact of an improved sediment condition of the river.	Implementation of the EWR in the eMandeni Stream will not result in any improvement to the wellbeing of the ecosystem of the stream. This is primarily due to the existing augmentation of the stream which exceeds the Ecological Reserve requirements of the stream.

Scenarios	Ecological endpoints	Social endpoints	Thukela River	eMandeni Stream
SC4: Alternative (Alt.) Management (Man.) Options (Opt.) I: 100% eMandeni release at Sappi mill	This scenario will result in a slight reduction in risk to the wellbeing of the ecological endpoints of the Thukela River. The modelled improvement in water quality into the Thukela River at EWR18 below the confluence with the eMandeni Stream is linked to the existing assimilative capacity of the eMandeni Stream. Relative to the Thukela River, the ecological endpoints of the much smaller eMandeni Stream will respond negatively to the release of the effluent being released in the stream. This will increase the probability (from 17% to 23% high risk).	The social endpoints associated with the Thukela River are considered to remain relatively consistent with a slight reduction in risk to the assimilative capacity of the river. The risk to the social endpoints in the eMandeni Stream are predicted to increase resulting in a higher probability of failure of the endpoints.	With a reduction of effluent being discharged directly into the Thukela River, and additional opportunity for water quality improvements associated with the assimilative capacity of the eMandeni Stream. With an increase in dependence on the water resources of the Thukela River upstream of the study area, this reduction in stress directly into the Thukela River at EWR 18 would result in increased resilience of the Thukela River itself.	In this scenario the increase in stress to the eMandeni Stream will result in a considerable increase in risk to the social and ecological endpoints of the stream. With this scenario the increase in high risk probability to the ecological endpoints at EMAN2 in particular will increase by 8% with a massive shift of the highest point of probability towards the high-risk range.
SC5: Alt. Man. Opt. II: 100% eMandeni release at weir	This scenario involves the relocation of the Sappi mill effluent release point into the eMandeni Stream at the weir on the lower part of the river just upstream of the Thukela River. Due to the close proximity of this scenario to the existing release point into the Thukela River (± 1km) very little impact on the wellbeing of the ecological endpoints of the Thukela River	No change to the risk to the social endpoints has been established with this scenario due to the proximity of the release point to the current release site.	The only ecological component of concern includes the potential use of the lower eMandeni Stream by fish in the Thukela River as a refuge area during freshet and flood events.	The wellbeing of the lower eMandeni Stream will deteriorate with this scenario, but the risk to the wellbeing of the system has not been quantified in this assessment as the location of the effluent release point is too close to the Thukela River and the current release point.

Scenarios	Ecological endpoints	Social endpoints	Thukela River	eMandeni Stream
	will be observed compared to present conditions (SC1).			
SC6: Alt. Man. Opt. III: 50% reduction in flow of effluent and eMandeni release at Sappi mill.	Similarly to SC4, this scenario will result in a slight reduction in risk to the wellbeing of the ecological endpoints of the Thukela River. Relative to the Thukela River, the ecological endpoints of the much smaller eMandeni Stream will respond negatively to the release of the effluent being released in the stream. The risk to the ecological endpoints in the stream will however increase slightly from a 17% probability of high risk to 19%. This represents a considerable improvement in risk in the stream compared with SC4.	The social endpoints associated with the Thukela River are considered to remain relatively consistent with a slight reduction in risk to the assimilative capacity of the river. The risk to the social endpoints in the eMandeni Stream are predicted to increase slightly compared with present SC2 resulting in a higher probability of failure of the endpoints. This will however be lower than the risk proposed for SC4.	Similarly to SC4, with a reduction of effluent being discharged directly into the Thukela River, and additional opportunity for water quality improvements associated with the assimilative capacity of the eMandeni Stream, the stress to the Thukela River at EWR 18 would be reduced resulting in increased resilience of the Thukela River itself and reduced risk to the wellbeing of the river. This scenario represents the best cost benefit gain for effluent management and associated stress to the wellbeing of the Thukela River.	In this scenario the increase in stress to the eMandeni Stream will result in a moderate increase in risk to the wellbeing of the stream. Risk to the high rank will increase by 5% with a moderate shift of the highest point of probability towards the high-risk range. Although the risk to the social and ecological endpoints at EMAN2 are relatively greater for this scenario compared to SC2, the benefit to the Thukela River which has a relatively higher ecological importance potentially out weights the increased stress to the wellbeing of the eMandeni Stream. With this 50% reduction in effluent into the stream from the Sappi mill and some additional mitigation to water quality from upstream users such as the Sundunbili WWTW a suitable

Scenarios	Ecological endpoints	Social endpoints	Thukela River	eMandeni Stream
				balance between the use and protection of the eMandeni Stream can be achieved with overall benefits to the Thukela River.
SC7: Alt. Man. Opt. IV: 100% eMandeni release at Sappi mill with 50% reduction in water quality alteration potential. **SC8: Alt. Man. Opt. V: 100% eMandeni release at Sappi mill with 75% reduction in water quality alteration potential.**	Ecotoxicology results from the assessment demonstrate that the water quality alteration potential of the Sappi mill effluent is limited to chemical oxygen Demand (COD) which has not been evaluated in the assessment as the effluent samples have to be aerated before testing. These outcomes demonstrate that only a very little improvement in the wellbeing of the Thukela River will be observed by further reductions in water quality alteration potential of the Sappi mill effluent above 50%. As a result, the risk to the ecological	This scenario will result in a slight reduction in risk to the wellbeing of the ecological endpoints of the Thukela River. Relative to the Thukela River, the ecological endpoints of the much smaller eMandeni Stream will respond negatively to the release of the effluent being released in the stream. The risk will however to the ecological endpoints in the stream will increase slightly from a 17% probability of high risk to 19%. This represents a considerable improvement in risk in the stream compared with SC4.	These scenarios will result in a slight reduction in risk to the wellbeing of the ecological endpoints of the Thukela River. Relative to the Thukela River, the ecological endpoints of the much smaller eMandeni Stream will respond to the increased dilution potential and or reduction in water quality alteration potential of the water.	These scenario will result in a considerable reduction in risk to the wellbeing of the ecological endpoints of the eMandeni Stream. Relative to the Thukela River, the ecological endpoints of the much smaller eMandeni Stream will respond with either a dilution of existing toxicants or reduction in their loading. Risk to the wellbeing of the social and ecological endpoints of the eMandeni Stream will decrease to a low to moderate risk profile. Although these scenarios would represent ideal mitigation measures for the

Scenarios	Ecological endpoints	Social endpoints	Thukela River	eMandeni Stream
	endpoints for these scenarios will be comparable with SC6.			eMandeni Stream the cost of water quality treatment would potentially be very high.
SC9: Alt. Man. Opt. VI: 100% eMandeni release at Sappi mill with 50% reduction in water quality alteration potential of Sappi mill and other eMandeni effluents. **SC10: Alt. Man. Opt. VII: 100% eMandeni release at Sappi mill with 100% reduction in water quality alteration potential of Sappi mill and other eMandeni effluents.**	With these scenarios that consider a considerable reduction in overall water quality alteration potential of the eMandeni Stream, a considerable reduction in risk to the ecological endpoints of the eMandeni Stream will be achieved. This will result in some benefits to the ecological endpoints of the much larger Thukela River. With a considerable improvement in the wellbeing of the eMandeni Stream, the potential for species and processes from the Thukela River to be re-connected with the eMandeni tributary which will benefit the ecological endpoints of the region.	For this scenario the risk to the social endpoints excluding the "maintain effluent assimilative capacity of the environment" will reduce. The risk to this endpoint will increase as the opportunity for water users to utilise the assimilative capacity of the river will decrease with the requirement for users to treat their effluent. The overall benefit to the social endpoints will however be considerable. The cost of the water quality treatment will however also be considerable.		

CHAPTER 5

5 CONCLUSION

The main aim of the chapter is to emphasize the importance of the Thukela River catchment and provide considerations for the sustainable management of the lower reach of the Thukela River to negate the impacts on the Thukela Estuary and the marine environment.

The Thukela River catchment has proven over the years to be an important water resource for the people of South Africa and its growing economy, through the various ecosystem services it provides. Not only is the water used to develop various economic sectors and social needs within the catchment but also provides water to other parts of the country to meet national growing needs. Communities within the catchment rely on the water resources for consumption, sanitation, a source of food and irrigation for subsistence farming. Unfortunately, the observed increase in the use of the water resources has resulted in negative impacts to the wellbeing of regional aquatic ecosystems. The aquatic ecosystem in many of the rivers' reaches within the catchment are ecologically important and sensitive providing unique ecosystems that offer habitats for a high diversity of fauna and flora, with various areas categorised as fish support and sanctuary areas in particular. The ecological state of the Thukela River in 2003 - 2004 varied from a Largely Natural to a Largely Modified state and impacts to the water resources have been attributed to, among others, dormant mines, effluent from industries, failure of municipal services, water transfer schemes, abstraction for irrigation and overgrazing of livestock. An important impact to consider is the estimated 27% reduction in flow throughout the system (Van Niekerk and Turpie, 2012), as this does not just impact on the riverine fish life but has a significant impact on the Thukela Bank and the biology of the KZN Bight. The lower reach of the Thukela River is therefore important as it is the link between the riverine and receiving marine environment, but this reach is under stress due to the Umgemi

Water Bulk Transfer Scheme (UBTS), the effluent from the Sappi paper and pulp mill that is discharged into the Thukela River as well as polluted water from eMandeni Stream.

The results of an ecological state assessment of the lower reach of the Thukela River and eMandeni Stream indicates that the water quality of the eMandeni Stream is being greatly impacted by stressors like the upstream Isithebe Industrial complex, the waste water treatment works and the landfill site. The overall ecological integrity of the sites on the eMandeni Stream has fluctuated between 2010 and 2018 from a fair to seriously/critically modified state. The overall ecological integrity of the Thukela River has remained more stable over this time period with all the sites remaining in either a poor or fair state but these results were generally lower than the results of the 2003-2004 Reserve study, and mostly did not attain the high C (fair state) recommended ecological reserve category set for this reach of the river (DWAF 2004c). The biomonitoring results for the site below the Sappi discharge point and the confluence with the eMandeni Stream, indicated that although the overall integrity of the site has remained stable, differences in the water quality and biological response components of the site versus the upstream reference site do suggest that the downstream aquatic ecology of the Thukela River is probably being impacted upon by the eMandeni Stream and the Sappi mill effluent. The full impact of these stressors is being mitigated by the size and dilution capacity of the Thukela River but during low flows or times of drought, the Thukela River will be more sensitive to these stressors. The completion of the UBTS in 2016 and other water requirements upstream in the catchment will impact on the flow regime of the lower reach of the Thukela River that could have long term effects on the ecological integrity of the riverine and associated marine environments. These results support the hypothesis that there is a decreasing trend in the ecological state of the lower reach of the Thukela River due to the increased use of water resources in the catchment.

The regional scale ecological risk assessment provided alternative scenarios that can be considered by managers to achieve a better, sustainable balance between the use and protection of the water resources in the region and mitigate impact of the Sappi mill effluent on the socio-ecologically important Thukela River. The risk assessment included the consideration of the relative effect, from current conditions, of releasing the Sappi mill effluent into the eMandeni Stream. Results from this scenario assessment include probable benefits to the Thukela River that will receive partially treated wastewater of an improved quality from the eMandeni Stream, compared to effluent that is currently being discharged directly into the Thukela River. This scenario will negatively impact on the habitat and water quality of the eMandeni Stream and will impact the overall wellbeing of the ecosystem but will have positive benefits on the lower reach of the Thukela River, and possibly the Thukela Estuary supporting the hypotheses that the Sappi Thukela mill is having a negative impact on the lower reach of the Thukela River but through the implementation of mitigation measures, a better balance between the use and protection of the system can be achieved.

Possible impacts to the Thukela Estuary and the offshore Thukela Bank need to be taken into consideration when any management decisions are made with regards to the Thukela River as the organic matter and nutrients from the Thukela River form the Thukela Bank and largely maintains the biology of the KZN Bight. South African legislation requires that an ecological reserve be set to ensure that sufficient freshwater flows are available to sustain aquatic ecosystems and therefore the freshwater requirements of the marine environment should also be taken into consideration. This offshore area is not just important from a biological point of view but also a socio-economic one as it supports subsistence, commercial and recreational fishing.

To sustainably maintain a suitable balance between the use and protection of the Thukela River and estuary, it is recommended that the results of the risk assessment (Chapter 4) be validated and an updated Ecological Reserve study should be completed for the Thukela River, taking into consideration the freshwater requirements of the marine environment. Resource Quality Objective should also be established to enable decision makers to make informed decisions on the management of the Thukela system. The functionality of the UBTS fishways should be investigated as well as the impacts of the weir as a barrier for fish migration

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