A preliminary assessment linking altered catchment land-cover to the health of four temporarily open/closed South African estuaries

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DEPARTMENT OF GEOGRAPHY

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ABSTRACT

Estuaries worldwide are being subjected to various degrees of catchment degradation, which is having severe consequences on the integrity of these aquatic ecosystems and their ability to function properly. This thesis investigated the relationship between catchment land-cover and estuarine health in four temporarily open/closed estuarine systems (TOCEs) in South Africa, namely the Groot Brak, East Kleinemonde, Mdloti and Tongati. GIS techniques were employed to delineate catchments, lower sections of catchments, 1 km and 100 m buffer zones, and to quantify the extent of land-cover classes present within these delineations. Anthropogenic activities outlined by the Department of Water Affairs and Forestry (DWAF) Resource Directed Measures (RDM) studies and their associated land-cover classes were described. The possible links between catchment and buffer zone land-cover class composition and health of the estuaries were explored. Results indicated that there was a relationship between catchment and estuarine health within the Coastal Protection Zone (CPZ) (1 km and 100 m) buffers, but not at a broader catchment level. Out of natural, urban built-up and cultivation land-cover classes, natural land was determined to be the best predictor of estuarine health within the CPZs. A method of rapidly assessing South African TOCE condition was applied and could be used to prioritise these estuaries for rehabilitation and/or conservation.

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ACRONYMS

CD:NGI	Chief Directorate: National Geo-spatial Information
CPZ	Coastal Protection Zone
CSIR	Council for Scientific and Industrial Research
DEM	Digital Elevation Model
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EHI	Estuarine Health Index
EIS	Estuarine Importance Score
ERC	Ecological Reserve Category
ESRI	Environmental Sciences Research Institute
GIS	Geographic Information System
ICMA	Integrated Coastal Management Act
LULC	Land-use/Land-cover
MAR	Mean Annual Runoff
MASL	Meters above sea level
NBA	National Biodiversity Assessment
NLC	National Land-Cover Database Project
NWP	National Water Policy
PES	Present Ecological Status
RDM	Resource Directed Measures
SAIAB	South African Institute for Aquatic Biodiversity
SANBI	South African National Biodiversity Institute

TOCE	Temporarily open/closed estuary
WISA	Water Institute of Southern Africa
WWTWs	Waste Water Treatment Works

CHAPTER 1: GENERAL INTRODUCTION

Globally estuaries are regarded as important ecosystems and as an important component of the environment that contributes significantly to social and economic systems (Hay *et al*., 2010: 6). Estuaries are ranked highly in terms of their productivity as ecosystems and their ability to supply goods and services (van Niekerk and Turpie, 2012: 9), and are important in terms of human welfare as they offer a diversity of goods, services and attributes (DWA, 2010: 23). The services that estuaries provide include "nursery functions, freshwater flows to the marine environment, carbon sequestration, flood regulation, storm protection, safe bathing areas, and estuarine plants as food, fuel and building resources" (van Niekerk and Turpie, 2012: 10). Management of these ecosystems is difficult due to the sheer complexity of the systems and the multiplicity of factors that can influence the overall health status of each system. The inherent management issues combined with increasing global populations inhabiting estuary peripheries and catchments has led to decreased estuarine health, decreased water quality and altered ecosystem service delivery of these ecosystems (Wolanski, 2007: 11).

"The South African Constitution calls for the prevention of pollution and ecological degradation, promotion of conservation, and the securing of ecologically sustainable development and use of natural resources" (Dickens *et al*., 2003: 3). Natural resources include water resources, but it is questionable as to how well or how much attention is given to estuaries and their associated catchments. In South Africa more than half of the population resides within 100 km of the coast (Harrison *et al*., 2000: 61). This has resulted in increased anthropogenic activities such as domestic settlements (urban encroachment), industrial development, farming, water abstractions as well as river impoundments occurring within river catchments and in some cases the peripheries of estuaries (Allanson and Baird, 1999: 292). This has resulted in indications of modification, degradation and even destruction of South African estuaries. One of the biggest threats to the health of estuaries is their dependency on natural seasonal variations in clean freshwater inflows, which some anthropogenic catchment activities do affect (Whitfield and Cowley, 2010: 1). Another impending threat is that of global climate change affecting rainfall variability over a country which is already water scarce.

As human populations increase, so do their demands for freshwater. This will lead to increased future competition with estuaries for the resource. Increased urban development within estuary surrounds and river catchments could also potentially decrease the availability and quality of much needed freshwater, nutrients and sediments reaching estuaries. Constant monitoring of land-use activities within river catchments and estuary surrounds is therefore necessary to achieve the objectives outlined in the South African Constitution as well as sustaining estuarine integrity at present and for future generations. Monitoring and assessment of catchments has been conducted at various scales, but one effective methodology for this type of assessment is through the use of Geographical Information Systems (GIS).

1.1 South African Estuaries

1.1.1 Definition

The South African coastline is well endowed with river systems that have been classified as estuaries. According to Harrison *et al*. (1996: 3) the most commonly used definition for an estuary is a "partially enclosed coastal body of water which is either permanently or periodically open to the sea and within which there is a measurable variation of salinity due to the mixture of sea-water and freshwater derived from land drainage".

1.1.2 Description

Estuaries are one of the smaller constituents of the coastal zone, and yet they contribute substantially to the ecology, economics and cultures of the coast (Harrison *et al*., 2000; 1). The characteristics of estuaries within South Africa are described by Allanson and Baird (1999), Harrison *et al*. (2000), Perissinotto *et al*. (2004), Turpie (2004), Wolanski (2007), Hay (2010), Hosking (2010) and van Niekerk and Turpie (2012).

Harrison *et al*. (2000: 1) describe estuaries as bodies of water which "form an interface between the terrestrial drainage system and the sea and are thus susceptible to changes far inland in the coastal hinterland". Estuaries are also susceptible to impacts from their surrounds as well as conditions at sea (Allanson and Baird, 1999: 289). Due to the locality of estuaries they are subject to many different influences that may affect their functional capabilities as well as their rated importance and current state. These influences will be discussed later in this chapter.

1.1.3 Types of estuaries

The authors Harrison *et al*. (1996, 1997) and the DWA (2010) agree that estuaries need to be classified according to their climatic and geomorphological variation in order to be placed within the Estuarine Health Index (EHI) which will be discussed later in this chapter. The importance of classification arises when trying to analyse a specific estuary as the hydrological and geomorphological characteristics play a role in determining the resulting environment. No two environments are identical and therefore systems that share similar characteristics should be grouped together for comparative reasons. This is emphasised by Harrison *et al*. (1996: 3): "Without classification one cannot hope to remember or manipulate the individuals or see relationships between them". Classification of estuaries also helps in research when identification of similar estuaries is necessary for comparative purposes (Harrison *et al*., 1997: 3).

One classification elaborated on by Allanson and Baird (1999: 30) and Turpie (2004: 3) is the grouping of estuaries by biogeographic regions. These regions originate from local influences of the sea, seasonal rainfall, wave and wind disturbance, icthyofaunal diversity and nutrient availability from the ocean (Allanson and Baird; 1999: 30). The South African coast is divided into three biogeographic zones: cool temperate, warm temperate and subtropical (Figure 1.1). The cool temperate zone extends from the Orange River on the west coast to Cape Agulhas and the warm temperate from Cape Agulhas to the Mbashe Estuary on the east coast. The sub-tropical zone extends from the Mbashe Estuary to Kosi Bay on the north-eastern edge of the coastline.

Further classification is needed to differentiate between individual systems within biogeographic zones. A classification system based on physical features of estuaries has also been created for South African systems (Whitfield, 1992). Papers that use this classification system include: Harrison *et al*. (1996, 1997, 2000), Allanson and Baird (1999), Turpie (2004), DWA (2010) and Whitfield and Cowley (2010).

South Africa has a coastline approximately 3000 km long, with approximately 370 outlets to the sea of which 250 have been classified into five major estuarine categories (Whitfield and Cowley, 2010). Estuary categories include estuarine lakes, estuarine bays, permanently open estuaries, temporarily open/closed estuaries (TOCEs) and river mouths. Further details on specific estuary types can be found in the paper by Whitfield (1992), this study will only focus on TOCEs.

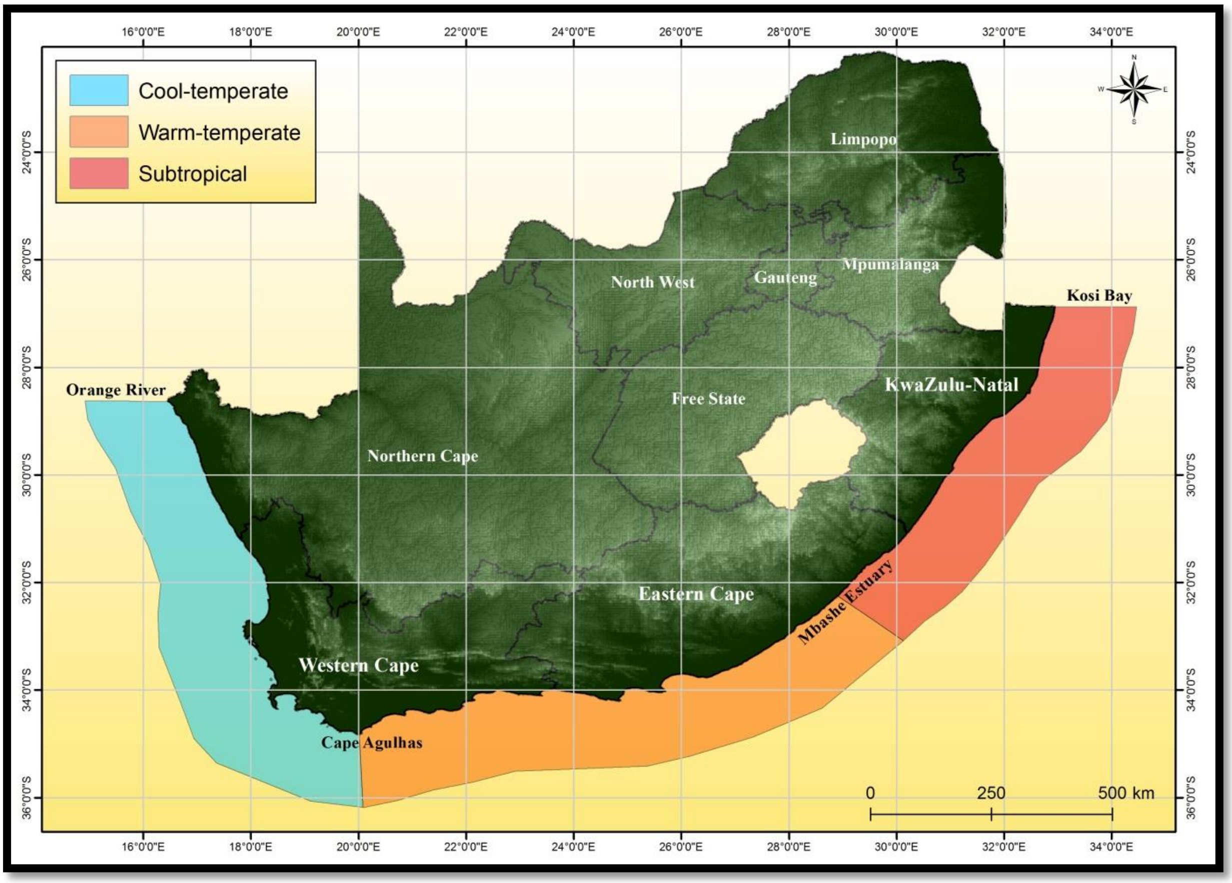

Figure 1.1: Different estuarine biogeographic zones of South Africa.

1.1.4 Temporarily open/closed estuaries

Research on TOCEs according to Whitfield and Cowley (2010) only became prominent in the 1980s and 1990s. Since then the understanding of these systems has grown significantly and this has enabled detailed analyses of this estuary type (Whitfield and Cowley, 2010). Relevant publications concerning the characteristics and functioning of TOCEs have been conducted by Harrison *et al*. (2000), Perissinotto *et al*. (2004), Turpie (2004), van Niekerk *et al*. (2008) and Whitfield and Cowley (2010).

TOCEs are the most common type of estuary found along the South African coastline, amounting to 75% of the total estuary numbers (DWA, 2010: 17). Their distribution is however not uniform. Whitfield and Cowley (2010) give TOCE counts in the cool temperate, warm temperate and sub-tropical of 11, 80 and 94 respectively. Another general characteristic of TOCEs highlighted by van Niekerk *et al*. (2008) is that the average size of these systems decreases from the west to the east of the country.

According to Whitfield (1992: 96) TOCEs are characterised by:

- Sand bars that form across the estuary mouth blocking connection with the sea for varying periods of time due to low river flow conditions and longshore sand movements;
- Small catchments no bigger than 500 km^2;
- Minimal or no river flow for long periods;
- A small tidal prism ($<1 \times 10^6$) during open mouth conditions and which is absent during mouth closure;
- Sediment which is lost during mouth breaches, but subsequent infilling from fluvial and marine sediment is usually rapid;
- A direct relationship between catchment runoff and mouth state.

Perissinotto *et al*. (2004; 1) adds that the mouth condition of TOCEs is primarily responsible for the ecology of the ecosystem. Mouth dynamics of these estuaries are highly dependent on the inflow of freshwater from the catchments which causes estuary mouths to be closed during dry periods and open during the rainy season and/or through the event of a flood (Perissinotto *et al.*, 2004: 1). Due to variations in mouth condition of TOCEs, they exhibit fluctuating physico-chemical dynamics that make their study highly complicated. Understanding the physical characteristics and ecological functioning needs of these systems is therefore of importance and studies concerning TOCEs recognise this fact and regularly contribute to national estuarine information. Some studies include: DWA (2010), Perissinotto *et al*. (2004), van Niekerk *et al.* (2008), Whitfield (1992) and Whitfield and Cowley (2010).

As TOCEs normally remain closed to the sea, they often become hypersaline during periods of drought (DWA, 2010: 17). During periods of mouth closure these systems can achieve high water residual times which can lead to a build-up of contaminants originating from the river catchment. Marine, estuarine and freshwater life in these systems is directly dependant on mouth state. TOCEs have also been found to be a key nursery site for many fish species (Perissinotto *et al*., 2004; 2).

South Africa has laws and policies in place for the protection of estuarine ecosystems along the coast. In theory these laws and policies are sound, but many estuarine systems are still being subjected to degradation (Turpie, 2004; 9). Perissinotto *et al*. (2004; 1) states that TOCEs are key ecosystems, but they are highly threatened and dealing with the threats to the integrity and ecological functioning of these systems is inherent in their management. Turpie (2004; 12) lists two factors that threaten the ecological functioning and integrity of TOCEs: firstly, activities that occur within and on the ecosystems surrounds and secondly, activities that reduce the supply of freshwater inputs. Another important factor is activities that reside within a river catchment that threaten TOCEs (Perissinotto *et al*., 2004: 2). Catchment activities are often touched on by studies conducted on estuaries but it does not receive a lot of attention, studies are typically conducted on either the river catchment or the estuary at the outlet of the river. In order to assess the true condition of an ecosystem, all parts need to be analysed in a holistic manner (i.e. both the estuary and the catchment simultaneously).

1.1.5 Estuarine functional zone

The estuarine functional zone is a delineation “encapsulating not only the estuary water body but also supporting physical and biological processes and habitats necessary for the estuarine function and health” (van Niekerk and Turpie, 2012: 28). For all classified estuaries along the South African coast, estuarine functional zones were delineated using the 5 m topographical contours (van Niekerk and Turpie, 2012: 31). All areas which fall within the estuarine functional zone are classified as sensitive areas and permission is required for developments within this area (van Niekerk and Turpie, 2012: 28). This regulation has been put in place to hinder undesirable future developments within this zone and preserve the integrity of estuaries.

1.1.6 Key pressures on estuaries

The National Biodiversity Assessment of 2011 (NBA) edited by van Niekerk and Turpie (2012: 66) outline the key threats to estuarine health and biodiversity as comprising of flow modification, pollution, exploitation of living resources, habitat destruction within the estuarine functional zone and climate change.

According to van Niekerk and Turpie (2012: 66) flow modification refers to “both increases and decreases in freshwater inputs to an estuary”. Increased freshwater inputs result from water transfer schemes, outflows from Waste Water Treatment Works (WWTWs) and surface hardening within catchments. Decreases in freshwater inputs result from abstractions within the catchment and dam and reservoir development. The functional capabilities of estuaries rely on unrestrained access to both marine and freshwater inputs (Hosking, 2010: 1). According to Hay *et al*. (2010), Hosking (2010), Perissinotto *et al*. (2004), van Niekerk *et al*

(2008) and Whitfield and Cowley (2010) estuaries around the coast are being subjected to various degrees of hindered freshwater and marine inputs, decreasing the functional ability of numerous estuarine systems in South Africa.

Pollution entering estuarine systems can be attributed to agricultural runoff, WWTWs, industrial waste water, municipal waste water and sediments (van Niekerk and Turpie, 2012: 66). Agricultural runoff entering estuarine systems contaminate the ecosystems by introducing harmful toxins (herbicides and pesticides), providing excessive nutrients and sediments resulting from soil erosion (Niekerk and Turpie, 2012: 72). Currently WWTWs discharge effluent into many estuaries resulting in increased flows and on occasion pollution. Potential risks associated with WWTWs are malfunction and/or deterioration of structures, as well as sewage spills (van Niekerk and Turpie, 2012: 70). Smaller urban areas usually utilise septic tanks which also pose a potential threat to estuaries if seepage occurs. Estuaries situated in close proximity to urban areas are also at risk of pollutants entering the system through stormwater runoff. Contaminated runoff can be linked to urban areas, commercial and industrial areas, golf courses and roads, with stormwater pollutants including microbial contaminants, excessive nutrients and organic matter, high suspended solid loads, trace metals, hydrocarbons, solid waste and litter (Niekerk and Turpie, 2012: 71).

Development within and surrounding the estuarine functional zone, as well as poor land-use can result in habitat degradation and destruction (van Niekerk and Turpie, 2012: 78). Many anthropogenic activities residing within the estuarine functional zone and immediate surrounds have been deemed to negatively affect estuarine systems, including floodplain developments such as urban areas, roads, bridges and jetties, land reclamation, mining activities and harbour and marina construction (van Niekerk and Turpie, 2012: 78). Van Niekerk and Turpie (2012: 78) state that land-use changes within estuarine catchments are of importance as changes may result in altered sediment loads reaching the coast. In conclusion, if a habitat of an estuary has been jeopardised it may have dire consequences for the system.

1.1.7 Resource Directed Measures and Ecological Reserve determination

To protect ecological functioning and the integrity of South African estuaries the Resource Directed Measures (RDM) process was created (DWA, 2010: 2). The objective of RDM is to "ensure the protection of water resources, in the sense of protecting ecosystem functioning and maintaining a desired state of health (integrity or condition) of aquatic and groundwater dependent ecosystems" (DWA, 2010: 2). One of the processes in which RDM achieves protection of this water resource is through the setting of the Ecological Reserve in accordance with the National Water Act (NWA) No. 36 of 1998. The Ecological Reserve is described as the "quantity and quality of water reserved to support ecosystem function" (DWA, 2010: 2).

Within the Ecological Reserve determination process, one of the steps involves determining the Recommended Ecological Reserve Category for the resource. This entails estimating Reference Conditions, present condition and ecological importance of a resource, to recommend the level of protection and management assigned to it (DWA, 2010: 5). Components assessed in determining the Recommended Ecological Reserve Category include: Estuarine Health Index (EHI), Present Ecological Status (PES), Functional Importance, Estuarine Importance Score (EIS) and Ecological Reserve Category (ERC).

The EHI is a baseline study which assesses, describes and scores estuarine health (DWA, 2010: 29). Use of the EHI in estuarine studies has resulted in a health status being allocated to the majority of South African estuarine systems and in turn have raised issues pertaining to decreased functionality of these resources. The PES of a system is based on the assessed EHI and provides a general description of the state of the system and classifies the system according to the level of modification (DWA, 2010: 6). The Functional Importance and EIS indicate the importance of the estuarine systems and their potential need for protection and or improvement. The determined ERC for each system is based on the EHI and PES scores. The ERC combined with the determined EIS provides a categorisation of the system in terms of Recommended Ecological Reserve as well as the degree to which the system should be improved.

1.1.8 The National Water Policy

In order to ensure freshwater supplies to estuaries as well as preserving estuarine health, South Africa has laws in place to protect these ecosystems. The National Water Policy (NWP) of 1997 is explained in the DWA (2010) and Hosking (2010) reports. The key features of the NWP are explained below.

The NWP of 1997 has established three main goals for the successful management of the country's water resources (DWA, 2010: 1). These include efficiency, equity and sustainability. This can be seen in the official objective of the DWA, "ensuring some, for all, forever, together" (DWA, 2010: 1). The NWP recognises the environment as a water user and makes allowances for its protection, while not hindering economic returns from aquatic resources and meeting human needs. Understanding these laws is critical for studies that will examine estuarine health and processes that will affect the integrity and functioning of estuarine systems.

1.1.9 State of South African estuaries

Knowing the individual and overall state of South African estuaries is important for estuarine management and conservation. Harrison *et al.* (2000) have conducted an in-depth study of the state of South African estuaries with regard to geomorphology, ichthyofauna, water quality and aesthetics. More contributions are made with regard to estuary conditions by Harrison *et al*. (1996) and Whitfield and Baliwe (2013). The state of South African estuaries is shown according to biogeographic region (Table 1.1).

Table 1.1: Current state of estuaries in different biogeographic zones (from Whitfield and Baliwe, 2013).

Regions								
Estuarine Condition	Cool Temperate		Warm Temperate		Subtropical		South Africa	
	No.	%	No.	%	No.	%	No.	%
Poor	9	35	6	5	24	19	39	14
Fair	9	35	37	29	48	38	94	34
Good	7	27	71	56	40	31	118	42
Excellent	1	4	13	10	15	12	29	10
TOTAL	26	100	127	100	127	100	280	100

The state of an estuary may result from different factors, but usually a negative state can be attributed to anthropogenic activities within river catchments (Allanson, 2000: 97). In addition, with expanding populations and associated land-cover changes, future predictions of estuarine health are not positive and therefore even estuaries that have a 'good' or 'excellent' rating should be considered for conservation.

1.2 Catchments

1.2.1 General description and processes

A catchment is described as "a basic unit of landscape particularly for investigations of hydrological processes" and normally the boundary of a catchment "coincides with the hydrological boundary causing any precipitation falling on to the catchment to be routed to a stream where it is transported out of the catchment" (Peters, 1994). In a sense, catchments can be viewed as drainage basins which transport sediment, water and nutrients through the various elements of the landscape. The hydrology of drainage basins is characterised by the collection, movement, and storage of water and sediments through the system (Booth, 1991: 93). The movement and storage of water through a system relies highly on catchment health, and hydrological systems (such as rivers and estuaries) are highly sensitive to alterations of the landscape (Booth, 1991: 93). Alteration of a catchment from a natural state could dramatically impact on hydrological processes, affecting all attributes of the ecosystem, including estuaries.

1.2.2 The role of natural vegetation in catchments

Natural vegetation plays a key role within the hydrological cycle of catchments and the associated effects have been well documented. Vegetation intercepts and steers precipitation through the land phase of the hydrological cycle (Newson, 2002: 58). Vegetation cover intercepts precipitation before it reaches the catchment surface, increasing infiltration and minimizing erosion. In riparian zones (i.e. area adjacent to hydrological systems), vegetation acts as a sink to mitigate nutrient and sediment inputs into water columns (Li *et al.*, 2009: 317). The removal of natural vegetation within catchments has the potential to negatively alter the hydrological cycle and hydrological systems. Consequences of vegetation removal on the hydrological cycle include: low infiltration, high runoff peak rate and total amount, accelerated soil erosion, siltation and flash flooding (Newson, 2002: 66).

1.2.3 Riparian zones and the Integrated Coastal Management Act

The riparian zone is described as "the interface between freshwater and land systems", it acts as a filter for nutrients and sediments and maintains channel form (Walmsley, 2002: 202).

Riparian zones, if unaltered, usually comprise of natural vegetation supporting natural processes. Riparian developments in the past have resulted in degradation of these areas and have caused severe damage to ecosystems (Walmsley, 2002: 202). Without healthy riparian zones, the integrity of aquatic ecosystems is jeopardised. In essence, riparian zones can be viewed as natural buffers for aquatic ecosystems. Riparian zones, if properly managed, can to a certain degree mitigate the effects of poor land use practices within catchments and improve water quality while conserving the integrity of aquatic ecosystems (Tiner, 2004: 228 & 240; Viaud *et al*., 2004: 559). The Integrated Coastal Management Act (ICMA) of 2008 seeks to address this issue by preserving and hindering development within riparian zones along the South African coast.

The ICMA describes the composition and boundaries of the Coastal Protection Zone (CPZ). The CPZ is roughly defined as 1 km inland of the high water mark in rural areas and 100 m in urban areas (Republic of South Africa, 2009: 34). The purpose of these CPZs is to ensure natural riparian buffers around aquatic ecosystems, in order to preserve and protect their ecological functioning (Republic of South Africa, 2009: 36). Monitoring and assessment of land-cover/land-use within these buffers is essential for ensuring the preservation of health for aquatic ecosystems.

1.2.4 Interactions between catchment processes, anthropogenic activities and estuaries

Estuaries within catchments, form part of the hydrological cycle and rely on natural conditions within catchments in order to supply necessary inputs essential to estuaries. Thus estuaries and their catchments are linked via the drainage network and are susceptible to changes originating from within the catchment. Estuaries are regarded as sink zones for materials, sediments and nutrients derived from the catchment, which usually enters estuaries from land runoff transported by rivers (Harrison *et al*., 2001: 1). Water quality entering rivers and estuaries is dependent on the land surface over which it flows, and alterations of natural land-cover can have adverse effects, as water carries residues from the land (Tong and Chen, 2002: 377). Runoff from different land-cover and land-use types induce different contaminants into hydrological systems, and there is a strong link between land-use types and the quantity and quality of water in a system (Tong and Chen, 2002: 377).

Anthropogenic activities within catchments heavily impact on hydrological systems and can reduce connectivity between rivers and estuaries (Bierschenk *et al*., 2012: 637; Stein *et al*., 2002: 1). Intensification of land use is associated with changes to physiochemistry and ecosystem functioning within catchments, and consequentially results in decreased ecosystem health (Bierschenk *et al*., 2012: 637; Rothwell *et al.*, 2010: 153). Extensive research has been conducted on land-use and land-cover types and their associated affects, but little research has evaluated the combined effect of multiple land-use activities (Basnyat, 1999: 539).

1.2.5 Effects of catchment land-use/land-cover on hydrological processes and systems

Natural land conversion within catchments threatens ecosystem health of rivers and estuaries (Bierschenk *et al*., 2012: 637; Tiner, 2004:227). Land-cover and associated land-uses have a large impact on the hydrological processes and systems within catchments. The detection and assessment of human impacts associated with land-cover/land-use is complex due to the diverse nature of biological, chemical and geophysical components of catchments (Gergel *et al.*, 2002: 118). Human impacts, reported by Hopkinson and Vallino (1995: 598), have greatly altered the timing, magnitude and nature of inputs of materials to estuaries.

1.2.5.1 Impacts of urban development

The impacts of urban land-cover and land-use within catchments has been largely been explored (Basnyat *et al*., 1999; Booth, 1991; Donohue *et al*., 2006; Harrison *et al*., 2001; Hascic and Wu, 2006; Newson, 2002; Pratt and Chang, 2012; Stein *et al*., 2002; Wickham *et al*., 2000). Urban development within catchments is associated with the removal of natural vegetation, increases in impervious surfaces, increased runoff, increased storm water discharge and nutrients (domestic and WWTWs) entering hydrological systems. Urban land-use within coastal areas is a major threat to the productivity and biodiversity of aquatic ecosystems (Hascic and Wu, 2006: 214) and thus attracted interest for research in many disciplines. Research suggests that there is a correlation between nutrient loads and the extent of urban development within catchments (Wickham *et al*., 2000: 1420). Urban development, as identified in the literature, can be regarded as a main source of alteration to the quantity and quality of water within catchments, and is regarded as an important factor to consider when evaluating hydrological system health.

1.2.5.2 Impacts of agricultural activities

Impacts associated with agricultural land-cover and land-use is well explored (Basnyat *et al*., 1999; Donohue *et al*., 2006; Buck *et* al., 2004; Harrison *et al*., 2001; Hascic and Wu, 2006; Newson, 2002; Pratt and Chang, 2012; Stein *et al*., 2002; Wickham *et al*., 2000). Agricultural activities in catchments are associated with the removal of natural vegetation, alteration of drainage patterns, sedimentation and excess nutrient inputs (fertilizers, minerals and pesticides). Cultivated lands within drainage systems are regarded as major sources of nonpoint source pollution, heavily affecting water quality (Basnyat *et al*., 1999: 539) and research suggests that there is a correlation between nutrient loads and the extent of cultivation within catchments (Wickham *et al*., 2000: 1420).

1.2.5.3 Impacts of water impoundments and abstractions

Issues pertaining to water impoundments of rivers (dams) and water abstractions associated with urban development and cultivation are of particular concern within countries which are water scarce. Impoundments are built for various reasons, including management of flood waters, hydroelectric power, potable water, industry and irrigation (Snoussi *et al*., 2007: 589). Consequences of impoundments of rivers are associated with alterations to natural flow of water, nutrients and sediments through a catchment, as impoundments effectively 'starve' downstream ecosystems of these elements. It is reported, that damming and water diversion play a major role in habitat loss and aquatic ecosystem alteration and degradation (Marques *et al*., 2004: 68).

1.2.5.4 Impacts of mining

Mining within catchments is associated with both chemical and physical alterations of the landscape. Chemical alterations occur as a result of runoff from chemical deposits, originating from mining activities (dusts, vapours and gases) (Ashton *et al*., 2001: xxv). Alteration to the physical environment are identified as increased salinization, increased turbidity, removal of natural vegetation, land excavations, and the diversion of watercourses (Ashton *et al*., 2001: xxv) and thus could potentially have major implications for catchment hydrology and downstream ecosystems.

Sandmining operations are practiced within some South African estuaries and have the potential to impact on these ecosystems. Impacts of sandmining activities are characterised by changes to hydrological systems attributes such as channel geometry, bed elevation, substrate composition and stability, flow characteristics (depth, velocity, turbidity, sediment transport, stream discharge and temperature) (Demetriades, 2007d: 1).

1.2.5.5 Assigning weights to impacts

A method proposed for determining impacts of anthropogenic activities on river health in Australia, uses weights to assign the magnitude of impact associated with anthropogenic disturbances on aquatic ecosystems (Stein *et al*., 2002). Table 1.2 is a summary of anthropogenic disturbances utilised in the research and the weight assigned to each attribute (maximum 1.0) based on impacts.

Table 1.2: Anthropogenic disturbances on aquatic ecosystems and assigned weightings (summary from Stein *et al*. 2002).

Disturbance	Weight assigned
Urban land-use	1.0
Cultivation (cropping and irrigated cropping)	1.0
Plantations and livestock grazing	0.75
Natural land-cover	0.0
Operating mine	1.0
Point chemical pollution	1.0
Point nutrient pollution	1.0
Quarry	0.4
Major impoundment (dam)	1.0
Impoundment weir	0.3
Minor impoundment	0.1

1.2.6 Catchment land-use activities affecting estuarine integrity

Anthropogenic activities according to Allanson (2000: 97) constitute the largest threat to estuarine ecosystems due to bad land-use practices and inherent management issues. Catchment land-use activities have the potential to negatively impact on estuarine ecosystems (Whitfield and Cowley, 2010) and may permanently change an estuary’s characteristics and functioning capabilities (Schumann *et* al., 1999: 49). Within TOCEs, the main negative land-use activities and associated affects highlighted in the literature are shown in Table 1.3.

1.2.7 The utilization of land-use/land-cover in research and key findings

Studies concerning landscape ecology are primarily interested in the interactions between spatial patterns and ecological process. According to Gergel *et al*. (2002: 125) using simple landscape metrics such as "proportion of the catchment or a buffer zone in different land-covers and a measure of the arrangement or connectivity of natural and human-modified cover types in the riparian zone," is effective and can be useful in indicating anthropogenic disturbances on water chemistry, biotic and hydrologic variables of river-floodplain ecosystems. Furthermore, land-use/land-cover (LULC) patterns are usually closely related to wetland (estuarine) condition, but sometimes LULC analysis does not fully describe disturbance levels (Brooks *et al*., 2004:11). Thus LULC can be regarded as key predictors of aquatic ecosystem health.

Within the literature pertaining to hydrological systems, researchers are primarily concerned with the effects of LULC on catchment integrity, water quality and/or aquatic ecosystem health. As identified in the literature, urban and agricultural LULC (and associated effects) are usually the main source of concern (Amiri and Nakane, 2008; Bierschenk *et al*., 2012; Mamoun *et al*., 2013; Sliva and Williams, 2001; Viaud *et al.*, 2004), as these LULC types threaten aquatic ecosystems globally and catchment land-use intensity of these LULC classes correlates well with physiochemistry and ecosystem functioning (Bierschenk *et al*., 2012: 637). In the study by Bierschenk *et al*. (2012), the authors highlight a positive correlation between catchment intensity and inorganic nutrients in estuaries.

According to Bierschenk *et al*. (2012: 638), investigations concerning land-use effects on freshwater and estuarine ecosystems have rarely been studied together, but some research does address this issue, as estuaries rely heavily on the input of natural freshwater inflows. Assessments utilising LULC have been conducted at varying scales through whole catchment analysis (Brooks *et* al., 2004; Bierschenk *et al*., 2013), buffer analysis (Viaud *et al*., 2004; Mamoun *et al*., 2013) or a combination of the two (Amiri and Nakane, 2008; Sliva and Williams, 2001).

Table 1.3: Negative anthropogenic catchment land-use activities and contributing authors.

Negative anthropogenic land-use activities	Authors
Reduction to freshwater inflow (impoundments and water abstraction).	Edgar *et* al. (1999; 20), Hosking (2010; 1), Morant and Quinn (1999; 292), Perissinotto *et al*. (2004; 2), Schumann *et* al. (1999; 49), Turpie (2004; 21), van Niekerk *et al*. (2008; 15), Whitfield and Cowley (2010; 49).
Nutrient loading (farming, sediments, human settlements and WWTWs).	Edgar *et* al. (1999; 20), Hosking (2010; 1), Morant and Quinn (1999; 292), Schumann *et* al. (1999; 49), Turpie (2004; 21), van Niekerk *et al*. (2008; 15), Whitfield and Cowley (2010; 49).
Catchment degradation (clearing of natural vegetation and hardening of surfaces).	Edgar *et* al. (1999; 20), Morant and Quinn (1999; 292), Perissinotto *et al*. (2004; 2), Schumann *et* al. (1999; 49), Whitfield and Cowley (2010; 49).
Land-use activities situated on the peripheries or within estuaries.	Hosking (2010; 1), Morant and Quinn (1999; 292), Perissinotto *et al*. (2004; 2), Turpie (2004; 21), van Niekerk *et al*. (2008; 15), Whitfield and Cowley (2010; 49).
Artificial mouth breaching.	Morant and Quinn (1999; 292), Perissinotto *et al*. (2004; 2), Turpie (2004; 21), Whitfield and Cowley (2010; 49).
Mining and sandwinning operations.	Edgar *et* al. (1999; 20), Perissinotto *et al*. (2004; 2).
Invasion of catchment by alien vegetation.	Hosking (2010; 1), Morant and Quinn (1999; 292).

A described method for evaluating catchment health includes assessing percentages of LULC, which are known to affect water quality and subsequently aquatic ecosystems (Tiner, 2004: 228) or conversely, the percentage of natural land-cover could also be used. Research by Bierschenk *et al*. (2012: 639) involved using the percentage of pristine (naturalness) areas within catchments to measure land-use intensity, as it correlated well with predicting levels of physiochemical variables. Brooks *et al.* (2004) also employs the use of percentage natural vegetation in buffer areas surrounding wetlands to infer their condition successfully, but also stated that other areas may need other metrics to express human disturbance.

The theory behind using various scales of analysis is to determine the effects of LULC through the catchment to coast continuum. The prevailing method for evaluating links between catchment land-use and river water quality is to consider the whole catchment and buffer zones separately, but dealing with catchments and buffer zones simultaneously could be a useful model (Amiri and Nakane, 2008; Bierschenk *et al*., 2012; Sliva and Williams, 2001). One study which used this approach (Sliva and Williams, 2001) investigated land-use impacts within a catchment and 100 m buffer zone on water quality. It was found that at a catchment rather than buffer scale there was a slightly greater influence on water quality from LULC, within the study catchment urban land-use had the greatest influence on water quality, and after urban land-cover, natural vegetation cover was the next best predictor of water quality.

Some research also employs the use of correlation/regression approaches to examine the link between altered catchment land-cover and the health of aquatic ecosystems. The use of statistical analysis in LULC analysis can be used to highlight possible correlations between landscape variables and variables such as water quality (Basnyat *et al*., 1999: 542). Based on the scale of all the following studies they were able to use statistical methods to examine the relationship between variables. The application of statistical methods is demonstrated in research by Amiri and Nakane (2008) where a multiple regression model was used to link changes in water quality of 12 rivers in Yamaguchi Prefecture Japan, to land-uses at two scales of analysis: the entire catchment and a buffer zone. It was found that considering both the entire catchment and buffer zone together provided a stronger link when predicting concentrations of Suspended Solids and Total Nitrogen. Bierschenk *et al*. (2012) analysed the link between land-use intensity within three habitats, namely freshwater, estuarine and near-marine habitats of ten study sites, and ecosystem function. It was identified that a negative correlation existed between the concentrations of dissolved inorganic nutrients and the percentage of natural land-cover in all their study sites, inferring that increasing catchment development paralleled higher nutrient levels. The study by Basnyat *et al*. (1999) assessed the relationship between land-use and nonpoint source pollutants in streams across 17 selected basins of the Fish River, Alabama. A regression model was employed to analyse the link between streamside buffer zones/riparian areas land-use and stream water quality. Results from the study indicated that water quality was highest when natural land was located adjacent to streams, rather than agricultural and urban land-uses (Basnyat *et al*., 1999: 539). Another study by Donohue *et al*. (2006) utilised stepwise logistic regression analysis to identify which out of numerous factors was the principle factor impacting on the ecological status of 797 hydrologically independent Irish rivers sites. The results from the study indicated that urbanisation, arable farming and extent of pasturelands were all principle factors impacting on Irish stream and river ecology (Donohue *et al*., 2006: 91).

Buffer zones around aquatic ecosystems usually coincide with riparian areas which are regarded as necessary areas to maintain the ecological functions of these systems. Thus buffer zone analysis quantifies the intactness of natural vegetation within riparian areas, as to quantify the decrease in functional ability of these areas to negate effects derived from catchment activities. Buffer zone delineations within the literature vary in distance from aquatic system, but the most prevalent buffer zone delineations used were in the region of 1 km and 100 m (Brooks *et al*., 2004; Mamoun *et al*., 2013; Sliva and Williams, 2001). Aquatic ecosystem buffers are usually explicitly defined by laws pertaining to water resources within countries and are in place to preserve ecosystem integrity. One study uses buffer zone analysis to determine the condition of land-cover within legislative buffer zones to prioritise wetlands for conservation (Mamoun *et al*., 2013).

1.3 Overview of South African catchment land-cover

South Africa's coast stretches along many of the provinces and spans various biomes. Catchments along the coastline will have differing characteristics in terms of geomorphological and hydrological functioning. In order to identify differences and similarities between catchments, small scale assessment of the whole country is needed. The information pertaining to LULC needs to be accurate and up to date to contribute meaningfully to strategic planning, sustainable resource management as well as environmental research (Fairbanks *et al*., 2000: 69).

Historically land-cover was determined through simple assessments of gross land-cover and surface properties (Fairbanks *et al*., 2000: 69). According to Fairbanks *et al*. (2000: 69) the most commonly used collation of land-cover and surface data were Acocks' veld types and the National Botanical Institutes vegetation potential map. Problems with the use of this data materialised due to the low resolution imagery used (1: 1 000 000) and a lack of standardisation. A higher resolution mapping exercise, the National Land-Cover Database Project (NLC) (first published 1996) seeks to address this problem.

1.3.1 National Land-Cover Database Project

The NLC was initiated due to the lack of knowledge pertaining to catchments of the whole of South Africa (Harrison *et* al, 2001: 1). Previous assessment of land-cover in South Africa was conducted by the Council for Scientific and Industrial Research (CSIR) and the Agricultural Research Council (Harrison *et al*., 2001: 1). The outcome of the NLC was to create a standardised digital land-cover database that covers South Africa, Lesotho and Swaziland (Fairbanks *et al*., 2000: 69). This project was aimed at small scale mapping applications, at a scale of 1: 250 000.

The NLC provides classifications for both land-cover and land-use, two related but different terms. Fairbanks *et al*. (2000: 70) defines land-cover as: "all the natural and human features that cover the earth's immediate surface, including vegetation (natural or planted) and human constructions (buildings, roads), water, ice, bare rock or sand surfaces"; while land-use refers to: "the human activity that is associated with a specific land-unit, in terms of utilisation, impacts or management practices". Therefore there may only be one land-cover type for any specific point on the earth's surface, but this land-cover type might be host to many different land-uses.

1.3.2 Land-cover classification

The standardised land classification scheme developed within the NLC has been outlined in detail by Harrison *et al*. (2001). According to Harrison *et al*. (2001) these land-cover classes that have been created are based on those that were developed by Thompson (1996) specifically for South Africa. The NLC classification scheme consists of 31 different classes of land-cover. In order to ensure international relevance of research using this classification scheme, the NLC classifications has been "designed to conform to internally accepted standards and conventions in order to ensure cross-border compatibility and integration with existing national and international land-cover classifications systems and datasets" (Harrison *et al*., 2001: 2).

Table 1.4: NLC land-cover classifications (from Harrison *et al*., 2001).

NLC Code	Land-cover class	Description
1	Forest and Woodland	All wooded areas with greater than 10% tree canopy cover, where the canopy is composed of mainly self-supporting, single stemmed, woody plants >5 m in height. Essentially indigenous tree species growing under natural or semi-natural conditions.
2	Forest	
3	Thicket, scrub forest, bushland & high Fynbos	Communities typically composed of tall, woody, self-supporting, single and/or multi-stemmed plants (branching at or near the ground), generally with no clearly definable structure. Total canopy cover >10%, with canopy height between 2-5 m. Essentially indigenous species growing under natural or semi-natural conditions.
4	Shrubland & low Fynbos	Communities dominated by low, woody, self-supporting, multi-stemmed plants branching at or near the ground, between 0.2-2 m in height. Total tree cover <1.0%.
5	Herbland	Communities dominated by low, non-woody, self-supporting, non-grass like plants, between 0.2-2 m in height. Total tree cover <1.0%.
6	Unimproved grassland	Areas dominated by grass-like, non-woody, rooted herbaceous plants. Essentially indigenous species growing under natural or semi-natural conditions.
7	Improved grassland	Planted grassland, containing either indigenous or exotic species, growing under man-managed conditions for grazing, hay or turf production, and recreation (e.g. golf courses).
8	Forest plantations	Areas of systematically planted, man-managed tree resources, composed of primarily exotic species (e.g. pine, eucalypt, wattle).
9	Waterbodies	Areas of open water including natural and man-made water bodies such as rivers, dams, permanent pans, lakes, lagoons and coastal waters.
10	Wetlands	Natural or artificial areas where the water level is at (or very near) the land surface on a permanent or temporary basis including saltmarsh, pans, reed-marsh, papyrus-swamp and peat bogs.
11	Barren rock	Natural areas of exposed sand, soil or rock with no, or very little, vegetation cover during any time of the year such as rock outcrops, dune and beach sand, dry river beds and gravel plains.
12	Dongas and sheet erosion scars	Permanent or seasonal, man-induced areas of very low vegetation cover (i.e. removal of tree, bush and/or herbaceous cover) in comparison with the surrounding natural vegetation cover. Typically associated with subsistence level farming and rural population centres,
13	Degraded: forest and woodland	
14	Degraded: thicket &	

	bushland etc.	where overgrazing of livestock and/or wood-resource removal has been excessive. Often associated with severe soil erosion problems.
15	Degraded: unimproved grassland	
16	Degraded: shrubland and low Fynbos	
17	Degraded: herbland	
18	Cultivated: permanent - commercial irrigated	Lands cultivated with crops that occupy the area for long periods and are not replanted after harvest. Examples include tea plantations, vineyards, sugar cane, citrus orchards, hops and nuts.
19	Cultivated: permanent - commercial dryland	
20	Cultivated: permanent - commercial sugarcane	
21	Cultivated: temporary - commercial irrigated	Land under temporary crops that are harvested at the completion of the growing season that remains idle until replanted. Examples include maize, wheat, legumes, potatoes, onions and Lucerne.
22	Cultivated: temporary - commercial dryland	
23	Cultivated: temporary - subsistence dryland	
24	Urban: residential	Areas in which people reside on a permanent or near-permanent basis including both formal and informal settlement areas, ranging from high to low building densities.
25	Urban: residential (smallholdings - forest & woodland)	
26	Urban: residential (smallholdings - thicket, bushland ...etc)	
27	Urban: residential (smallholdings - shrubland & low fynbos)	
28	Urban: residential (smallholdings - grassland)	
29	Urban: commercial	Non-residential areas used primarily for the conduct of commerce and other mercantile business, typically located in the central business district.
30	Urban: industrial/transport	Non-residential areas with major industrial or transport related infrastructure. Examples include power stations, steel mills, dockyards and airports.
31	Mines and quarries	Areas in which mining activity has been done or is being done. Includes opencast mines and quarries as well as surface infrastructure (mine dumps etc.) associated with underground mining activities.

Subsequently the land-cover classes were aggregated into four classes to provide a generalised synopsis of land-cover characteristics within catchments (Table 1.4).

Table 1.5: NLC land-cover classes grouped into agriculture, degraded, natural and urban categories (from Harrison *et al*., 2001).

NLC Code	Land-cover class	Aggregated categories
7	Improved grassland	Agriculture
8	Forest plantations	
18	Cultivated: permanent - commercial irrigated	
19	Cultivated: permanent - commercial dryland	
20	Cultivated: permanent - commercial sugarcane	
21	Cultivated: temporary - commercial irrigated	
22	Cultivated: temporary - commercial dryland	
23	Cultivated: temporary - subsistence dryland	
12	Dongas and sheet erosion scars	Degraded
13	Degraded: forest and woodland	
14	Degraded: thicket & bushland etc.	
15	Degraded: unimproved grassland	
16	Degraded: shrubland and low Fynbos	
17	Degraded: herbland	
1	Forest and Woodland	Natural
2	Forest	
3	Thicket, scrub forest, bushland & high Fynbos	
4	Shrubland & low Fynbos	
5	Herbland	
6	Unimproved grassland	
9	Waterbodies	
10	Wetlands	
11	Barren rock	
24	Urban: residential	Urban
25	Urban: residential (smallholdings - forest & woodland)	
26	Urban: residential (smallholdings - thicket, bushland ...etc)	
27	Urban: residential (smallholdings - shrubland & low fynbos)	
28	Urban: residential (smallholdings - grassland)	
29	Urban: commercial	
30	Urban: industrial/ transport	
31	Mines and quarries	

Furthermore the aggregated land-cover classes were increased to include waterbodies, plantations and mines classes equating to a total of seven aggregated classes as seen in the 2009 NLC dataset (SANBI, 2009: 20).

The literature provides standardised land-cover classes for the whole of South Africa that can be used to homogenise methodologies for research based in the country. One limitation in the classification scheme is discrepancies in allocating land-cover activities to specific classes. Another is due to the data capture scale of the data set as only catchments that are greater than 500 km² have been mapped (Harrison *et al.*, 2001: 2). The classification scheme is adequate for this research and it is possible to apply these generalised classes to smaller catchments.

1.4 Geographic Information Systems

1.4.1 Description

GIS is described as a field that "is concerned with the description, explanation, and prediction of patterns and processes at geographic scales" (Longley *et al.*, 2005: xi). Longley *et al.* (2005: xi) goes on to further describe GIS as a "science, a technology, a discipline, and an applied problem solving methodology".

GIS is usually regarded as software, but it is more complex than it appears. According to Craigie (2008: 15) GIS consists of five components which are data, software, tools/analysis, hardware and people. These five components are described by Craigie (2008: 15) as:

- Data – "is the collection of measurements required for the analysis;"
- Software – "is the program that performs the analysis;"
- Tools/ analysis – "are the applications where the problem or query is defined;"
- Hardware – "is the computer processor;"
- People – "are the most important component as they influence all the other components".

GIS is not only used in the production of maps, but it allows one to perform complicated analysis as well as being able to perform queries of spatial as well as non-spatial data (Craigie, 2008: 15). An example of a spatial query might be: list all water abstraction activities along the Fish River in the Eastern Cape.

The capabilities of GIS are hugely beneficial to governments, scientists, researchers and to the general public. Longley *et al*. (2005: 7) states that "with a single collection of tools, GIS is able to bridge the gap between curiosity-driven science and practical problem-solving". GIS technologies are widely available today and easily accessible for almost anyone to use. There is evidence that GIS has unlimited applications and is used in each person's daily life, whether they realise it or not.

1.4.2 Applications

GIS applications are used widely on a day to day basis by various people, businesses, organisations and assorted government departments. Some authors that contribute towards the understanding of GIS applications are: Cojocaru *et al*. (2008), Craigie (2008), ESRI Australia (2009), Longley *et al*. (2005), Renchin *et al*. (2009), Sreenivasulu and Bhaskar (2010), Tegene (2002) and Twumasi and Merem (2007). These authors either describe where GIS applications are used and/ or how they are used. These papers provide international relevance of GIS applications as well as methods used, which will allow the applications to be used anywhere in the world were relevant data is available.

Geographic problems are described by Longley *et al*. (2005: 4) as problems that include the aspect of location. This may occur in both the information used to solve the problems and/ or within the proposed solution themselves (Longley *et al*., 2005: 4). Geography is the core of GIS analysis: "almost everything that happens, happens somewhere. Knowing where something happens can be critically important" (Longley *et al*., 2005: 4). At an international scale, GIS technologies are applied by health care companies, delivery companies, transport authorities, geodeomographic consultants, forestry companies, national park authorities, governments, farmers as well as travellers and tourists to name a few (Longley *et al*., 2005; 4). Within South Africa GIS is widely used by national, provincial and local government departments such as the Department of Environmental Affairs, Cape Nature, consultancies and businesses, researchers and for personal use.

One area in particular where GIS is particularly useful is that of natural resources management (Twumasi and Merem, 2007: 174). According to Twumasi and Merem (2007: 174) GIS and remote sensing data in conjunction with geospatial tools of GIS has already been used widely in the disciplines of forestry, water management, resource management and resource planning during environmental crisis. The use of GIS and remote sensing in water resource management aids in achieving objectives for integrated resource management which were stipulated in Agenda 21 document of the United Nations (Twumasi and Merem, 2007: 174).

Another widely applied use of GIS and remote sensing is to analyse LULC. This enables accurate LULC information to be generated at various scales. The information gained may be used to analyse changes to the landscape, spatial assessments between different LULC classes in addition to providing crucial information to policy and decision makers for resource management.

1.4.3 GIS applications in land-use/land-cover assessments

The application of GIS and remote sensing in research concerning LULC is widely spread throughout the world. Countries where such research has taken place, to name a few include: America, India, Romania, Ethiopia, Mali, Niger, Australia and South Africa. Several papers that use GIS and remote sensing in land-cover and land-use assessments include: Cojocaru *et al*. (2008), Craigie (2008), ESRI Australia (2009), Renchin *et al*. (2009), Sreenivasulu and Bhaskar (2010), Tegene (2002) and Twumasi and Merem (2007).

The most common motivation for the above stipulated research papers are to understand the dynamics of the various landscapes in response to LULC changes. Another is to gain valuable information with regards to functionality and condition of river catchments in response to human land-use activities. The acquisition of such information regarding LULC through this area of research is imperative for natural resource managers (Tegene, 2002; 1). Information gained will aid in planning and managing the sustainability of natural resources and help to avoid conflicts between human usage of natural resources and their ability to function naturally (Tegene, 2002: 1). This will also aid in maintaining the ecological integrity of natural resources and their ability to supply necessary goods and services.

Based on the authors listed above, the following general methods and procedures have been identified:

- Obtaining GIS data for the relevant study area such as satellite imagery, aerial photographs (1: 50 000) and topographic maps;
- Importing this data into GIS software for analysis;
- Creation of a Digital Elevation Model (DEM) for the region;
- Production of primary maps such as slope, elevation and aspect;
- Creation of a land-use map through spectral reply as well as interpretation through aerial photograph;
- On screen digitising of LULC;
- Classification of LULC classes;
- Calculating LULC percentage areas;
- Measuring percentage change of LULC through satellite time series analysis;
- Calculation and interpretation of percentage change of different LULC.

Methods described in the literature differed in the following ways:

- GIS imagery was obtained from different satellites, resulting in different resolution of the data and thus varying accuracy was gained;
- Topographic maps used have various scales;
- Different GIS software used for analysis of GIS data;
- Classification schemes used for LULC differed as the majority of the researchers created their own classifications;
- Imagery used to determine LULC change obtained for different years and thus different temporal scales were used;
- Only some of the authors applied ground truth verification.

The literature shows useful methods for determining LULC. These methods can be easily applied in any context with the right hardware, software, GIS data and GIS tools and analysis. Research in South Africa is slightly less time consuming as a LULC classification scheme already exists.

1.5 Motivation

It is apparent that with increasing inhabitancy of coastal areas within South Africa, estuaries, particularly TOCEs, are increasingly under threat for competition of natural resources and are being subjected to deterioration of health from land-cover changes and associated affects in the catchment. Thus it is of importance to establish a link between catchment condition and the health of TOCEs, which few studies have attempted, and to develop a method which could be used in South Africa to rapidly assess TOCE health to aid in conservation/rehabilitation of these aquatic ecosystems.

1.6 Study hypothesis

Estuarine health is directly related to catchment land-cover, with increasing alterations from a natural state being associated with a decline in estuarine health.

1.7 Aim and objectives

The aim of this study is to analyse the extent to which a relationship can be drawn between catchment land-cover and the health status of associated temporarily open/closed estuarine systems.

In order to achieve the aim the following objectives were set:

- To identify, collate and review existing literature relating to estuarine health, catchment land-cover/land-use and GIS, so as to identify suitable sites for assessment.
- To identify and create a database of suitable existing spatial raster and vector datasets.
- To establish the state of estuary catchments and buffer zones based on spatial data.
- To identify if there is a relationship between catchment land-cover at various scales and the established condition of the estuary, so as to identify a relationship between catchment integrity and the state of the estuary.
- To evaluate the effectiveness of this method based on literature, current legislations and findings, as to determine the validity, usefulness and applicability of this approach on other TOCEs and to possibly prioritise these estuaries for conservation.

1.8 Conclusions

The review of the literature has shown that much knowledge has already been gained on South African estuaries, catchment land-cover and land-use in addition to GIS techniques used in research of land-cover and land-use. Information explored concerning estuaries in South Africa, specifically TOCEs, catchment hydrology and associated impacts of land-uses will prove useful in this research as well as use of the NLC classification scheme and GIS techniques analysed.

CHAPTER 2: METHODS

2.1 Evaluation of literature, collection of Resource Directed Measures assessments and selection of estuaries for comparison

Collation and assessment of existing literature was conducted, in order to identify information and studies concerning estuaries and their catchments, as well as methods used to evaluate aquatic ecosystem health from a catchment basis. This provided a holistic understanding of the dynamics and interlinked nature of the two systems. GIS methods utilised in similar studies were also identified for potential use in this thesis. Information gathered is presented in the form of a general introduction in this thesis.

Within the literature, it was identified that the DWAF RDM assessments exist for some South African estuaries. The results presented in the assessment indicated the health of the estuary and influences which are detrimental to the system's integrity. DWAF (1999) states that the required level of assessment on estuarine systems is determined by:

- Degree to which the catchment is already utilised;
- Sensitivity and importance of a catchment;
- Potential impact of proposed water use.

The higher the level of assessment, the more detailed the study will be. The highest level of assessment is 'comprehensive', but not many estuarine systems in South Africa have been assessed at this level. The level of RDM assessment required for consideration in this project will thus be 'intermediate'. Information regarding RDM assessments already conducted on estuarine systems over the past 10 years in South Africa was obtained from van Niekerk (2011).

A list of all existing estuaries within South Africa as well as availability of information was compiled from Whitfield (2000). This paper also provided categorization of the individual systems into larger estuary type categorizations such as TOCEs. The criteria used for selecting comparable estuaries were:

- Only TOCE systems;
- Level of available information must be at least 'medium';
- A RDM assessment conducted at an intermediate level.

The four systems which met these criteria were: the East Kleinemonde Estuary, Groot Brak Estuary, Mdloti Estuary and the Tongati Estuary.

2.2 GIS data compilation

The available spatial data collated and utilised in this study are listed in Table 2.1.

Table 2.1: GIS data utilised in the project.

Data set name	Data type and spatial resolution	Year	Source	Utility
National Land Cover (NLC) 2009	Raster 30m * 30m	2009	Bhengu *et al*.	This raster was used to indicate land-cover type delineations within the catchments and buffers.
National Estuaries 2011	Vector - polygon	2011	van Niekerk and Petersen	Was used to show estuarine functional zone delineations.
Water Resources of South Africa (WR2005)	Vector – polygon	2008	Middleton and Bailey	Quaternary catchment polygons were used to delineate catchments.
South African census 2011	Vector – points, polygons and lines	2011	Statistics South Africa	Vector data was used to show provincial boarders, river delineations, and to locate main towns of interest.
Colour Digital Aerial Imagery at 0.5 m GSD (2008-current)	Colour digital photographs (1:10000)	2009	CD:NGI	These images were compared to data displayed in the NLC 2009 and used to update land-cover delineations.
Topographic Data	Vector – polygon and lines	1998, 2000, 2006, 2008.	CD:NGI	5 m contour lines were used to create DEMs. Rivers were used to create longitudinal profiles to divide the catchments into sections. The road delineations were used to update land-cover data.
SPOT-5 Mosaic	Raster 2.5 m resolution over South Africa	2010	CNES	These images were used in some maps for aesthetic reasons.

2.3 GIS analysis

2.3.1 Data creation and manipulation of catchments

Available spatial data layers for the analysis of each system were collated and the GIS program utilised in this study was ArcGIS 10.

2.3.1.1 Geographic coordinate system

Congruency between data layers was achieved by giving all layers the same spatial reference. The accepted datum for South Africa is Hartebeesthoek 94 or World Geodetic System 1984 (WGS84). These two datums are similar in accuracy and for this research WGS84 was utilised (National Geo-Spatial Information, 2013).

2.3.1.2 Clipping

Initially the three data layers used were the 5 m contour lines, WR2005 quaternary catchments and CSIR National Estuaries shapefiles. Standard GIS techniques were utilised to clip the shapefiles to an extent greater than the catchment study area.

2.3.1.3 Digital Elevation Model

A Digital Elevation Model (DEM) was created using the Inverse Distance Weighted (IDW) method for each catchment and aided in the preliminary delineation of the catchment boundary for each estuary.

2.3.1.4 Projection

Maximum accuracy of the data layers used was achieved with the selection of the correct projection. The projection chosen for this study was Albers Equal Area. Albers Equal Area projection makes use of two standard parallels to mitigate distortion of the area between the parallels (ArcGIS Resource Center, 2011b). Albers Equal Area was also the projection used by SANBI in their shapefile of the National Estuaries as well as the NLC database.

2.3.1.5 Flow direction raster and accuracy of catchment delineations

To aid in the accurate delineation of each catchment a 'flow direction' raster image was created. Simultaneous use of the DEM and flow direction raster to determine the highest points within the catchment enabled the correct delineation of the catchment. The resulting catchment was created using standard GIS techniques. This delineation was then assessed for accuracy by comparing it to the contour lines on a topographic map. Once the correct catchment had been delineated the DEM was clipped to its extent. Further assessment of the accuracy of the catchment area was conducted by comparing recorded catchment sizes against determined catchment areas.

2.3.2 Derivation of land-cover from existing data

The NLC database used enabled two classification assessments to be undertaken. The primary land-cover classification system illustrated land still in its natural state and land which has been transformed. The secondary land-cover classification aggregates the 31 land-cover classes into seven descriptive classes (SANBI, 2009: 20). The aggregated classes include: natural, waterbodies, cultivated, degraded, urban built-up, plantations and mines. Standard GIS methods were used to identify both classifications of land-cover classes present within each river catchment to ensure compatibility with other systems and future studies.

The land-cover raster data was masked to each study site location and both the primary and secondary classifications were converted to vector polygons. The data was then clipped to the show land-cover classifications within each catchment boundary. The larger catchments show and classify the estuary as natural, but within the smaller catchments the estuary was not shown. Estuary functional zone delineations were subsequently added to the maps and a new secondary land-cover class was created. The attribute data was then updated to show the geometry (ha) of each land-cover class.

2.3.3 Ground truthing

Ground truthing was performed in this study to verify the accuracy of the data used in the desktop analysis. Initially a pilot ground truthing exercise was conducted on the East Kleinemonde estuary catchment. Rhodes Geography honours students (2012) designed and implemented a ground truthing exercise on the catchment. The method used involved the creation of a sample map of the catchment area with an overlaid grid. Each grid block was allocated a reference and using excel 10% of the grid blocks were randomly selected. Field surveys were conducted where the sample blocks were visited. Land-cover data was captured and compared to the land-cover portrayed on the map. Any major discrepancies were noted and the land-cover map updated. This method of ground truthing was subsequently applied to the remaining study sites.

Although this method worked efficiently for the Kleinemonde East catchment some limitations and issues arose when applied to the remaining three larger catchments (Table 2.2).

2.3.4 Division of catchments into sections, new catchment delineations and new land-cover data generation

Tobler's First Law of geography dictates that land-cover in close proximity to an estuary would be more likely to have a greater impact on the system than land-cover further away in the catchment (Miller, 2004: 284). In accordance with this law, land-cover in closer proximity to the estuary was isolated at various scales for assessment.

Table 2.2: Limitations of the ground truthing exercise.

Limitation	Description
Terrain	Size of the catchments were extensive
	Difficulty of accessing sample sites
	Visibility was often poor at survey locations
Resources	Time constraints
	Limited man power to cover large areas
Generalisation	Holistic classification of land-cover was difficult due to sample blocks containing many land-cover types.

The initial assessment involved the division of the catchment into sections in order to isolate land-cover in the bottom third of the catchment which incorporated the estuary. This was achieved by creating a longitudinal river profile of the catchment to determine major changes in gradient along the river course. For two of the four study sites the last greatest elevation change occurred after the dam wall situated along the river and for assessment purposes the lower section of the catchment was delineated as area below this contour height. Standard GIS techniques were applied to the lower section to determine both primary and secondary land-cover classes and their respective areas occupied.

The next level of assessment involved the isolation of land-cover classes within two buffer zones, namely 1 km and 100 m around the estuaries. The distances of the buffer zones were aligned with the regulatory buffer areas (CPZs) set for the protection of marine and coastal ecosystems in the ICMA. The ICMA describes the composition and boundaries of the CPZs as roughly 1 km inland of the high water mark in rural areas and 100 m in urban areas (Republic of South Africa, 2009). These two buffer delineations were used to generate new catchment areas and land-cover data for analysis. At this larger scale the NLC data was found to lack accuracy and had to be updated.

Ground truthing data, existing land-cover data, national road vector data and aerial photographs were utilised to analyse and update the existing land-cover data. Standard GIS techniques were employed to update corrected delineations for existing land-cover and generate new data where applicable. For the purpose of this study all main, secondary and arterial roads were grouped into the land-cover class of urban built-up. Updated land-cover polygon areas were determined and tabulated.

The final scale of assessment included identifying land-cover classes present within the estuary functional zone. Standard GIS techniques were once again utilised to isolate and update existing land-cover that appear within the estuary delineation. Areas within the estuary that exhibited transformed land-cover were delineated and their associated geometry calculated. All other areas were classified as land-cover still in a natural state.

2.4 Assessment of characteristics of the individual estuary systems

2.4.1 Current state of the system

Assessments of the health of the estuarine study sites exist as components of the RDM studies (van Niekerk *et al*., 2008; van Niekerk *et al*., 2009; Demetriades, 2007a; Demetriades 2007c). The factors assessed in the determination of the Recommended ERC for each estuary include: EHI, PES, Functional Importance and EIS.

This information was used to show the present condition (compared to Reference Conditions) and ecological importance of each study estuary as well as illustrating which components of estuarine health have declined. It also highlighted each individual estuary’s potential need for protection and or improvement. Subsequently, a holistic understanding of the state of the estuary and the degree to which the estuarine components have deviated from the Reference Condition was provided. This information was used to provide a baseline for comparisons between study sites and provide a ranking from most pristine to most degraded system, i.e. ranking from 1 to 4.

2.4.2 Analysis of catchment land-cover

Analysis of catchment land-cover entailed tabulating data outputs from the GIS analysis conducted. Data outputs included spatial extents of different land-cover classes as well as the classes' representative catchment area occupied. Initially catchment land-cover was divided into natural and transformed land-cover classes to provide a preliminary assessment as to whether the catchment was in a natural or transformed state. A subsequent analysis was then conducted within the lower section, 1 km buffer and 100 m buffer zones and within the estuarine functional zone. The analysis considered natural and transformed classes, their total area, the percentage of catchment occupied by each class and proximity to the estuary. It provided insight into the main land-cover classes potentially affecting the health of the systems at different scales and allowed similarities and differences to be compared between catchments.

2.4.3 Identification of anthropogenic activities affecting the system

A list of key anthropogenic activities affecting the systems was compiled based on specialist reports from the RDM studies. The anthropogenic activities were divided into catchment activities and activities originating from within the estuarine functional zone, to isolate negative influences on the estuaries that derive from catchment and estuarine activities and possibly to assess their impact on the health status of TOCEs. Identification of individual systems anthropogenic activities also aided in the comparison between anthropogenic activities occurring and contributing towards decreased system health of the study sites evaluated in this project. This also inferred an indication as to the associated land-cover classes potentially affecting the systems and which would need to be assessed. This analysis also highlighted attributes which could be quantified from a catchment perspective, to possibly prioritise estuaries for conservation.

2.5 A method of rapidly assessing South African temporarily open/closed estuary condition to prioritise these ecosystems for rehabilitation and/or conservation

Based on the results of this thesis, a method of rapidly determining TOCE condition and potential need for rehabilitation and/or conservation was developed. This was achieved through assessing two buffer zones within the CPZ. The proposed method used GIS spatial data, a GIS program and basic GIS analysis. The spatial data needed included: BGIS estuary functional zone delineations, NLC data and digital photographs. The method involved nine steps which are shown in Table 2.3.

Table 2.3: A method employing GIS to assess South African TOCE condition rapidly.

Step	Description
1	Load BGIS estuary functional zone delineations;
2	Create two buffers of 1 km and 100 m around the estuarine functional zone in question;
3	Add NLC data;
4	Clip NLC data to the extent of each buffer;
5	Load digital photographs;
6	Preform a ground truthing exercise;
7	Update land-cover data delineations;
8	Determine the relative percentage of natural vegetation within each buffer to infer the estuary condition (conversion of natural land within these buffers indicated the degree to which the system is likely to be impacted) and determine the condition of the natural land-cover with regard to alien vegetation invasion through an assessment of changes over time (using aerial photographs);
9	Use the percentage of natural land-cover within the CPZ to highlight the estuary's need for conservation and/or rehabilitation (i.e. if close to 100% natural then no rehabilitation is needed, but should be conserved/protected; if 50% natural then the estuary should be prioritised for rehabilitation attention and conservation/protection).

CHAPTER 3: EAST KLEINEMONDE ESTUARY

3.1 Study area

3.1.1 Estuary

The East Kleinemonde Estuary is in the Eastern Cape Province, with the estuary mouth located at 33° 32' 23.76" S and 27° 03' 00.32" E. The town of Kleinemonde surrounds the lower reaches of the estuary and Port Alfred is approximately 15 km to the south-west (Figure 3.1).

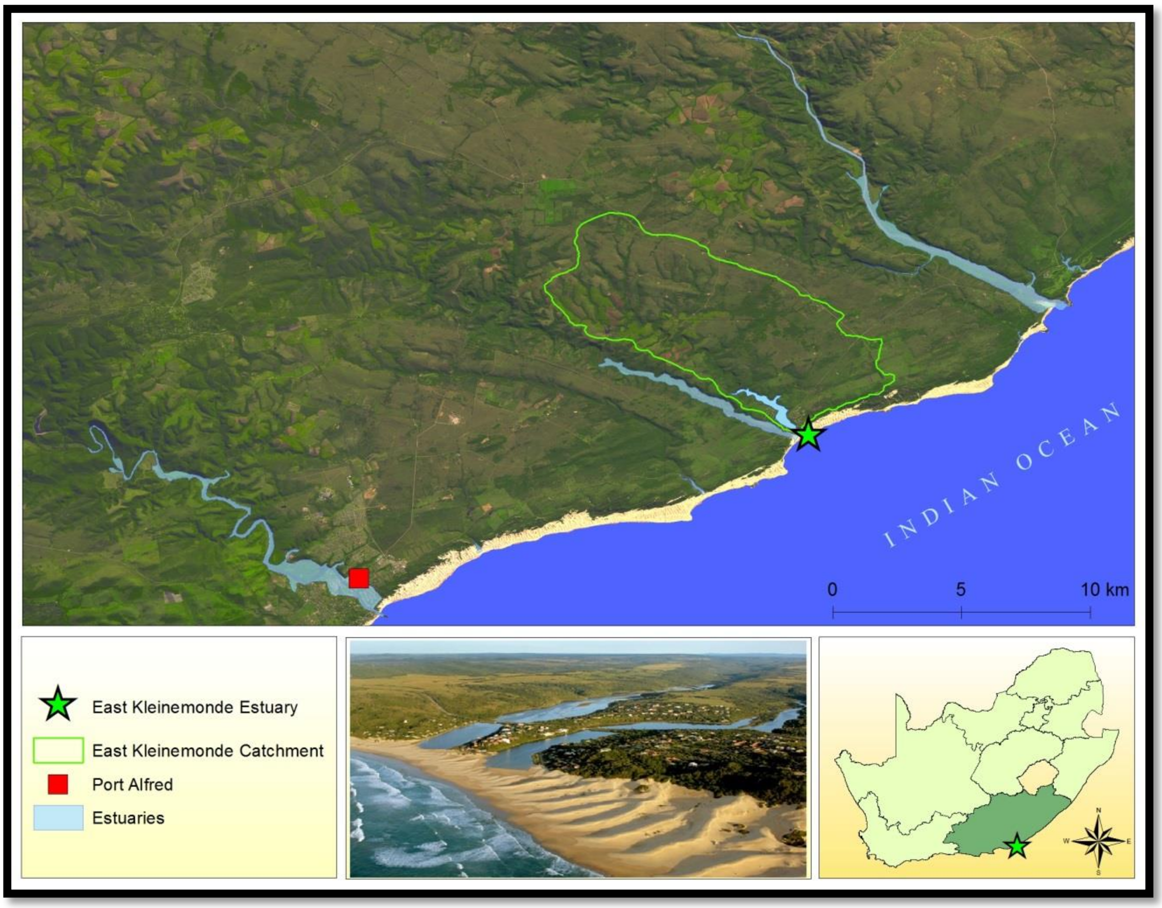

Figure 3.1: Location of the East Kleinemonde Estuary and associated catchment (inset image from the Eastern Cape Development Corporation, 2012).

The East Kleinemonde Estuary is regarded as a small estuary (Riddin and Adams, 2010: 120; Human and Adams, 2011: 168). At its widest point the estuary is 120 m across and extends 3.5 km from the mouth to the head (Figure 3.2). This system is generally quite shallow with the estuary exhibiting depths ranging between one and two meters in the channel (Human and Adams, 2011: 168).

According to the classification system for estuaries in South Africa the East Kleinemonde Estuary has been categorised as a TOCE (Cowley and Whitfield, 2002: 75). For most of the year the mouth of the estuary is closed to the ocean, but opens in response to freshwater outflow from the catchment when rainfall exceeds 100 mm within a short period (Riddin and Adams, 2010: 119).

The surface area of the estuary is dependent on the state of the estuary mouth. During periods of mouth closure, the surface area of the East Kleinemonde increases to an estimated 0.36 km^2 (Ridden and Adams, 2008: 87; Ridden and Adams, 2010: 120; Whitfield *et al*., 2008: 454). When the estuary mouth has been breached, estuarine water is released to the ocean and the surface area of the system is reduced to 0.12 km^2 directly after a breaching event (Whitfield *et al*., 2008: 454).

Flood magnitude and frequency has marginally decreased within the catchment and the natural input of sediments into the estuary through runoff has been minimally altered (van Niekerk *et al.*, 2008: 12). As the increase in sedimentation is small, van Niekerk *et al*. (2008: 12) state that the sedimentation occurring within the estuary is likely to be similar to that under natural conditions. The source of any increased sedimentation of the estuary can be attributed to changes in catchment land-use as can altered water quality (van Niekerk *et al.,* 2008: 12).

3.1.2 Catchment

The river catchment area that feeds the East Kleinemonde is approximately 46.9 km^2 (Figure 3.3), with an estimated natural mean annual runoff of 2.86 x 10^6 m^3 (Whitfield *et al*., 2008: 454). The catchment consists of “a gently sloping high lying region used for pineapple and cattle farming and a relatively undisturbed steep-sloping stream and river valley in the lower reaches” (van Niekerk *et al*., 2008: 93). The immediate estuary catchment exhibits a small area of residential development, with most of these developments restricted to the periphery of the system (Figure 3.2). The latter residential area consists of an array of holiday homes and permanent dwellings (Orr *et al*., 2008: 40). Residential development near the estuary mouth is deemed to be impacting on the shoreline of the system (Whitfield *et al*., 2008: 454). The main negative impact on the system by residential development is nutrient input (Riddin and Adams, 2010: 120). Currently no domestic waste water treatment facilities exist in the town of Kleinemonde and thus the residential area makes use of septic tanks which subsequently increase nutrient inputs into the system (Human and Adam, 2011: 168).

Figure 3.2: East Kleinemonde Estuary with overlaid estuary functional zone delineation. The West Kleinemonde Estuary is in the lower left side of the picture.

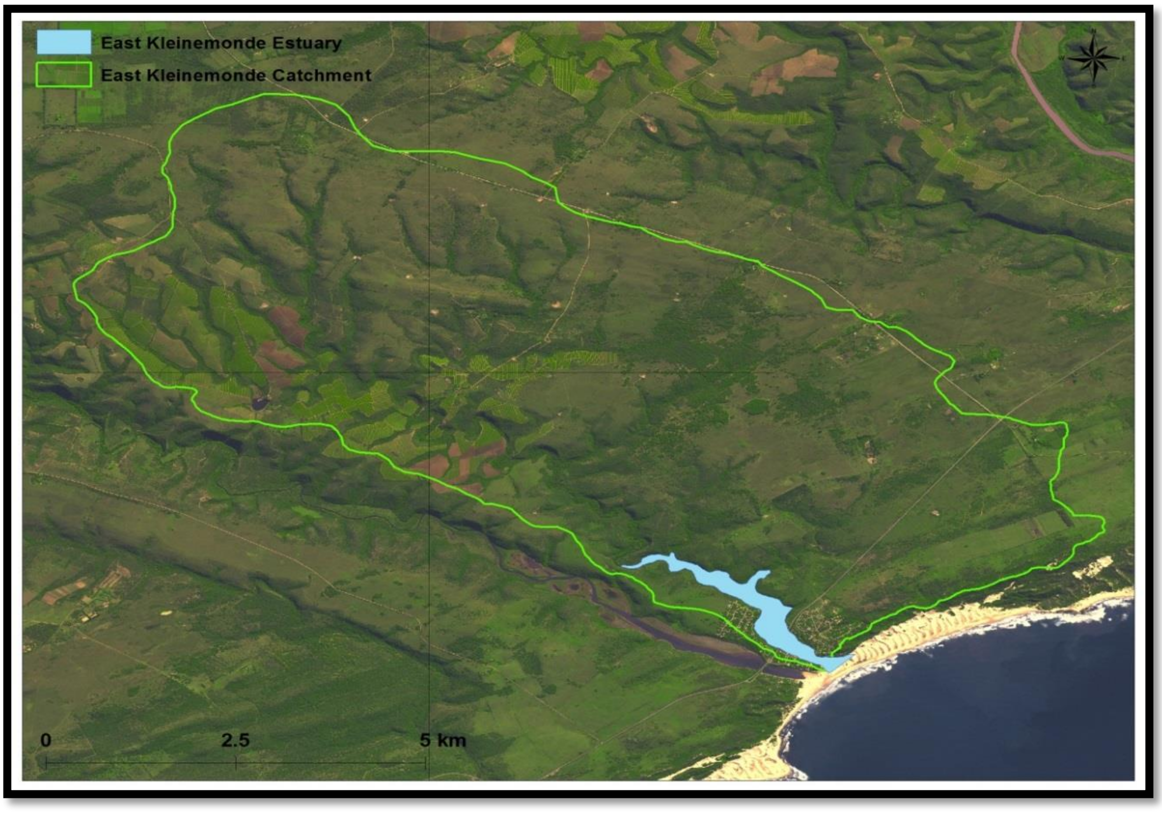

Figure 3.3: East Kleinemonde Estuary functional zone and catchment boundary delineations.

3.2 Current state of the system

The Ecological Reserve determination study for the East Kleinemonde was conducted by van Niekerk *et al*. (2008). Table 3.1 below shows the score attained for each EHI variable.

Table 3.1: Estuarine Health Index scores for the East Kleinemonde Estuary (van Niekerk *et al*., 2008: iv).

Variable	Weight (%)	Score	Weighted score
Hydrology	25	95	24
Hydrodynamics and mouth condition	25	90	23
Water quality	25	78	20
Physical habitat alteration	25	85	21
Habitat Health score			**87**
Microalgae	20	80	16
Macrophytes	20	85	17
Invertebrates	20	90	18
Fish	20	90	18
Birds	20	85	17
Biotic Health score			**86**
Estuarine Health score			**87**

Table 3.1 illustrates that the East Kleinemonde Estuary scored 87 out of a possible 100 for Habitat Health. The two weakest contributing variables to the Habitat Health score were water quality and physical habitat alteration. Water quality had the greatest decline from Reference Conditions but still scored 78 out of 100. The overall Biotic Health score for the estuary scored 86 out of 100. Under the Biotic Health score the five assessed variables scored similarly, with microalgae showing the greatest decline in health. The East Kleinemonde has an EHI score of 87 out of 100. An EHI of 87 classifies the PES of the Kleinemonde as B^+, i.e. largely natural with few modifications (Table 3.2).

The EHI of the East Kleinemonde categorises the PES of the East Kleinemonde as a Category B (Table 3.2). This means that the system has been modified from its Reference Condition, but overall it is still largely natural.

Table 3.2: Present Ecological Status classification based on the Estuarine Health Index (van Niekerk *et al*., 2008: iv).

Estuarine Health Index	Present Ecological Status	General Description
91 – 100	A	Unmodified, natural
76 – 90	**B**	**Largely natural with few modifications**
61 – 75	C	Moderately modified
41 – 60	D	Largely modified
21 – 40	E	Highly degraded
0 – 20	F	Extremely degraded

The East Kleinemonde has a Functional Importance score of 60 and the highest scoring criteria is the export of organic material generated within the estuary (van Niekerk *et al.*, 2008: 41). The East Kleinemonde's greatest function is that the system generates large amounts of organic material within the estuary during the closed phase and when the mouth opens the organic matter is then transported into the nearshore marine environment (van Niekerk *et al.*, 2008: 41).

Table 3.3: Estuarine Importance Scores for the East Kleinemonde Estuary (van Niekerk *et al*., 2008: iv).

Criterion	Weight	Score	Weighted Score
Estuary Size	15	70	11
Zonal Rarity Type	10	10	1
Habitat Diversity	25	90	23
Biodiversity Importance	25	84	21
Functional Importance	25	60	15
Estuarine Importance Score			**70**

The EIS for the East Kleinemonde was 70 out of 100 (Table 3.3), which classifies the estuary as being "Important" (Table 3.4).

Table 3.4: Estuarine Importance Score based on Present State (van Niekerk *et al*., 2008: iv).

Importance Score	Description
81 – 100	Highly important
61 – 80	**Important**
0 – 60	Of low to average importance

The EHI and PES of the Kleinemonde has been established to be 87 and B respectively, this places the estuary in an Ecological Reserve Category of B (Table 3.5). This classification represents the lowest ERC that should be permitted for the system, i.e. this system must not be allowed to deteriorate below a B ERC.

Table 3.5: Ecological Reserve Category as applied in the estuaries RDM process.

Estuarine Health Index	Present Ecological Status	Description	Ecological Reserve Category
91 – 100	A	Unmodified, natural	A
76 – 90	**B**	**Largely natural with few modifications**	**B**
61 – 75	C	Moderately modified	C
41 – 60	D	Largely modified	D
21 – 40	E	Highly modified	-
0 - 20	F	Extremely degraded	-

The recommended ERC of an estuary is the degree to which the system should be elevated above its PES (van Niekerk *et al.*, 2008: v). Factors contributing to the elevation of the minimum estuary ERC are the current or desired level of protection as well as estuary importance (Table 3.6).

The East Kleinemonde Estuary's PES and minimum ERC have been classified as a B^+. According to van Niekerk *et al*. (2008: v) the East Kleinemonde "is being targeted as a Desired Protected Area by the C.A.P.E. Estuaries Conservation Plan for the temperate areas of South Africa". This places the East Kleinemonde into the recommended ERC of A or Best Attainable State (Table 3.6). Although the East Kleinemonde should be in a recommended ERC of A, van Niekerk *et al.*, (2008; v) states that, due to urban development on the periphery of the estuary the system cannot be rehabilitated above a category B. Therefore the East Kleinemonde should be categorised as having a recommended ERC of B and the integrity of the system should be maintained at that level.

Table 3.6: Recommended Ecological Reserve Category based on level of protection and importance of an estuary (van Niekerk *et al*., 2008: v).

Current/desired protection status and estuary importance	Recommended Ecological Reserve Category	Policy basis
Protected area	A or Best Attainable State	Protected and desired protected areas should be restored to and maintained in the best possible state of health
Desired Protected Area		
Highly important	PES + 1, min B	Highly important estuaries should be in an A or B class
Important	PES + 1, min C	Important estuaries should be in an A, B or C class
Of low to average importance	PES, min D	The remaining estuaries can be allowed to remain in a D class.

Currently the PES of the Kleinemonde reflects that the system is largely natural with few modifications. Part of the Ecological Reserve Determination is to determine how existing and future pressures will impact on a system. For the East Kleinemonde, the PES of the system is classified as being on a downward trajectory of change (van Niekerk *et al*., 2008: iv). Identification, quantification and monitoring of land-use activities within the estuary's river catchment might provide insight into the proposed decline in system integrity and how a continuation of this trend might be avoided.

3.3 Catchment land-cover analysis

The East Kleinemonde Estuary drains a catchment of approximately 4685.7 ha (Table 3.7). A comparison between the size of the estuarine functional zone relative to catchment size indicates that the estuary only occupies 1.3% of the total area. The representative sizes and percentage of the whole catchment occupied by natural and transformed land-cover classes are shown in Table 3.7.

Table 3.7: Primary land-cover classes within the East Kleinemonde catchment.

Class	Area (ha)	Catchment (%)
Natural	3815.35	81.43
Transformed	805.23	17.18
Estuary	65.11	1.39
Total	**4685.69**	**100**

Table 1 illustrates that the area of the catchment that is still in its natural state covers 81.4% of the total catchment area, indicating that the catchment is still in a relatively natural state. Transformed land covers 17.1% of the total catchment area. Locations of transformed land can be seen along the western boundary and scattered locations in the south eastern portion of the catchment (Figure 3.4). On either side of the bottom half of the estuary the land has also been transformed, the effects of which may have a direct influence on the health of the system.

The second catchment analysis further classifies the category of 'Transformed' land into various land-cover types. The land-cover classes that can be seen within the East Kleinemonde catchment include: waterbodies, cultivation and urban built-up. The relative area and percentage catchment occupied by each land-use type is shown in Table 3.8 and their locations and distribution can be seen in Figure 3.5.

Natural land, as previously mentioned, covers 80% of the catchment and thus is the largest area. The next largest is that of cultivation, with agriculture accounting for 15.8% of the total area. Cultivated lands are located along the south-western border of the catchment, as well as small patches in the south-east. There are also a few small areas of cultivated lands which are located in close proximity to the upper reaches of the estuary delineation.

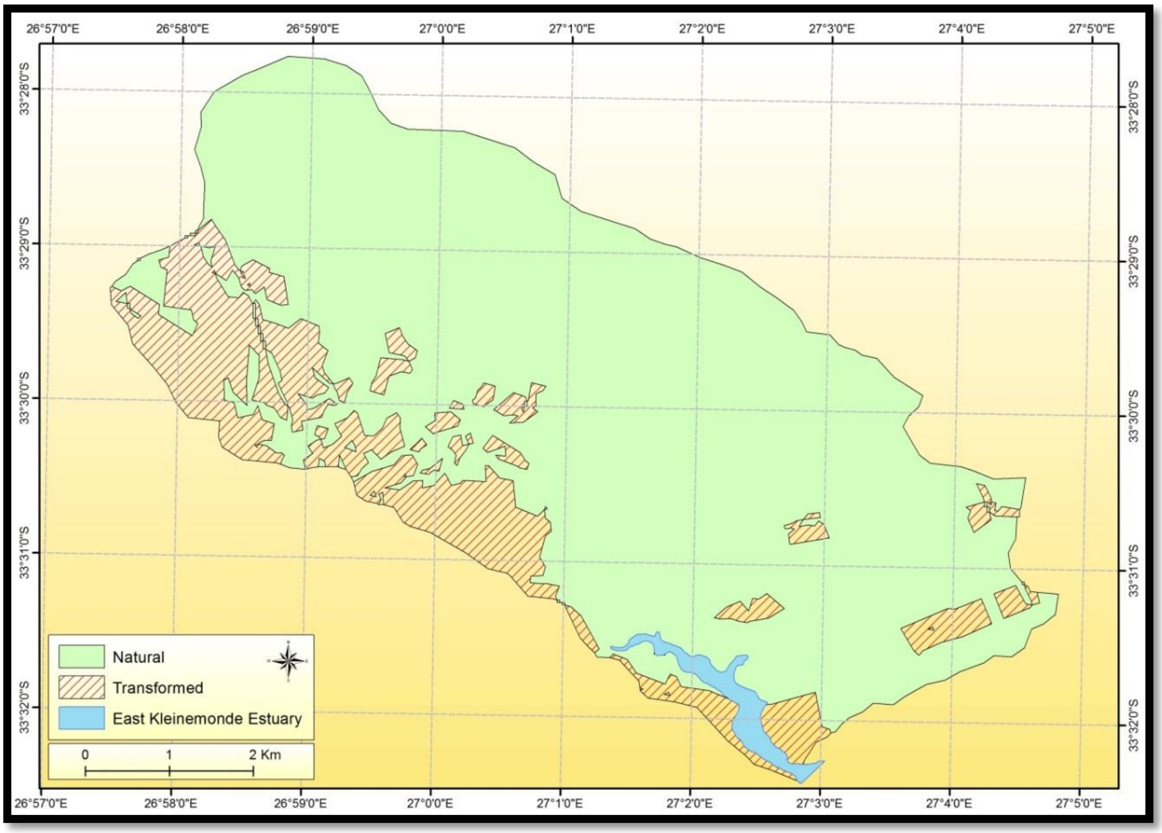

Figure 3.4: Primary land-cover classes within the East Kleinemonde catchment.

Table 3.8: Secondary land-cover classes within the East Kleinemonde catchment.

Class	Area (ha)	Catchment (%)
Estuary	65.11	1.39
Waterbodies	7.69	0.16
Natural	3807.59	81.27
Cultivation	739.80	15.79
Urban Built-up	65.16	1.39
Total	**4685.36**	**100**

The urban built-up area which is located on the immediate surrounds of the estuary covers 1.4% of the total catchment area. The last class of land-cover is that of waterbodies which account for just 0.2% of the catchment area. This land-use is mostly scattered within the natural areas, with the exception of a few small reservoirs being located near cultivated lands.

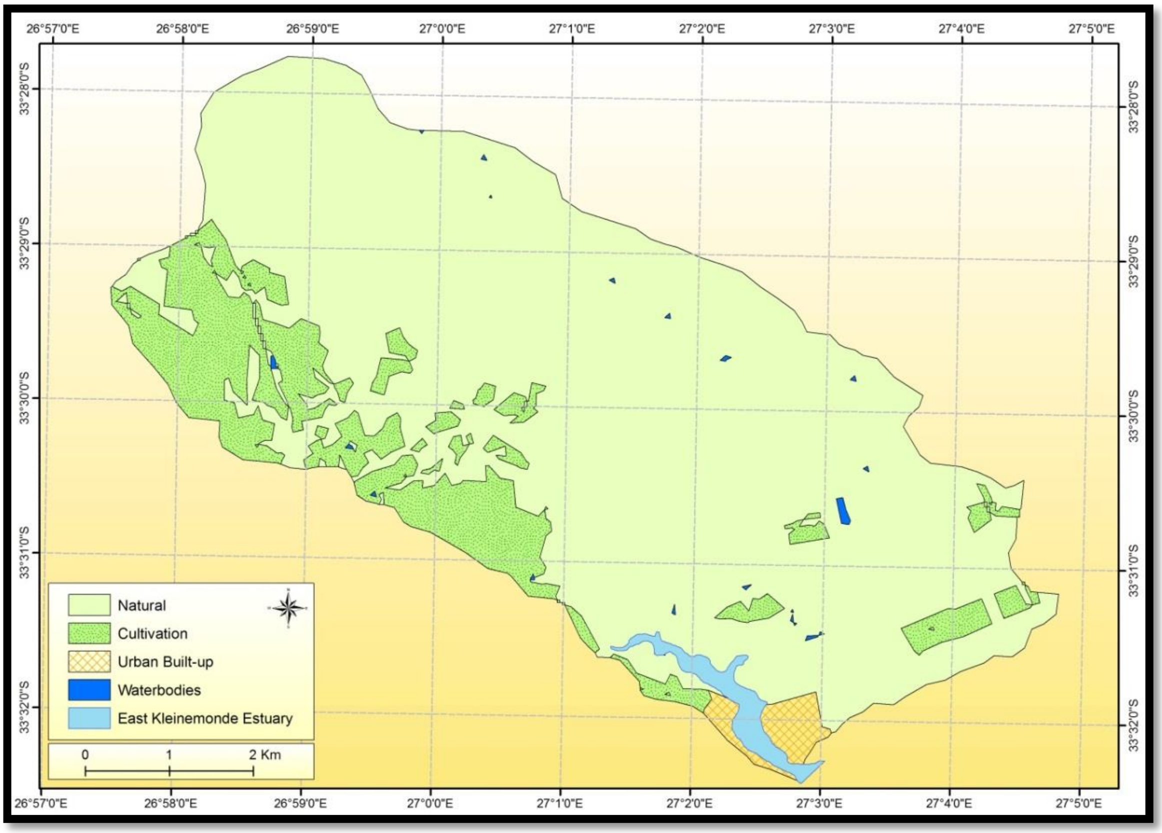

Figure 3.5: Secondary land-cover classes within the East Kleinemonde catchment.

A more in-depth analysis entailed dividing the catchment into sections. This isolated land-cover classes within each section for further analysis. Of primary concern was land-cover classes in the bottom section which, based on Tobler's First Law of geography would be more likely to have a greater impact on the system than land-cover further away in the catchment (Miller, 2004: 284). A DEM showing the path of the Kleinemonde River from source to estuary is displayed in Figure 3.6. The longitudinal profile of the river displaying gradient change is shown in Figure 3.7.

Dividing the catchment into sections proved difficult due to the absence of major changes in morphology and gradient of the river. For the purpose of this assessment the lower section of the catchment was therefore delineated at 40 m, as this is the last large gradient change along the river before it reaches the estuary (elevation change of 10 m over a short distance).

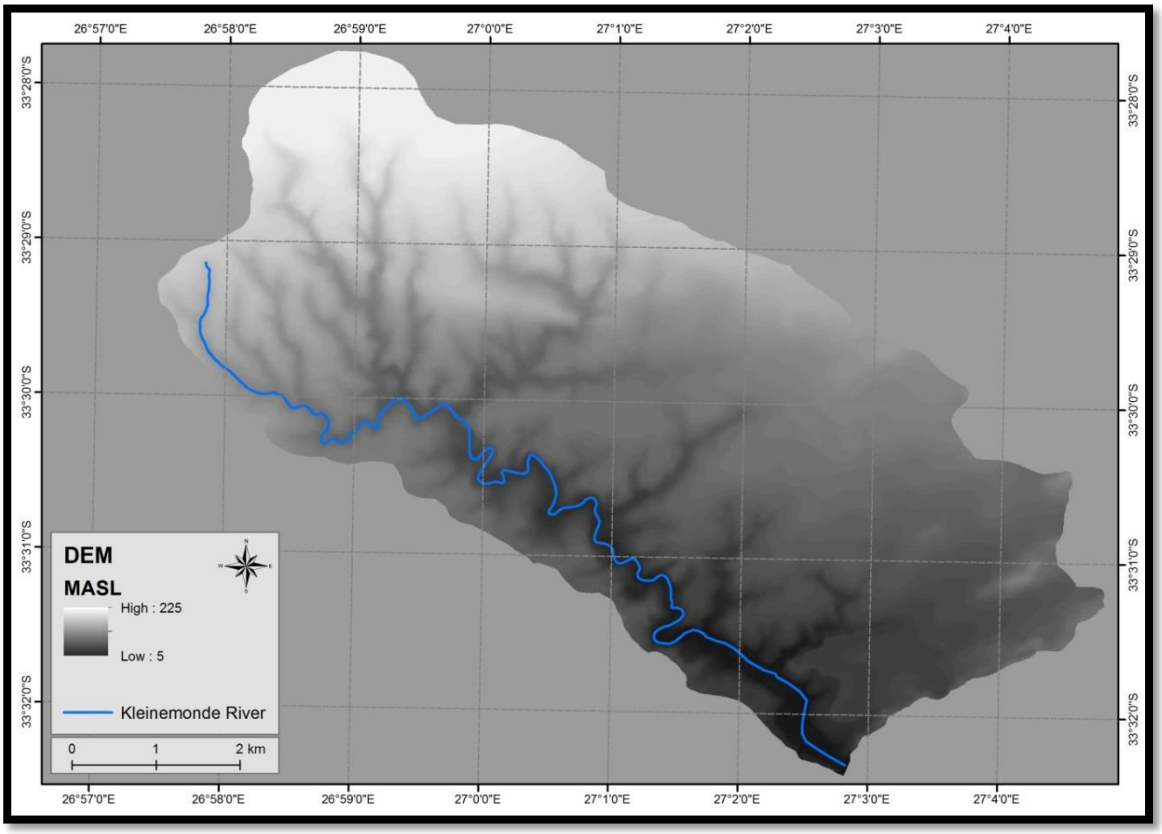

Figure 3.6: East Kleinemonde catchment Digital Elevation Model and river.

Secondary land-cover classes present in the lower section of the East Kleinemonde catchment include: natural, cultivation, urban built-up, waterbodies and the estuary. The distribution of the different land-cover classes within the lower section of the catchment are displayed in Figure 3.8. The representative areas and percentage of the catchment occupied by each land-cover class are shown in Table 3.9.

The predominant land-cover class in the lower section of the catchment is natural, accounting for 83% of the total area. The second largest land-cover class is cultivation occupying a total of 11.2% of the catchment. Urban built-up and the East Kleinemonde Estuary cover almost identical areas (each 2.7% of the catchment). Waterbodies are also present within the lower section of the catchment but account for <0.5% of the total area. This level of analysis yielded similar results to the previous assessment of the entire East Kleinemonde catchment.

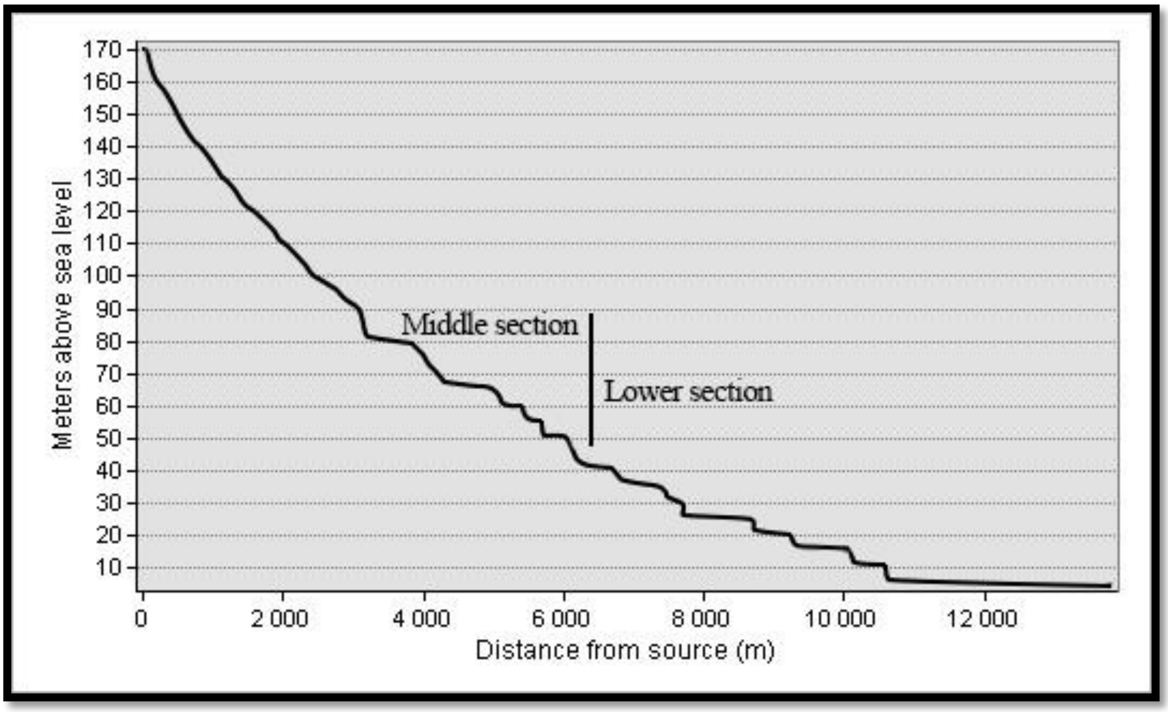

Figure 3.7: Longitudinal profile of the East Kleinemonde River.

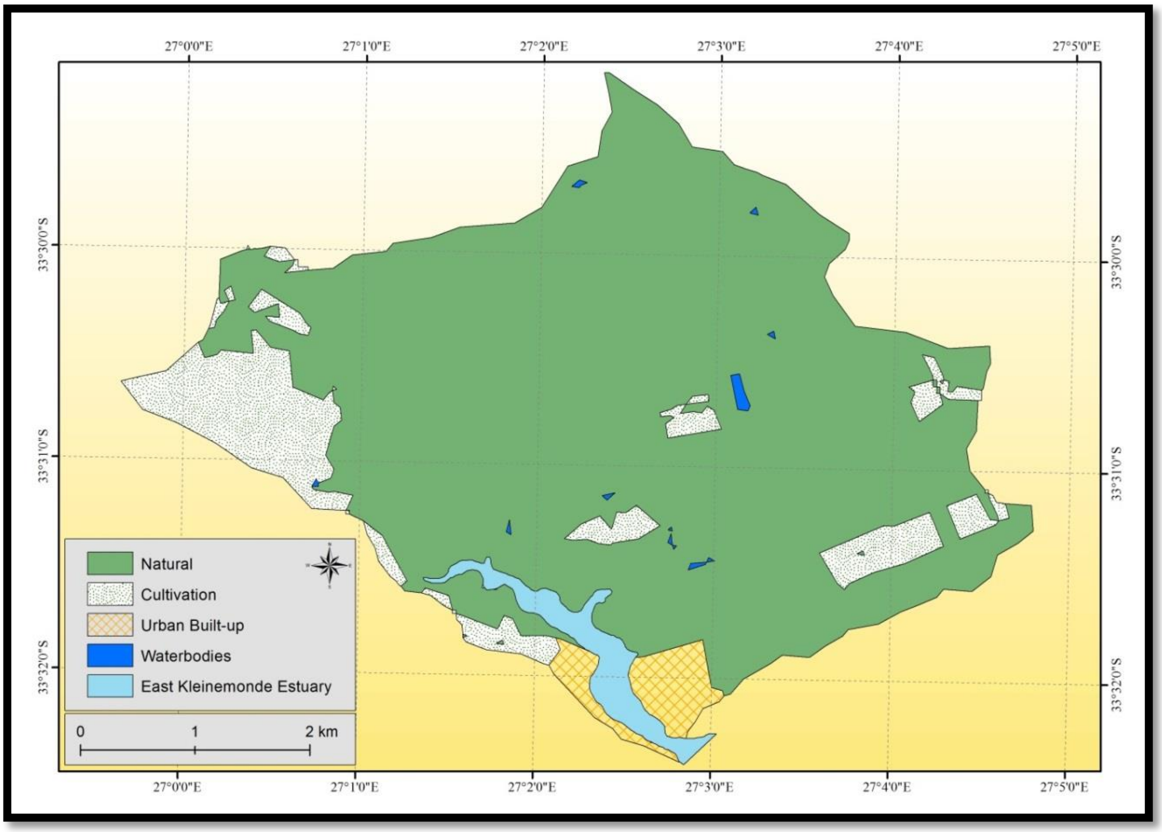

Figure 3.8: Secondary land-cover classes within the lower section of the East Kleinemonde catchment.

Table 3.9: Secondary land-cover classes within the lower section of the East Kleinemonde catchment.

Class	Area (ha)	Catchment (%)
Estuary	65.11	2.75
Waterbodies	5.44	0.23
Natural	1966.59	83.07
Cultivation	265.43	11.21
Urban Built-up	64.85	2.74
Total	**2367.42**	**100**

A 1 km buffer was created around the estuarine functional zone for further analysis of the surrounding catchment land-cover. Within the buffer zone three land-cover classes have been identified (Figure 3.9).

The 1 km buffer analysis again yielded similar results to the previous assessments. Natural land-cover is still the largest class covering 85.6% of the buffered area. Urban built-up within the buffer zone constitutes the second largest land-cover, accounting for 14.2% of the total area. Present within the buffer are a few scattered waterbodies that occupy only 0.2% of the total buffer area. Absent from within this buffer is the cultivation land-cover class which was present within the lower section analysis of the catchment.

An additional analysis in the form of a 100 m buffer around the estuary was also conducted on the catchment. Within this buffer, two land-cover classes are present, namely natural and urban built-up (Figure 3.10).

The 100 m buffer analysis showed that land still in a natural state accounts for 69.7% of the total area and is located mainly around the upper end of the estuary. Urban development is present mainly in the lower reaches of the estuary surrounds, occupying the remaining 30.3% of the buffer area.

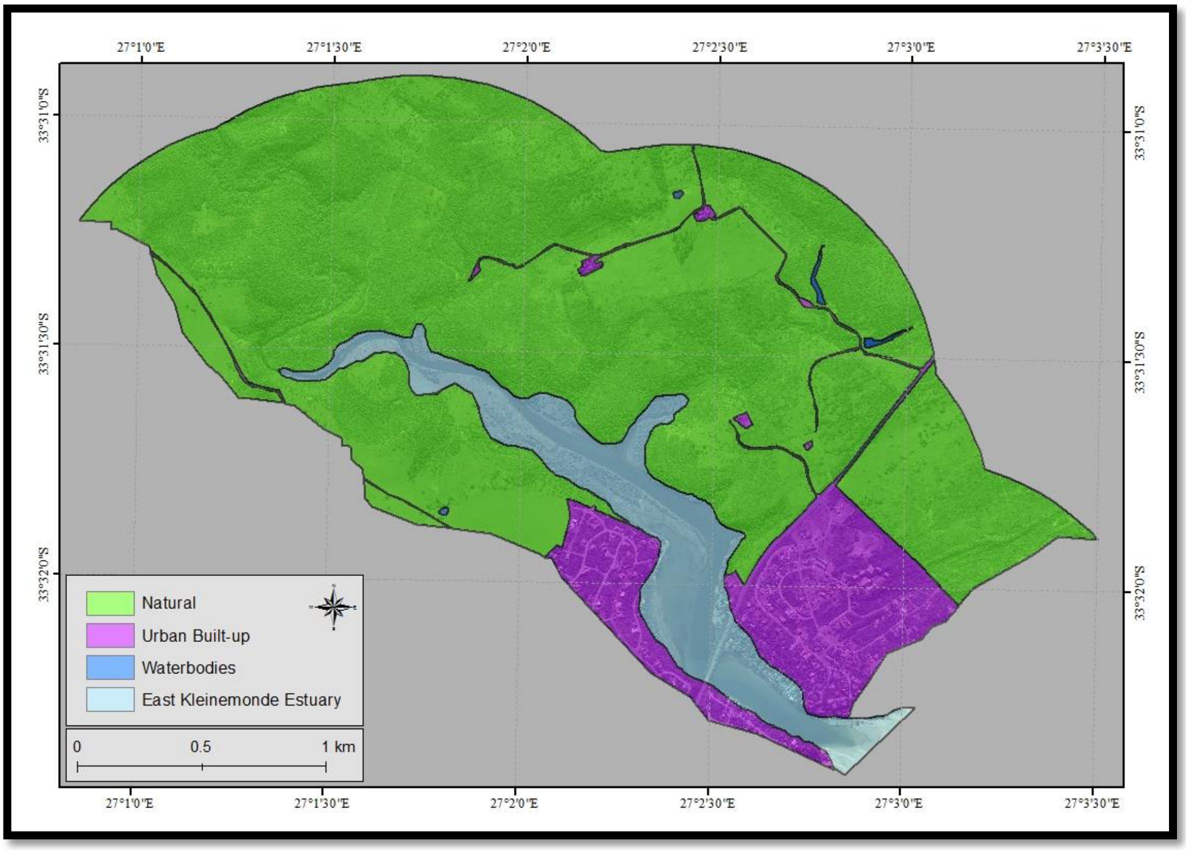

Figure 3.9: Secondary land-cover classes within a 1 km buffer of the East Kleinemonde Estuary.

An investigation of land-cover classes within the estuary delineation showed that the only class present is that of urban built-up (Figure 3.11). This urban encroachment of the estuary has transformed 10.6% of the estuarine functional zone, leaving 89.4% of the estuarine area in a natural state.

3.4 Anthropogenic activities affecting the current state of the system

In the study conducted by van Niekerk *et al*. (2008) the authors outlined influences which are currently affecting the East Kleinemonde Estuary negatively. At a specialist workshop for the study, it was noted that the influences negatively affecting the PES of the Kleinemonde system are: reductions in freshwater inflow, pressure from fishing within the estuary, anthropogenic disturbances in and around the estuary, as well as nutrients derived from catchment activities. Influences negatively affecting the estuary can be divided into two categories, namely those from the catchment and those from within the estuary.

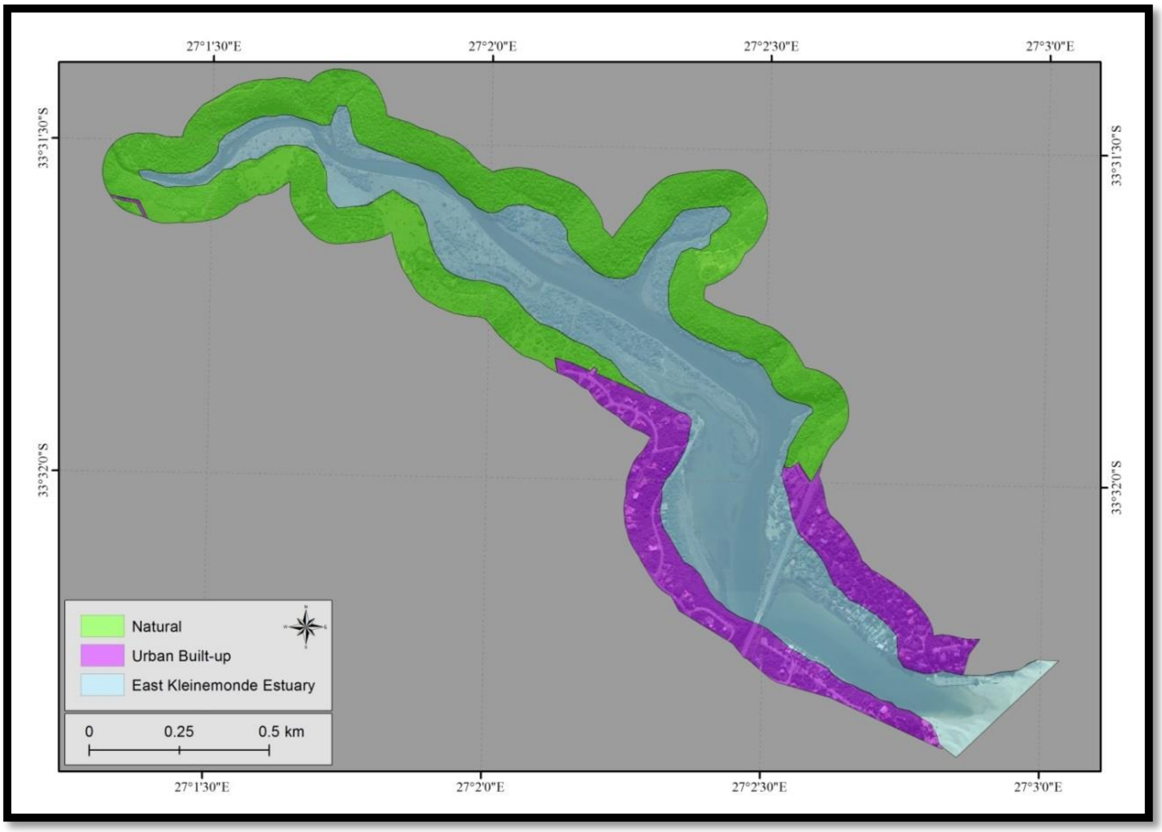

Figure 3.10: Secondary land-cover classes within a 100 m buffer of the East Kleinemonde Estuary.

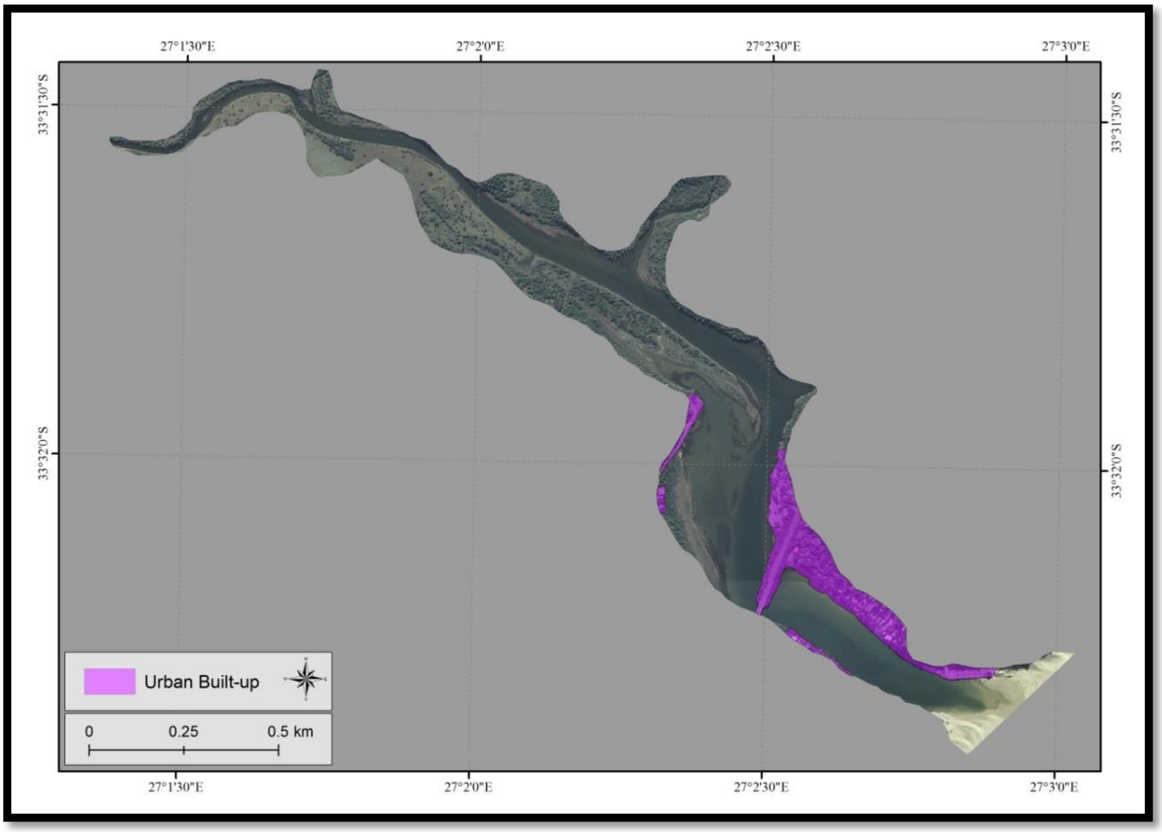

Figure 3.11: Secondary land-cover classes within the East Kleinemonde Estuary.

3.4.1 Catchment activities

Influences deriving from catchment activities include reductions in freshwater flow entering the estuary, whereas anthropogenic disturbances around the estuary mainly affect nutrients entering the system. Although reductions in freshwater inflows have been noted, inflow into the estuary has hardly changed from the estuary's Reference Condition (van Niekerk *et al*. 2008: 12), e.g. the present flood regime has had a measured decrease of only of 1.8% from natural. This also indicates that the present sedimentation processes within the estuary must be similar to those under Reference Conditions. Sedimentation has also been deemed to be similar to that under Reference Conditions, but van Niekerk *et al.* (2008: 12) states that there might be a slight increase in sediments from catchment land-use change.

Anthropogenic activities around the estuary and the presence of nutrients in the estuary can be linked. The results from the East Kleinemonde estuary water quality tests, conducted during the RDM study, indicated that no measurable influence of nutrient enrichment was detected from the surrounding urban settlement, but rather nutrient enrichment within the estuary was indicative of agricultural activities in the catchment (van Niekerk *et al*., 2008: 15). However, there is reason to believe that the use of septic tanks within the urban area is having an influence on the system, as seen in increasing reed growth around the estuary (van Niekerk *et al*., 2008: 15; Human and Adams, 2011: 177). In addition van Niekerk *et al*. (2008: 15) suggest that the main factor contributing to a decrease in water quality within the estuary is agriculture within the catchment, as typical water quality alterations arising from agricultural activities (elevated levels of dissolved inorganic nitrogen, organic loading and pesticide residues) were recorded.

3.4.2 Estuary activities

Negative influences originating from within the estuarine environment and that are currently affecting the estuary include anthropogenic disturbances as well as fishing pressures. Anthropogenic disturbances within the estuary can be attributed to the construction of a road bridge and embankments across the estuary (van Niekerk *et al*., 2008: 15). These constructions have subsequently changed the morphology of the estuary upstream from the mouth, e.g. scouring of deep channels have been promoted along the western side of the estuary in the vicinity of the road bridge and there has been extensive sediment deposition along the eastern estuary littoral downstream of the road embankment (van Niekerk *et al*., 2008: 15).

3.5 Discussion

The East Kleinemonde Estuary is regarded as an important ecosystem and PES of the system has been forecast to be on a projection of negative change. The estuary scored highly according to the EHI and the ERC allocated to the system, and the estuary is thus classified as largely natural with few modifications. The same classification could be applied to the catchment as it is also predominantly natural with few modifications.

Modification or transformation of natural land within the catchment is mainly in the form of cultivation and urban development. Although agricultural activities are considered to impact heavily on the system, they are not found within 1 km of the estuarine functional zone. It is possible that the dominance of natural vegetation in this 'buffer zone' mitigates the negative influence of the upper catchment agricultural activities (Tiner, 2004: 228; Viaud *et al*., 2004: 559).

The catchment land-cover analysis of this system showed that the greatest potential threat to the estuary was that of urban development due to the proximity of this land-cover to the estuarine functional zone. The majority of the area occupied by urban development occurs within the area demarcated as the CPZ (1 km buffer) and urban areas appear in larger proportions within the 100 m buffer zone around the estuarine functional zone. Effects deriving from this land-cover may drain directly into the ecosystem affecting its integrity. Urban development was also present within the estuarine functional zone contributing to habitat destruction, which is classified as a sensitive area for the ecological functioning of the system.

In conclusion, a relationship can be identified between land still in a natural state and health of the estuary. The CPZ and estuarine functional zone of this estuary is primarily still in a natural state with few land-cover changes and thus it is to be expected that the estuary scored a high EHI.

CHAPTER 4: GROOT BRAK ESTUARY

4.1 Study area

4.1.1 Estuary

The Groot Brak estuary is situated in the Western Cape Province, almost midway between the towns of Mossel Bay and George on the Garden Route (Figure 4.1). The location of the estuary mouth is 34° 03‘20” S and 22° 14’ 19” E and the estuary is 7.4 km in length.

Figure 4.1: Location of the Groot Brak Estuary and associated catchment (inset image from CSIR, n.d).

The Groot Brak Estuary has been classified as a TOCE, characterised by a sand berm at the mouth which periodically blocks salt water exchange with the ocean. The estuary mouth exhibits a low rocky headland on the eastern side and a sand-spit on the western side (Figure 4.2) (van Niekerk *et al.*, 2009: 5).

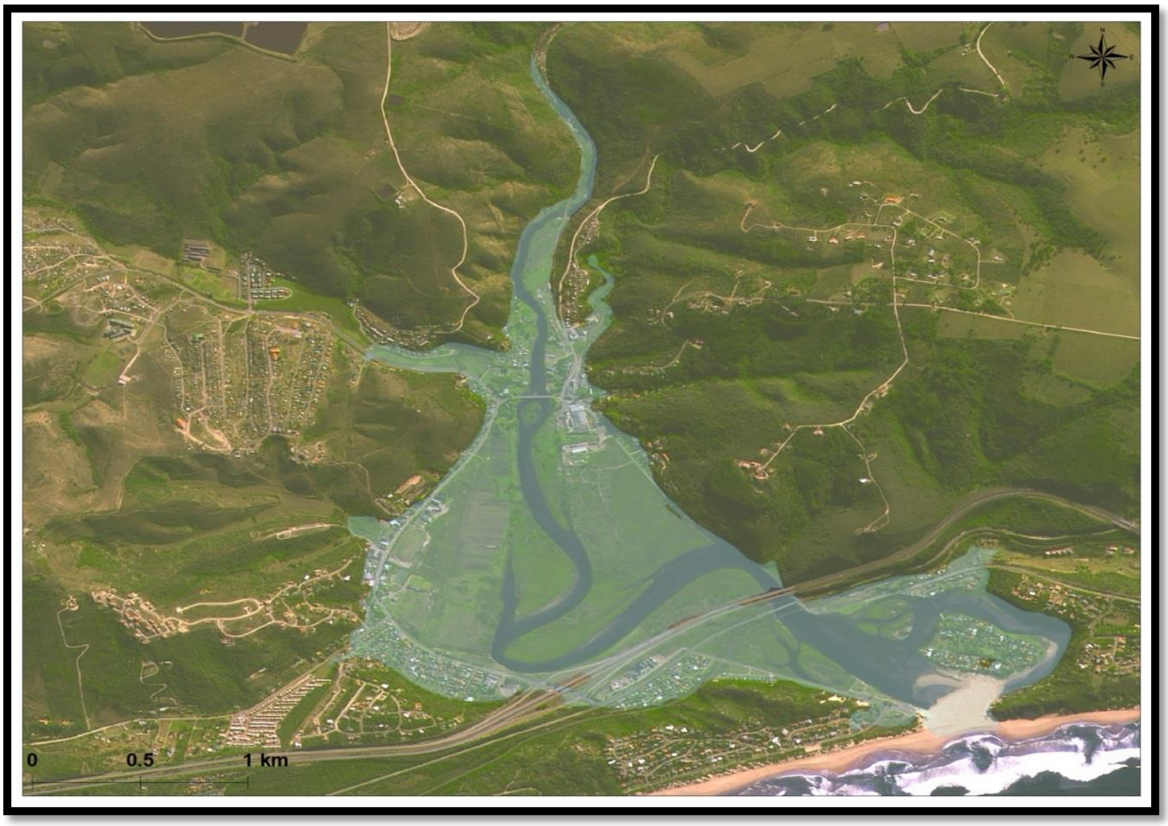

Figure 4.2: Groot Brak Estuary with overlaid estuary functional zone delineation.

TOCE systems are characterised as generally being shallow in depth. Depth of this estuary generally varies between 0.5 m and 1.2 m, with areas of deep scouring (2-4 m) occurring mainly around the road bridge (van Niekerk *et al*., 2009: 5). The estuary has a high tide area of 0.6 km^2 (Anchor Environmental, 2012: i) but this can increase further during the closed mouth phase.

Urbanisation is present within the estuary delineation and along portions of its peripheries (Figure 4.2). A noteworthy area of urbanisation exists on a permanent island in close proximity to the estuary mouth. The island is approximately 0.45 km by 0.25 km and is a permanently settled residential area (van Niekerk *et al.*, 2009: 5). In addition urban development is also present within the south-western border as well as the top end of the delineated estuarine functional zone.

4.1.2 Catchment

The Groot Brak catchment (Figure 4.3) is approximately 165 km^2. Rainfall within the catchment has low variability throughout the year, with the exception of slight peaks during spring and autumn (van Niekerk *et al*., 2009: 5). The catchment is occasionally subjected to periods of drought and also heavy rainfall leading to flooding. Recorded runoff within the catchment thus varies between 4.3 x 10^6 m^3 and 44.5 x 10^6 m^3 annually (van Niekerk *et al*., 2009: 5). Estimated MAR for the catchment is 39.52 x 10^6 m^3 (Anchor Environmental (2012: 9). Present day runoff entering the estuary is reduced due to water abstraction from the Wolwedans Dam and afforestation within the catchment (van Niekerk *et al*., 2009: 5).

The Wolwedans Dam is located approximately 2 km upstream from the head of the estuary (Huizinga, 1995: 88) and has a holding capacity of 23.0 x 10^6 m^3 (Slinger *et al*., 2005: 198) which is slightly more than half the catchment MAR. Water, nutrient and sediment trapping by the dam impacts negatively on the integrity of the Groot Brak estuarine system (Anchor Environmental, 2012: 40).

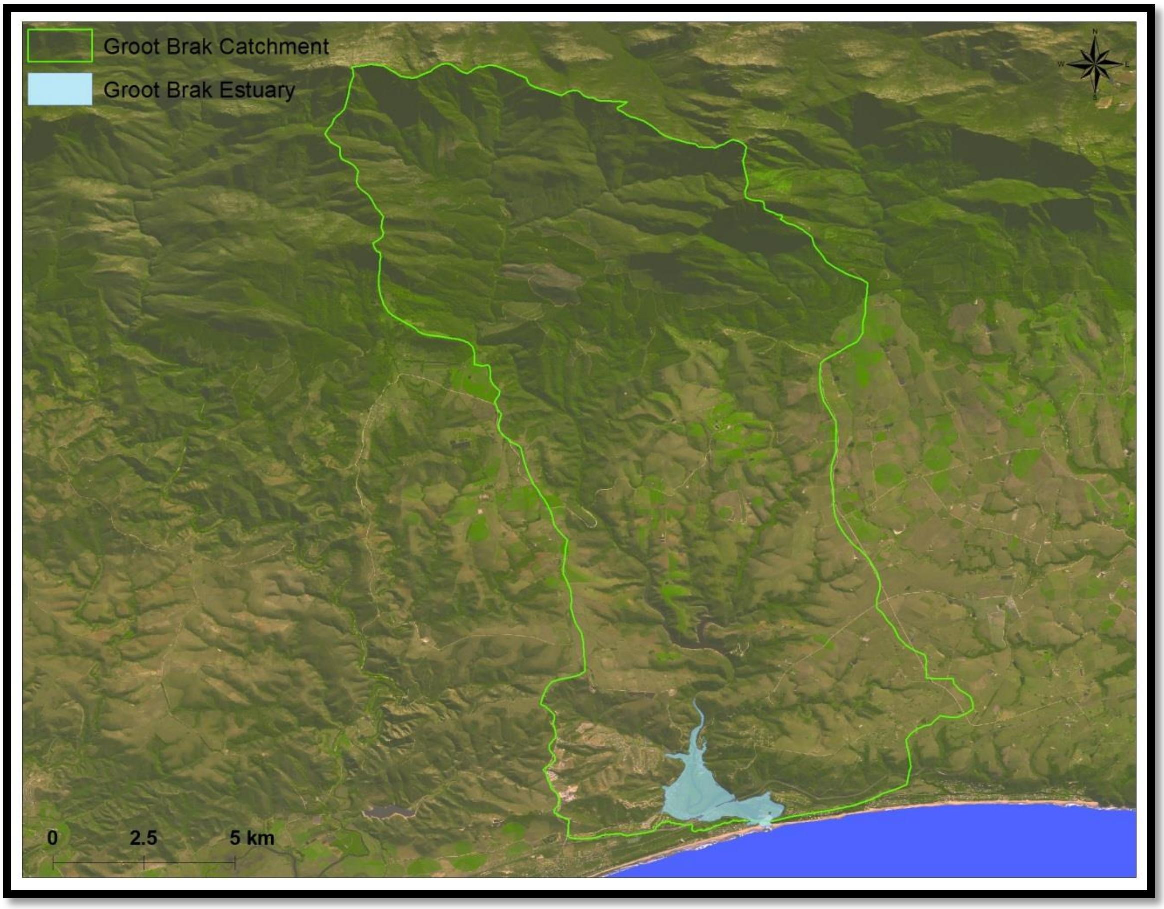

Figure 4.3: Groot Brak Estuary functional zone and catchment boundary delineations.

Agriculture and afforestation are practised within the catchment. Afforestation is primarily localised to the top third of the catchment and agriculture dispersed within the bottom two thirds (Figure 4.3). Types of agriculture practised include: pasture, wheat and vegetable cultivation (Anchor Environmental, 2012: 11). Afforestation, coupled with water abstractions have resulted in a flow decline of 36.8 x 10^6 m^3 to 16.3 x 10^6 m^3 per annum (van Niekerk *et al*., 2009: 5).

Small areas of urban development are present within the catchment, the majority of which are in the bottom third of the catchment, in close proximity to the estuary. The town of Groot Brak is located near the mouth of the estuary, with satellite developments occuring on the floodplain of the system (Anchor Environmental, 2012: 11). The estuary is a popular holiday destination and population figures for this area increase significantly over vacation periods (Anchor Environmental, 2012: 11).

4.2 Current state of the system

The Ecological Reserve determination study for the Groot Brak Estuary was conducted by van Niekerk *et al*. (2009). Table 4.1 below shows the score attained for each EHI variable.

Table 4.1: Estuarine Health Index scores for the Groot Brak Estuary (van Niekerk *et al.*, 2009: iv).

Variable	Weight (%)	Score	Weighted score
Hydrology	25	67	17
Hydrodynamics and mouth condition	25	56	14
Water quality	25	50.2	13
Physical habitat alteration	25	83	21
Habitat Health score			**64**
Microalgae	20	60	12
Macrophytes	20	40	8
Invertebrates	20	50	10
Fish	20	40	8
Birds	20	68	14
Biotic Health score			**52**
Estuarine Health score			**58**

The Groot Brak scored 64 out of 100 for the Habitat Health score (Table 4.1). The two worst scoring variables affecting the Habitat Health score are hydrodynamics and mouth condition, and water quality. Water quality has the lowest score meaning it is the variable that has deviated the most from Reference Conditions. The Groot Brak Estuary scored 52 out of a possible 100 for the Biotic Health component of the EHI. The variables that contributed equally to the Biotic Health score were macrophytes and fish. Overall the estuary was given an Estuarine Health score of 58 out of 100. This means that the PES of the system is calculated to be a D^+ (Table 4.2) which indicates that the system is largely modified and has been subject to degradation (van Niekerk *et al.*, 2009: iv). According to van Niekerk *et al.* (2009: iv) degradation leading to loss of integrity of the system can be linked to high nutrient inputs, over-exploitation of living resources and extended periods of mouth closure.

Table 4.2: Present Ecological Status classification of the Groot Brak Estuary based on the Estuarine Health Index (van Niekerk *et al.*, 2009: iv).

Estuarine Health Index	Present Ecological Status	General Description
91 – 100	A	Unmodified, natural
76 – 90	B	Largely natural with few modifications
61 – 75	C	Moderately modified
41 – 60	**D**	**Largely modified**
21 – 40	E	Highly degraded
0 – 20	F	Extremely degraded

The Groot Brak Estuary has a Functional Importance score of 70 (Table 4.3) based on its role as a "movement corridor for river invertebrates and fish breeding in sea" (van Niekerk *et al.*, 2009: iv).

The EIS for the Groot Brak Estuary was 72 out of 100 (Table 4.4), which classifies the estuary as being "important" (Table 4.5). The EHI and PES of the Groot Brak has been established to be 58 and D^+ respectively, this places the estuary in an Ecological Reserve Category of D (Table 4.6). This classification represents the lowest ERC allowed for this system.

Table 4.3: Functional Importance of the Groot Brak Estuary (van Niekerk *et al*., 2009: iv).

Functional importance	Score
(a) Export of organic material generated in the estuary (regional scale)	20
(b) Nursery function for fish and crustaceans (marine/ riverine)	50
(c) Movement corridor for river invertebrates and fish breeding in sea	70
(d) Roosting area for marine or coastal birds	10
(e) Catchment detritus, nutrients and sediments to sea	20
Functional importance score (maximum score of (a) to (e))	**70**

Table 4.4: Estuarine Importance Scores for the Groot Brak Estuary (van Niekerk *et al*., 2008: iv).

Criterion	Weight	Score	Weighted Score
Estuary Size	15	90	14
Zonal Rarity Type	10	10	1
Habitat Diversity	25	80	20
Biodiversity Importance	25	79.5	20
Functional Importance	25	70	18
Estuarine Importance Score (rounded off)			**72**

Table 4.5: Estuarine Importance Score based on Present State (van Niekerk *et al*., 2008: iv).

Importance Score	Description
81 – 100	Highly important
61 – 80	**Important**
0 – 60	Of low to average importance

The Groot Brak estuary has been deemed an important estuary and the recommended ERC for the system is PES + 1, i.e. a minimum of a C (Table 4.7). A contributing factor towards attaining a category C for the system is that many existing pressures can be mitigated and reversed with little effort and cost (van Niekerk *et al*., 2009: V).

Table 4.6: Ecological Reserve Category as applied in the estuaries RDM process.

Estuarine Health Index	Present Ecological Status	Description	Ecological Reserve Category
91 – 100	A	Unmodified, natural	A
76 – 90	B	Largely natural with few modifications	B
61 – 75	C	Moderately modified	C
41 – 60	**D**	**Largely modified**	**D**
21 – 40	E	Highly modified	-
0 – 20	F	Extremely degraded	-

Table 4.7: Recommended Ecological Reserve Category based on level of protection and importance of an estuary (van Niekerk *et al*., 2008: v).

<table>
<tr><th>Current/desired protection status and estuary importance</th><th>Recommended Ecological Reserve Category</th><th>Policy basis</th></tr>
<tr><td>Protected area</td><td rowspan="2">A or Best Attainable State</td><td rowspan="2">Protected and desired protected areas should be restored to and maintained in the best possible state of health</td></tr>
<tr><td>Desired Protected Area</td></tr>
<tr><td>Highly important</td><td>PES + 1, min B</td><td>Highly important estuaries should be in an A or B class</td></tr>
<tr><td>Important</td><td>PES + 1, min C</td><td>Important estuaries should be in an A, B or C class</td></tr>
<tr><td>Of low to average importance</td><td>PES, min D</td><td>The remaining estuaries can be allowed to remain in a D class.</td></tr>
</table>

4.3 Catchment land-cover analysis

The Groot Brak Estuary drains a catchment of approximately 165 km^2 (Table 4.8). A comparison between estuarine functional zone size relative to catchment size indicates that the estuary occupies 1.7% of the total area. The representative sizes and percentage of the whole catchment occupied by natural and transformed land-cover classes are shown in Table 4.8.

Table 4.8: Primary land-cover classes in the Groot Brak catchment.

Class	Area (ha)	Catchment (%)
Natural	5684.46	34.55
Transformed	10483.14	63.72
Estuary	284.51	1.73
Total	**16452.11**	**100**

Within the catchment of the Groot Brak Estuary the physical area categorised as transformed land covers 63.7% of the total catchment area. Excluding the estuary, the remainder of the catchment is natural land occupying 34.6% of the area. This substantial transformation must have a considerable impact on the natural processes within the catchment.

Much of the area of natural land is situated at the top of the catchment, with smaller portions existing in the middle region as well as patches surrounding the estuary itself (Figure 4.4). Most of the transformed land is located in the bottom two thirds of the catchment. It is also important to note that most of the area bordering the estuary has been transformed. This removal of a natural buffer will most likely have detrimental effects on the health of the estuary.

A more detailed classification divides the category of 'transformed' land into various land-cover types. The map shown in Figure 4.5 illustrates that land-cover within the Groot Brak catchment includes: waterbodies, cultivation, degraded land, urban built-up and plantations. The area and relative proportion occupied by each land-cover type is shown in Table 4.9.

The three land-cover classes occupying the greatest area in the catchment are natural land, cultivation and plantations, occupying 33.1%, 33% and 27.7% of the catchment respectively. As Figure 4.5 depicts, cultivated land occupies approximately the same area as the land still in its natural state. However the cultivated land within the catchment occupies much of the lower and middle region of the catchment compared to natural land which is mainly located in the upper catchment (Figure 4.5).

Plantations are located in two different areas within the catchment, the larger of which is located in the upper catchment, the second area is smaller and located adjacent to the Groot Brak Estuary. Other land-cover surrounding the estuary consists largely of urban built-up areas as well as small portions of natural and cultivated land. Urban areas cover approximately 2.6% of the catchment and are located in close proximately to the estuary, with only a small area situated within the northern plantations.

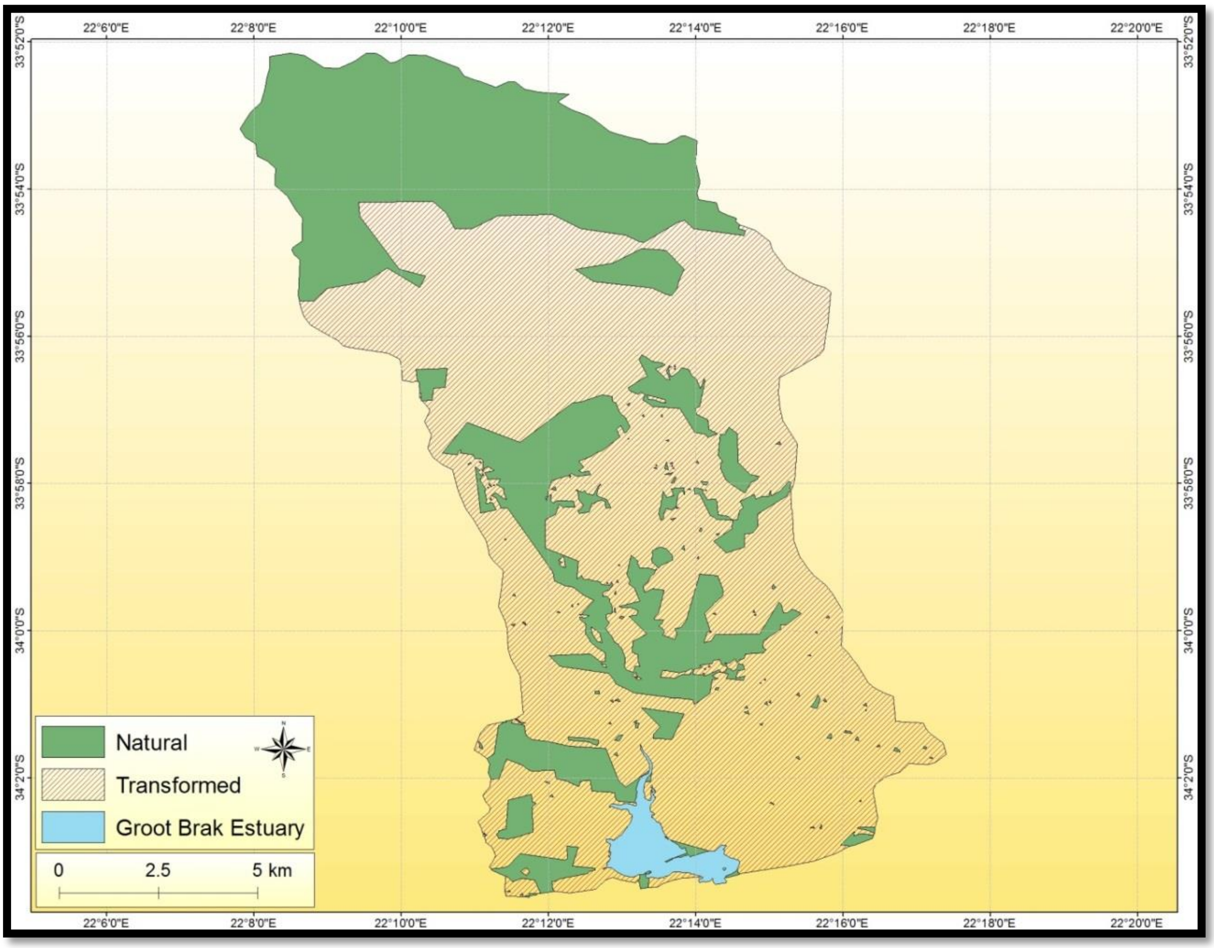

Figure 4.4: Primary land-cover classes within the Groot Brak catchment.

A major land-cover class which is evident in Figure 4.5 is that of waterbodies, the largest of which is the Wolwedans Dam located north of the of the Groot Brak Estuary. Other smaller waterbodies are scattered across the catchment, with the majority located amidst cultivated lands (suggesting that they may be used for irrigation purposes). Lastly, Figure 4.5 shows that 0.4% of the catchment cover has been degraded. Many of these degraded areas situated between areas of cultivated land in the middle portion of the catchment.

Table 4.9: Secondary land-cover classes in the Groot Brak catchment.

Class	Area (ha)	Catchment (%)
Estuary	284.51	1.73
Waterbodies	249.43	1.52
Natural	5436.72	33.05
Cultivation	5422.67	32.96
Urban Built-up	434.31	2.64
Plantations	4554.17	27.68
Degraded	70.52	0.43
Total	**16452.34**	**100**

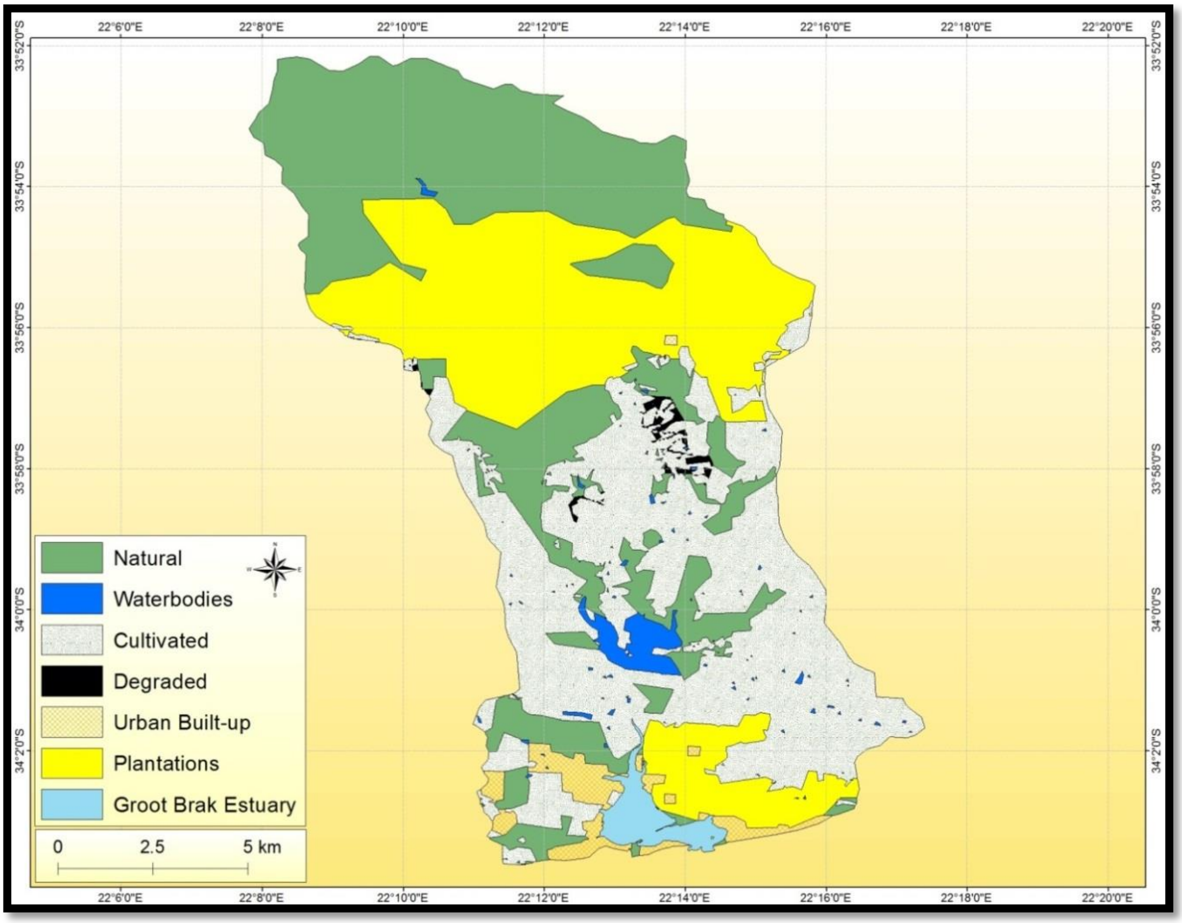

Figure 4.5: Secondary land-cover classes within the Groot Brak catchment.

Further analysis was conducted to divide the catchment into upper, middle and lower sections. This enabled the isolation of land-cover classes within the lower section of the catchment which, based on Toblers First Law of geography, would more likely have a greater influence on the system than land-cover classes in the middle and upper sections of the catchment (Miller, 2004: 284). A DEM showing the path of the Groot Brak River from source to estuary is displayed in Figure 4.6. The longitudinal profile of the river displaying gradient change is shown in Figure 4.7.

Figure 4.7 depicts that there is a major change in gradient at 100 MASL approximately 22 km from the source of the river. This indicates the location of the Wolwedans Dam which has a major impact on the morphology of the river channel. Therefore the lower section of the Groot Brak catchment incorporates all land that is below 100 m.

Secondary land-cover classes present within the lower section of the Groot Brak catchment include: natural areas, cultivation, urban built-up, waterbodies, plantations and the estuary. The locations of the land-cover classes depicted by the NLC database can be seen in Figure 4.8 and their representative areas occupied and percentage of the catchment are given in Table 4.10.

The land-cover class occupying the greatest area of the lower section of the catchment is cultivation which accounts for 52.2% of the total area. Cultivated lands are spread across the lower catchment section, predominently to the north and north-east of the estuary. Plantations, which occupy a large portion of land adjacent to the estuary, account for 17.3% of the catchment, thus making it the second highest land-cover class in the section. Areas delineated as urban built-up (10.5%) and natural land-cover (12.7%) classes are predominantly situated in close proximity to the estuary and account for similar percentages of the catchment. Small waterbodies are scattered throughout the lower section, predominently amongst or near cultivated lands.

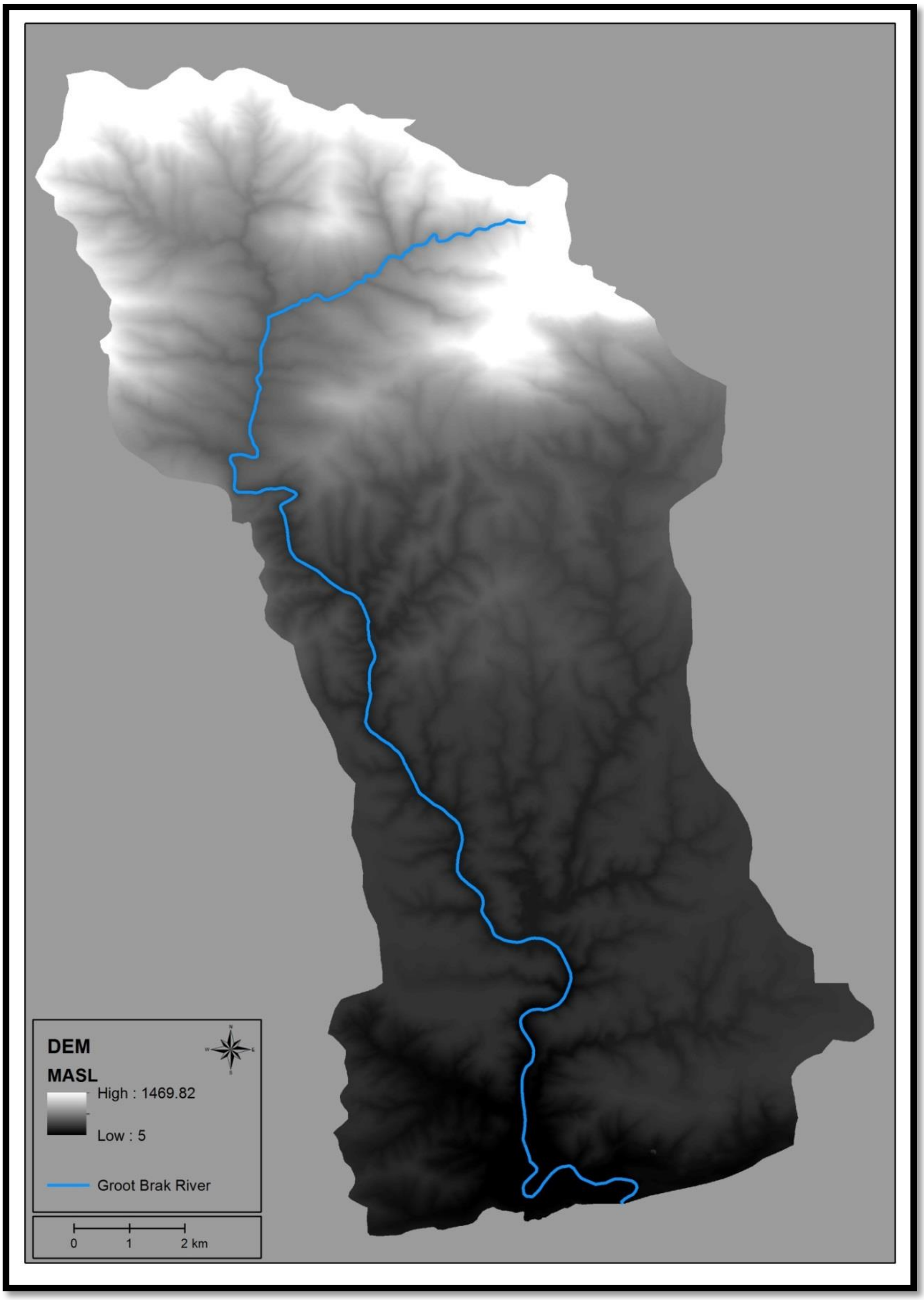

Figure 4.6: Groot Brak catchment Digital Elevation Model and river.

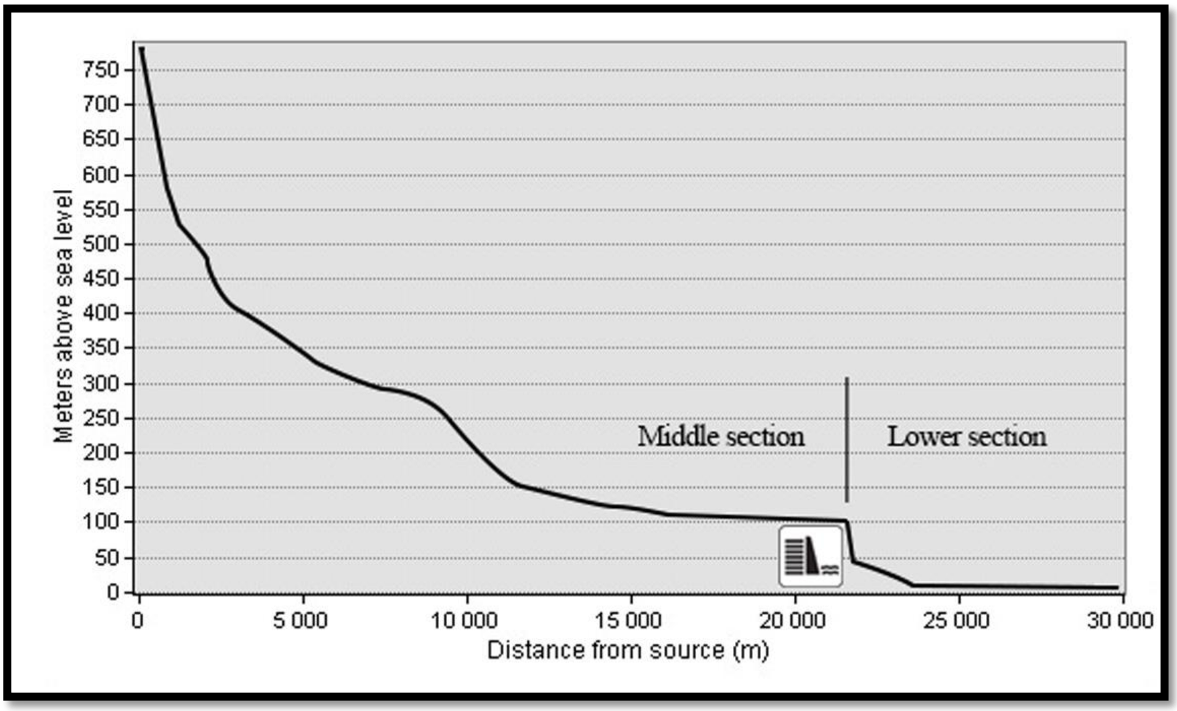

Figure 4.7: Longitudinal profile of the Groot Brak River.

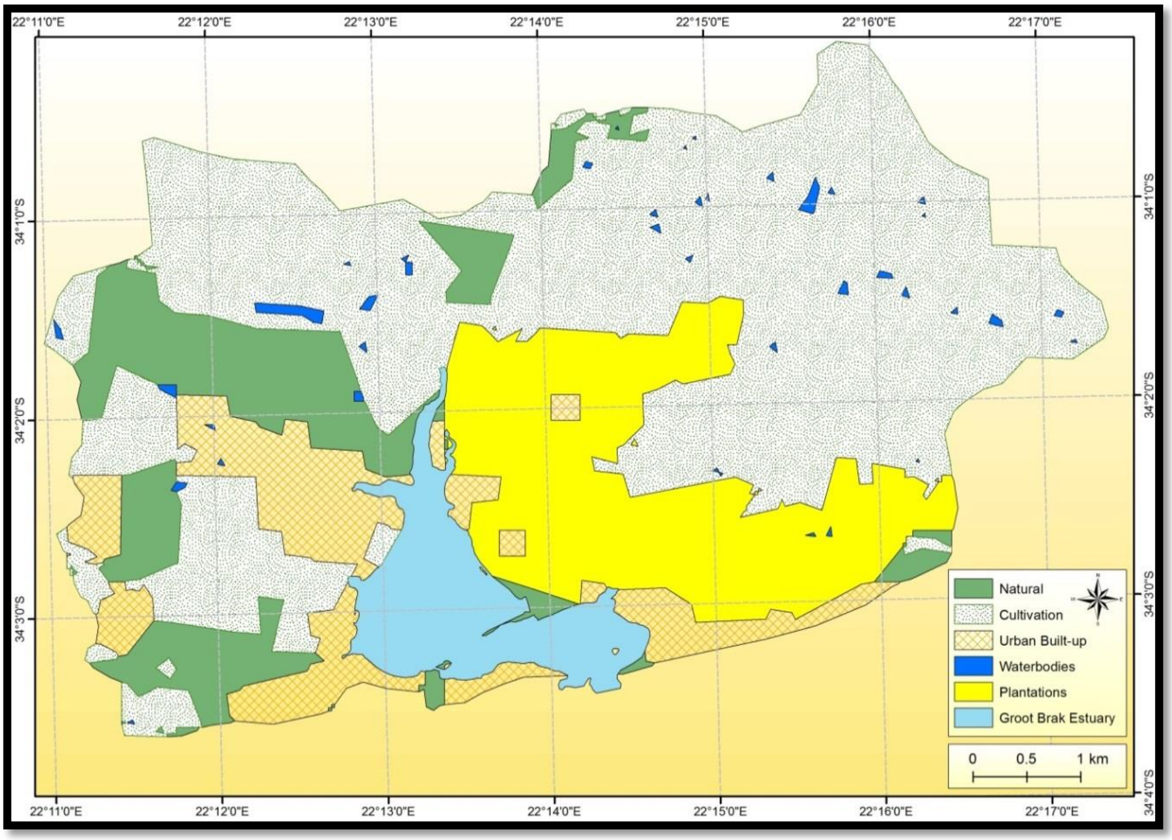

Figure 4.8: Secondary land-cover classes within the lower section of the Groot Brak catchment.

Table 4.10: Secondary land-cover classes within the lower section of the Groot Brak catchment.

Class	Area (ha)	Catchment (%)
Estuary	284.51	6.92
Natural	520.43	12.65
Cultivation	2145.22	52.16
Urban Built-up	430.83	10.48
Waterbodies	22.60	0.55
Plantations	709.27	17.25
Total	**4112.86**	**100**

A 1 km buffer was created around the estuary delineation for further analysis of the surrounding catchment land-cover and within this buffer zone five land-cover classes are present (Figure 4.9).

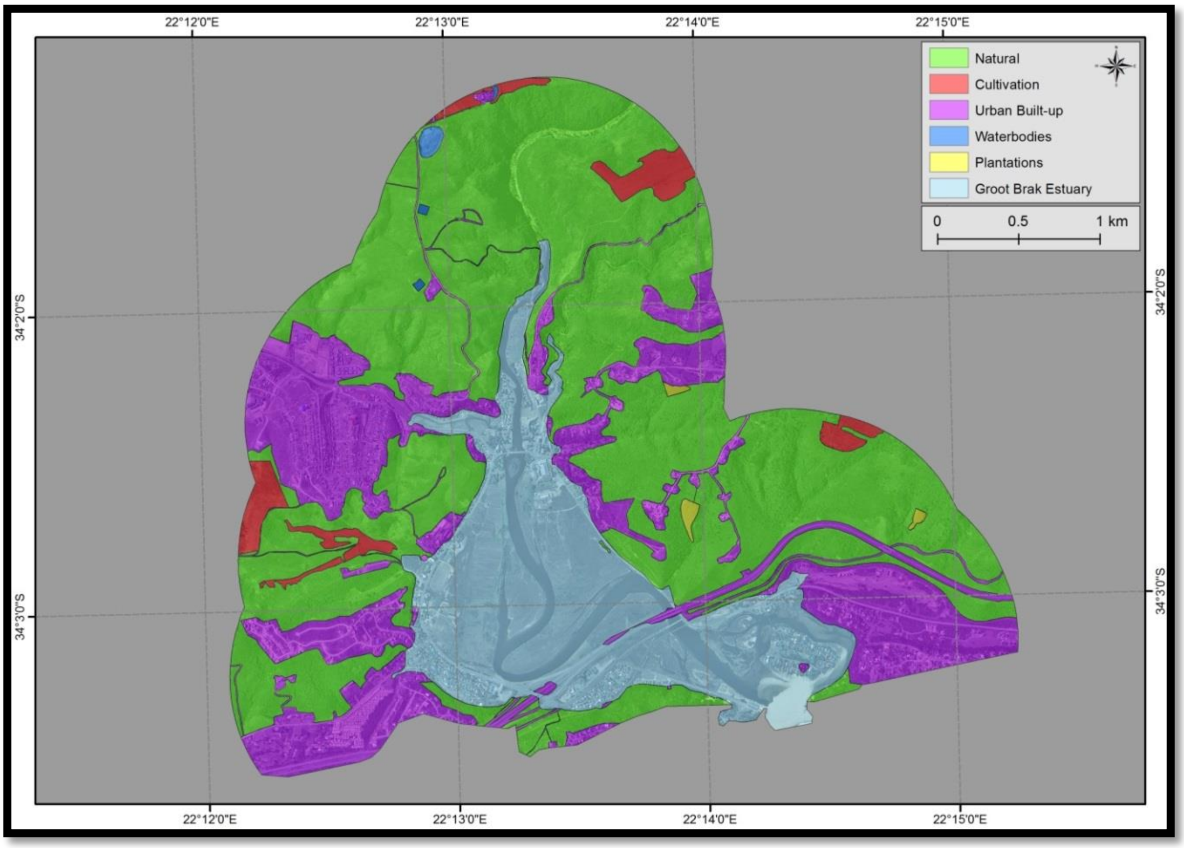

Figure 4.9: Secondary land-cover classes within a 1 km buffer of the Groot Brak Estuary.

Natural land-cover accounts for 66.1% of the 1 km buffer zone. This could indicate some natural buffering of detrimental polutants originating from catchment activites entering the system. The second largest land-cover class within this buffer zone comprised urban built-up, accounting for 29.9% of the buffer land-cover area. Cultivation, waterbodies and plantations are seen within the buffer zone, but only as relatively small percentages of the total area.

Within a 100 m buffer of the estuary delineation only three land-cover classes are present: natural, cultivation and urban built-up (Figure 4.10). The two largest land-cover classes are natural and urban-built-up accounting for 57.4% and 42.4% respectively. Cultivated land is also present within 100 m of the estuary but only occupies a very small percentage of the total area within the buffer.

Within the Groot Brak estuary delineation there are three land-cover classes including: natural, cultivation and urban built-up. Of the land delineated by the estuarine functional zone, 64.2% of the area is still in a natural state. The largest land-cover change is the encroachment of urban development, occupying 30.5% of the area within the estuary delineation. Cultivation is also identified within the estuary zone occupying 5.3% of the total area.

4.4 Anthropogenic activities affecting the current state of the system

In the RDM assessment by van Niekerk *et al.* (2009) the authors list activities which are negatively affecting the Groot Brak Estuary. The activities include: river flow reduction, artificial breaching, deteriorating water quality, structures in the intertidal area, development in and around saltmarshes, over-exploitation of both fish and bait organisms, disturbance of birds, and obstruction of the estuary and river by causeways, weirs and the Wolwedans Dam. Although these activities are currently negatively influencing the integrity of the system many have been deemed reversible (van Niekerk *et al*., 2009: v).

Activities with a negative influence affecting the estuary can be divided into two categories based on their location namely catchment and estuary. Catchment activities include: the Wolwedans Dam, weirs, river flow abstraction, deteriorating water quality, urban development and obstruction of the river by causeways. Estuarine activities include: bridges and causeways, human exploitation and artificial mouth breaching.

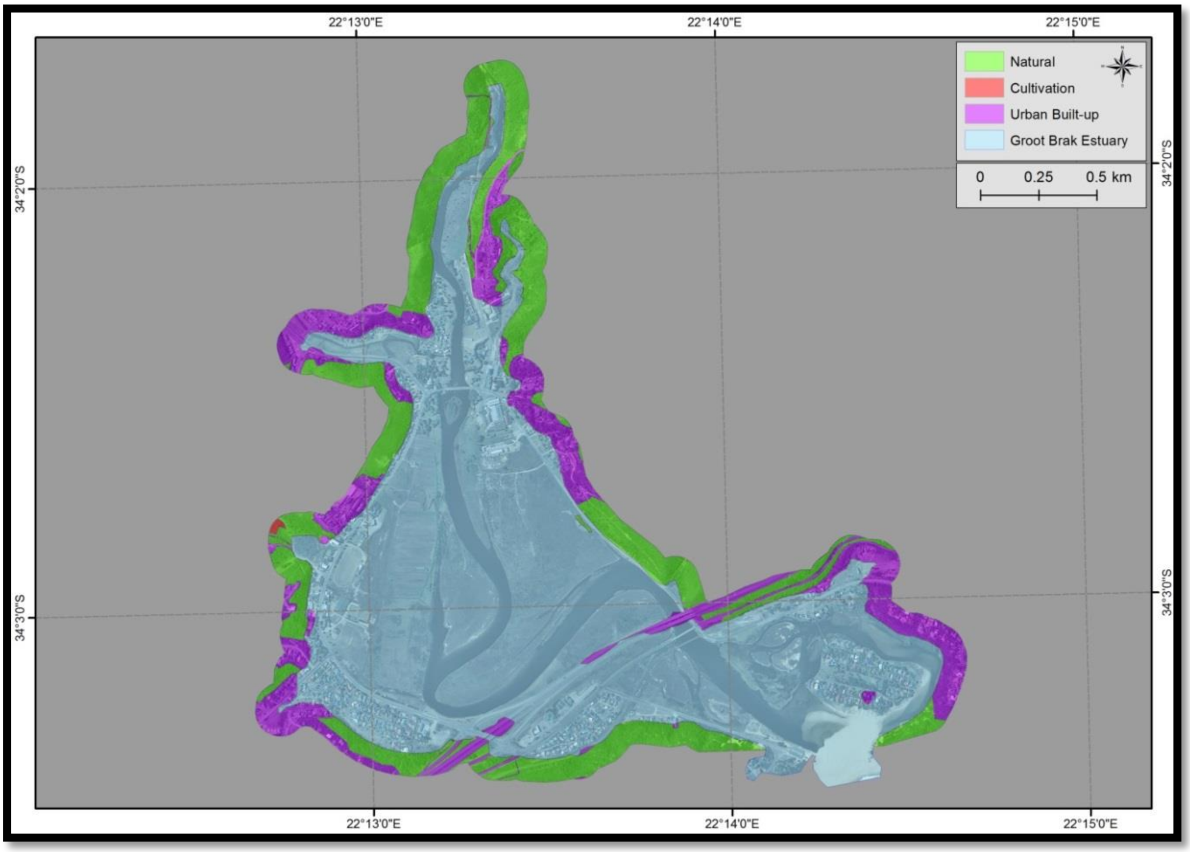

Figure 4.10: Secondary land-cover classes within a 100 m buffer of the Groot Brak estuary.

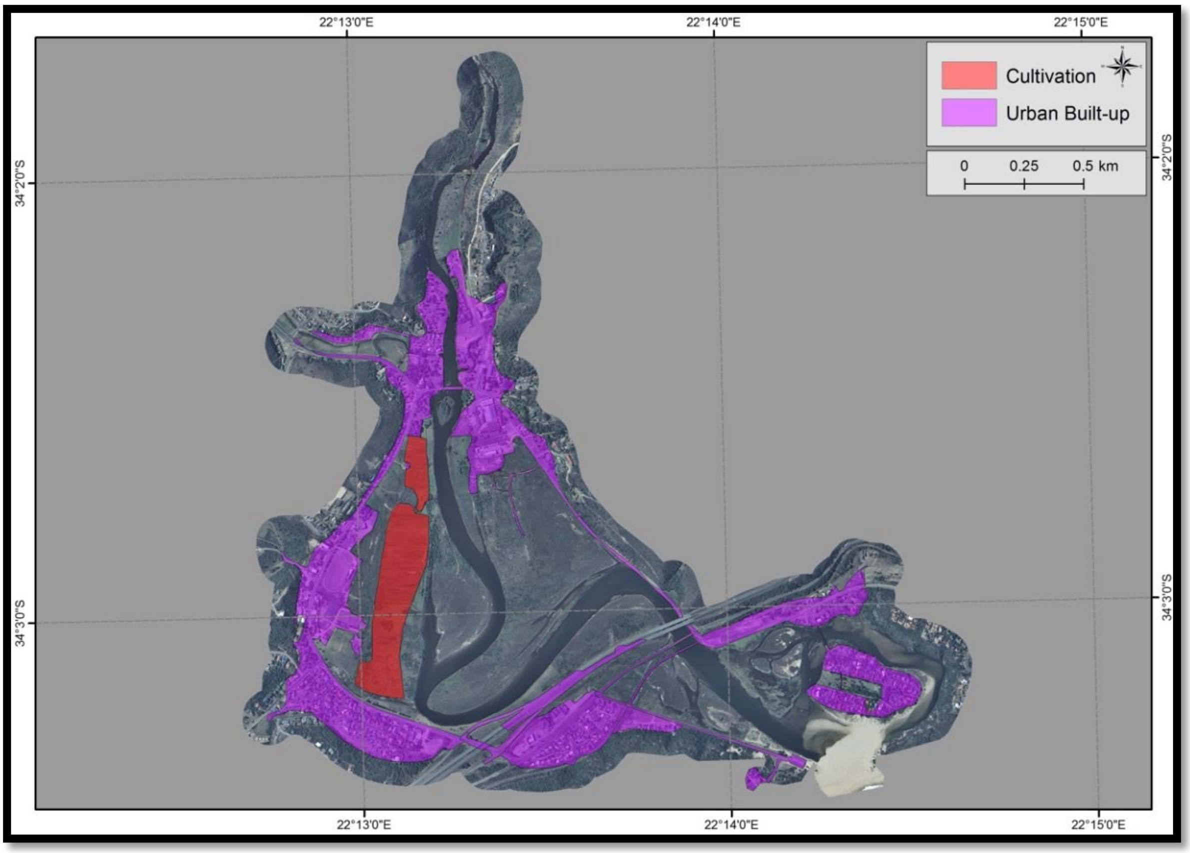

Figure 4.11: Secondary land-cover classes within the Groot Brak Estuary.

4.4.1 Catchment activities

The Wolwedans Dam is currently affecting the present flood regime and sedimentation processes in the estuary (van Niekerk *et al*., 2009: 17). The present flood regime still results in freshwater pulses entering the estuary, but the occurrence and magnitude of major floods has been reduced by 10-15%. Most river sediments are trapped by the dam, as the holding capacity of the dam is one and a half times the MAR of the catchment (van Niekerk *et al.*, 2009: 18). It is safe to assume that virtually all larger particles are trapped and only some of the finer sediment actually passes through the dam during flooding. The combined impact of reduced floods and the sediment trap efficiency of the dam have had a large impact on erosion and sedimentation in both the lower catchment and estuary. The amount of sediment that reaches the estuary has been greatly reduced (van Niekerk *et al.*, 2009: 18) and the sediment that is deposited is less likely to be washed out to sea due to reduced flushing.

Estuarine water quality has been affected due to catchment nutrient discharges into the system (van Niekerk *et al*., 2009: 21). Land adjacent to the estuary hosts various land-uses that discharge nutrients into the system including: extensive residential development, agricultural land, commercial land and a golf course (van Niekerk *et al*., 2009: 21). Whereas the first three land-uses affect larger portions of the estuary, the golf course discharges primarily into the lower reaches of the system. Another factor contributing to poor water quality is sewage effluent that was pumped into the estuary pre-1993 (van Niekerk *et al*., 2009: 21). With flushing flows reduced following the construction of the Wolwedans Dam, the system is susceptible to nutrient build-up below the dam.

4.4.2 Estuary activities

Within the Groot Brak Estuary there are five bridge structures which potentially negatively affect the abiotic characteristics of the system. Three of the five bridges do not pose a threat to estuarine flows within the system as they are well built, but they do exhibit zones of additional scouring in their near proximity (van Niekerk *et al*., 2009: 20). According to van Niekerk *et al*. (2009: 20) two of the bridges have altered the state of the estuary namely the bridge connecting the Groot Brak Island to the peripheries of the estuary and the Charles Searle Bridge in Groot Brak. Both bridges obstruct flows within the estuary and in periods of high flow may also hinder movement of debris through the system. The Charles Searle Bridge also obstructs the flows of saline and freshwater through the estuary (van Niekerk *et al*., 2009: 20). Freshwater during low flows is thus retained by the bridge in the upper reaches of the estuary and saline water below the bridge. A causeway in the upper reaches of the system obstructs tidal flows within the estuary similar to the Chares Searle Bridge (van Niekerk *et al*., 2009: 20).

Human exploitation within the estuary is attributed to recreational angling and illegal gillnetting (van Niekerk *et al*., 2009: 22). An estimation of 3.1 tonnes of fish are caught per annum and remnants of gillnet floats and actual nets are often found.

Artificial breaching of the system is practised due to the reduced high flows created by the Wolwedans Dam. The mouth is systematically breached when there are high flows in the estuary to prevent back-flooding of the residential island within the estuary (van Niekerk *et al*., 2009: 22). Flushing capabilities of the system during the open mouth phase have decreased somewhat from Reference Conditions resulting in greater sedimentation within the estuary. This is due to the mouth being breached at lower water levels than under Reference Conditions and thus outflow velocities are less (van Niekerk *et al*., 2009: 22).

4.5 Discussion

It has been established that the Groot Brak Estuary is regarded as an important ecosystem, with many of the current pressures on the system deemed to be reversible. The RDM assessment categorises the estuary as largely modified and the PES of the system is a category D. The same classification can be provided for the Groot Brak catchment as the catchment analysis has identified that large modifications have been made to the catchment land-cover.

The pressures outlined from the RDM study can be seen at the various scales of assessment conducted on the catchment. A large portion of pressures exerted on the system are as a result of the Wolwedans Dam. Other pressures arise due to transformation of natural land-cover to anthropogenic activities and the negative effects derived from these activities. The catchment land-cover analysis of this chapter showed that the dominant transformed classes present were plantations, cultivation and urban built-up. Plantations dominate higher up in the catchment with minimal plantations found within the CPZ. Cultivated areas were more prevalent within the lower section of the catchment, declining in closer proximity to the estuary. Cultivated areas are noted as occupying roughly 5% of the sensitive area of the estuarine functional zone. It was found that through each level of catchment assessment, the proportion of urban land-cover increased with proximity to the estuary. The largest proportion area occupied by urban development was found to be within a 100 m buffer of the estuarine functional zone. Within the estuarine functional zone delineation urban development has transformed some 30.5% of the natural habitat which can pose a large threat to the ecosystems integrity.

In accordance with the ICMA and the creation of the CPZ regulations, transformation of land-cover from a natural state should be minimal. The assessed catchment land-cover characteristics for this system, however portrays that these buffer areas have largely been transformed, with natural land accounting for roughly 60% of the land-cover. Therefore it can be said that health of the estuary can be related to catchment health.

CHAPTER 5: MDLOTI ESTUARY

5.1 Study area

5.1.1 Estuary

The Mdloti Estuary is situated in the province of KwaZulu-Natal, approximately 25 km north of Durban and 10 km north of Umhlanga (Figure 5.1). The geographic location of the estuary mouth is 29° 39' 0" S and 31° 07' 45" E.

Figure 5.1: Location of the Mdloti Estuary and associated catchment (inset image from WISA, 2007a).

The Mdloti Estuary has a functional delineation of 1 km^2. The length of the estuary is approximately 3 km and it is about 0.75 km wide at the broadest section (Figure 5.2).

The Mdloti Estuary is classified as a TOCE, with a sand berm present at the mouth when closed, but open when river flooding causes breaching of the bar (Kibirige *et al.*, 2006: 1307). Illegal artificial breaching of the mouth is still practised when backflooding effects agricultural activities and infrastructure such as cane haul roads on the floodplain

(Demetriades, 2007b, 5). According to Kibirige *et al*. (2006: 1307) the estuary is also subjected to inflows of treated sewage waters measuring approximately 8 Ml day^{-1}.

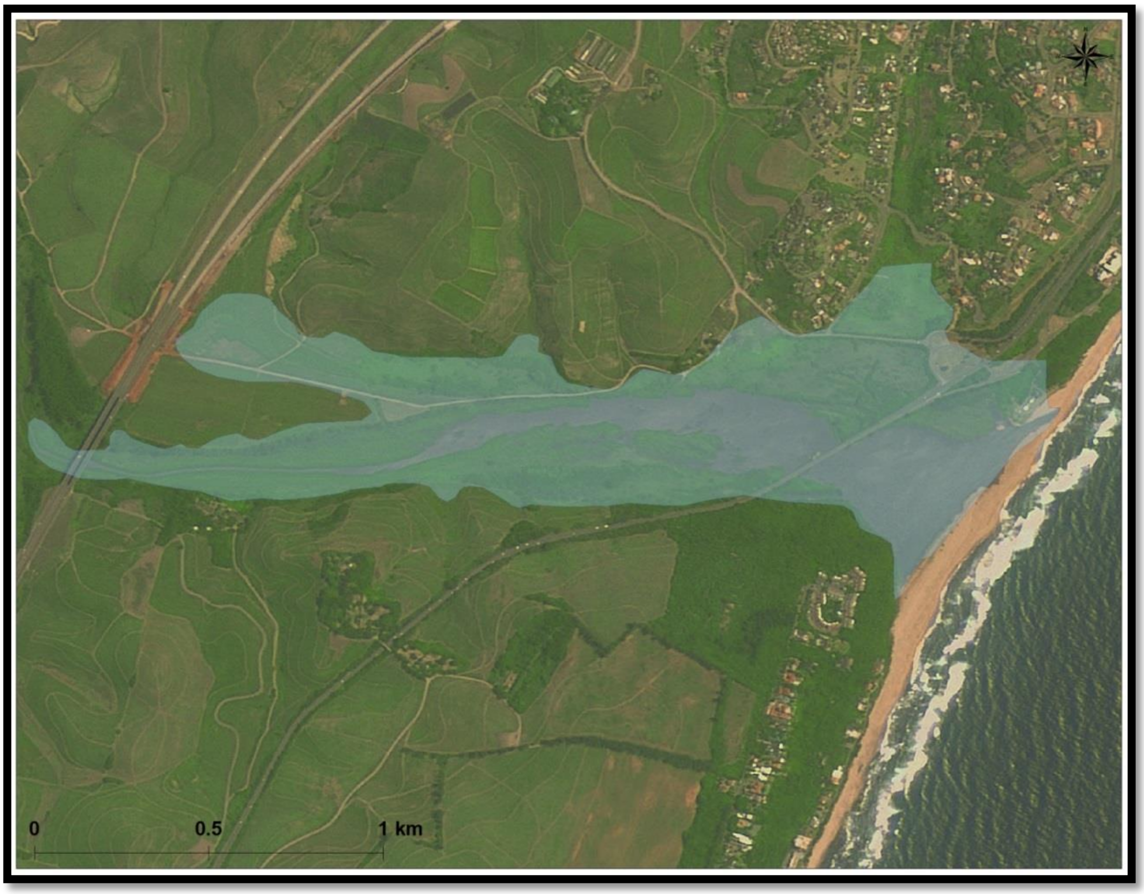

Figure 5.2: Mdloti Estuary with overlaid estuary functional zone delineation.

Within the delineation and peripheries of the estuary, large portions of natural land have been transformed (Figure 5.2). Two major roads cross the upper reach of the estuarine functional zone as well as within the lower reach in close proximity to the mouth (Forbes and Demetriades, 2009: 40). Arterial roads are also present within the estuary delineation and between the agricultural lands. These lands can be found bordering the majority of the estuary, as well as occupying some of the area within the estuarine functional zone. Extensive urban development is located adjacent to the lagoon in the mouth region of the estuary. Natural land surrounding the estuary is very limited, with small areas located north and south of the mouth as well as within the urban area.

5.1.2 Catchment

The Mdloti Estuary catchment is approximately 484 km^2 (Figure 5.3). Rainfall patterns within KwaZulu-Natal are seasonal, with much of the precipitation occuring during the summer months (Perrissinotto *et al*., 2004: 62). According to Perrissinotto *et al*. (2004: 75) the catchment receives a MAP of 1000 mm resulting in a MAR 2.06 m^3/s entering the estuary. This is a deviation from the natural MAR which is 2.64 m^3/s (Perrissinotto *et al*., 2004: 75). The loss of runoff entering the estuary is mainly attributed to the presence of the Hazelmere Dam about 20 km upstream of the estuary. The dam has a total capacity of 24 x 10^6 m^3 (33.4% of the MAR) (Kibirige *et al*., 2006: 1309).

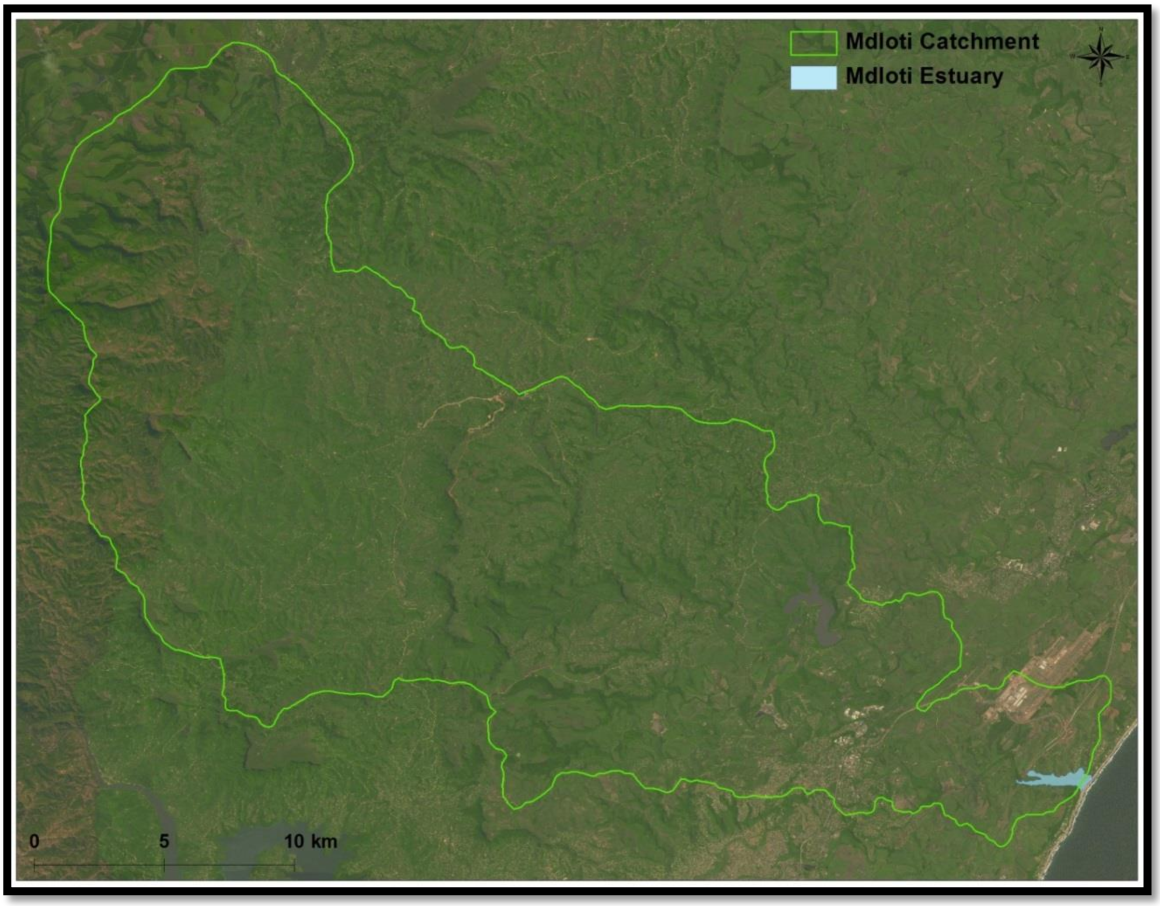

Figure 5.3: Mdloti Estuary functional zone and catchment boundary delineations.

Within the bottom third of the catchment, large urban settlements are present (Figure 5.3). The majority of the urban area is situated below the dam and above the estuary, potentially resulting in increased runoff and pollutants entering the system. In the past industrial pollutions originating in the upper catchment also occasionally entered the estuary (Blaber *et al*., 1984: 224). Less than 5 km north of the upper reach of the estuary is the King Shaka International Airport development.

Although a portion of the catchment is still in its natural state, there are large expanses of cultivated land within the catchment. Cultivated lands cannot properly be distinguished at the scale shown in Figure 5.3, but they are of greater magnitude and extent in the lower third of the catchment, i.e. closer towards the estuary. In the past, the upper catchment was used for grazing (Forbes and Demetriades, 2009: 40) but currently sugarcane is the main form of cultivation (Demetriades, 2007b: 5).

5.2 Current state of the system

The Ecological Reserve determination study for the Mdloti Estuary was conducted by Demetriades (2007a). Table 5.1 shows the score attained for each EHI variable.

Table 5.1: Estuarine Health Index scores for the Mdloti Estuary (adapted from Demetriades, 2007a: iii).

Variable	Weight (%)	Score	Weighted score
Hydrology	25	80	20
Hydrodynamics and mouth condition	25	72	18
Water quality	25	32	8
Physical habitat alteration	25	68	17
Habitat Health score			**61**
Microalgae	20	15	3
Macrophytes	20	25	5
Invertebrates	20	15	3
Fish	20	25	5
Birds	20	20	4
Biotic Health Score			**21**
Estuarine Health Score			**41**

The Mdloti Estuary scored 61 out of a possible 100 for Habitat Health. Water quality and physical habitat alteration are the two variables that scored poorly, resulting in a decreased Habitat Health score. Of the two variables water quality is the most affected, only scoring 32 out of 100 (indicating very poor water quality). The Mdloti Estuary scored 21 out of 100 for Biotic Health (Table 5.1). The two most affected biotic variables were microalgae and invertebrates, both scoring only 15 out of 100. The combined abiotic and biotic scores gave 41 out of a possible 100, placing the PES for the system in a Category D (Table 5.2). This means that the system in question has been largely modified and degraded from its pristine reference state.

Table 5.2: Present Ecological Status classification based on the Estuarine Health Index (adapted from Demetriades, 2007a: iii).

Estuarine Health Index	Present Ecological Status	General Description
91 – 100	A	Unmodified, natural
76 – 90	B	Largely natural with few modifications
61 – 75	C	Moderately modified
41 – 60	**D**	**Largely modified**
21 – 40	E	Highly degraded
0 – 20	F	Extremely degraded

The Mdloti Estuary has a Functional Importance score of 70 (Table 5.3) as it performs a nursery function for marine associated fish and crustaceans (Demetriades, 2007a: 39). The Estuarine Importance Score of 69 out of 100 (Table 5.4) classifies the estuary as being "Important" (Table 5.5).

Table 5.3: Functional importance of the Mdloti Estuary (adapted from Demetriades, 2007a: 39).

Functional Importance	Score
(a) Export of organic material generated in the estuary (regional scale)	40
(b) Nursery function for fish and crustaceans (marine/ riverine)	70
(c) Movement corridor for river invertebrates and fish breeding in sea	60
(d) Roosting area for marine or coastal birds	60
(e) Catchment detritus, nutrients and sediments to sea	40
Functional importance score (maximum score of (a) to (e))	**70**

Table 5.4: Estuarine Importance Scores for the Mdloti Estuary (adapted from Demetriades, 2007a: 39).

Criterion	Weight	Score	Weighted Score
Estuary Size	15	80	12
Zonal Rarity Type	10	10	1
Habitat Diversity	25	90	23
Biodiversity Importance	25	63.5	16
Functional Importance	25	70	18
Estuarine Importance Score (rounded off)			**69**

Table 5.5: Estuarine Importance Score based on Present State (Demetriades, 2007a: iv).

Importance Score	Description
81 – 100	Highly important
61 – 80	**Important**
0 – 60	Of low to average importance

Table 5.6: Ecological Reserve Category as applied in the estuaries RDM process (adapted from Demetriades, 2007a: iv).

Estuarine Health Index	Present Ecological Status	Description	Ecological Reserve Category
91 – 100	A	Unmodified, natural	A
76 – 90	B	Largely natural with few modifications	B
61 – 75	C	Moderately modified	C
41 – 60	**D**	**Largely modified**	**D**
21 – 40	E	Highly modified	-
0 – 20	F	Extremely degraded	-

The Ecological Reserve Category, as determined by the EHI and PES has been established as 41 and D respectively. This places the Mdloti Estuary in an ERC of D (Table 5.6) and represents the lowest ERC attainable for this system. The Mdloti Estuary is deemed an important estuary and the recommended ERC for this system is PES + 1, i.e. a minimum of a C Ecological Reserve Category (Table 5.7).

Table 5.7: Recommended Ecological Reserve Category based on level of protection and importance of an estuary (Demetriades, 2007a: v).

Current/desired protection status and estuary importance	Recommended Ecological Reserve Category	Policy basis
Protected area	A or Best Attainable State	Protected and desired protected areas should be restored to and maintained in the best possible state of health
Desired Protected Area		
Highly important	PES + 1, min B	Highly important estuaries should be in an A or B class
Important	PES + 1, min C	Important estuaries should be in an A, B or C class
Of low to average importance	PES, min D	The remaining estuaries can be allowed to remain in a D class.

5.3 Catchment land-cover analysis

The Mdloti Estuary drains a catchment of approximately 484 km^2 (Table 5.8). A comparison between estuarine functional zone size and catchment size indicates that the estuary only occupies 0.2% of the catchment. The representative sizes and percentage of the whole catchment occupied by natural and transformed land-cover classes are shown in Table 5.8.

Table 5.8: Primary land-cover classes in the Mdloti catchment.

Class	Area (ha)	Catchment (%)
Natural	29362.55	60.71
Transformed	18899.93	39.08
Estuary	99.49	0.21
Total	**48361.97**	**100**

Table 5.8 shows the breakdown of the catchment area into natural land, transformed land and the Mdloti Estuary itself. Within the Mdloti catchment the class that occupies the greatest area is natural land which covers 60.7% of the total area. However, a large portion of the catchment has been transformed from its natural state and occupies some 39.1% of the total area. The geographic location of both natural and transformed land is scattered across the catchment (Figure 5.4).

The second catchment analysis further classifies the category of 'transformed' land into various land-cover types. The land-cover types that can be seen within the Mdloti Estuary's catchment include: waterbodies, cultivated land, degraded land, urban built-up, plantations and mines. The relative area and percentage catchment occupied by each land-cover type are given in Table 5.9 and locations are shown in Figure 5.5.

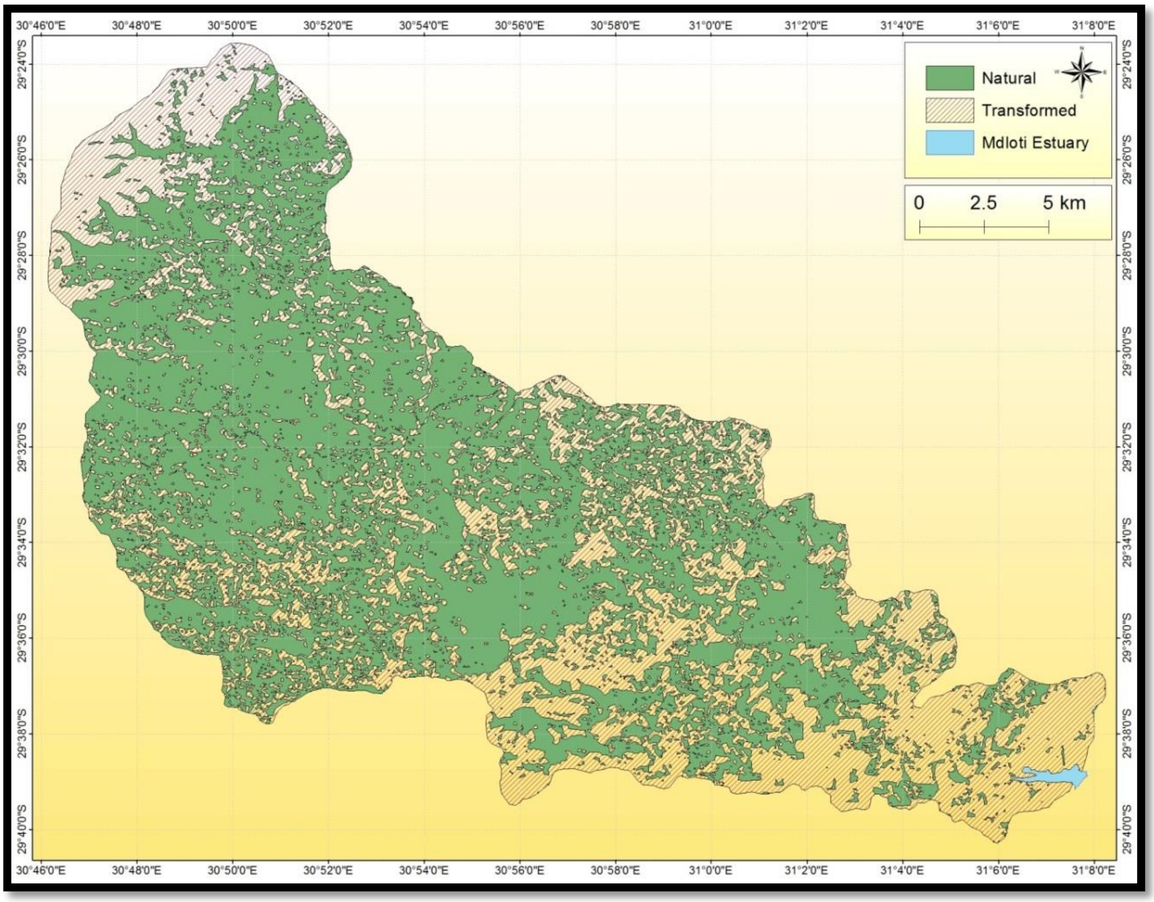

Figure 5.4: Primary land-cover classess within the Mdloti catchment.

The largest land-cover class within the catchment is natural land constituting 60% of the catchment. The second largest class is cultivation, which covers 21.7% of the catchment surface. The greatest portions of cultivated land are located in the top and bottom sections of the catchment, while the lower cultivated lands are closely associated with the immediate estuary drainage basin and peripheries.

Table 5.9: Secondary land-cover classes in the Mdloti catchment.

Class	Area (ha)	Catchment (%)
Estuary	99.49	0.21
Waterbodies	317.72	0.66
Natural	29159.71	60.30
Cultivated	10495.42	21.70
Urban Built-up	5398.49	11.16
Plantations	907.26	1.88
Degraded	1935.90	4.00
Mines	46.66	0.10
Total	**48360.65**	**100**

Urban areas occupy the third greatest part of the catchment, covering 11.2% of the catchment. The largest urban area is located west of the upper reach of the estuary. There is also a small built-up area located on the northern periphery of the estuary adjacent to the coast.

Plantations and scattered areas of degraded land are also present within the catchment. These two classes account for approximately 1.9% and 4% of the catchment. Larger areas of plantations are located within the upper section of the catchment between cultivated and natural land. In contrast degraded lands are scattered around the catchment, especially north-west of the largest urban area. It is also important to note that degraded areas are also present around some of the waterbodies, which could potentially impact on these watercourses and eventually the estuary.

Waterbodies and mines occupy the least area within the catchment. Both classes account for less than 1% of the total catchment area. Waterbodies account for 0.7% of the catchment and are generally located in the bottom third of the catchment (near the upper reaches of the estuary). The Hazelmere Dam is also located within the bottom third of the catchment. Mines occupy 0.1% of the catchment area, with the larger mines situated near the major urban area.

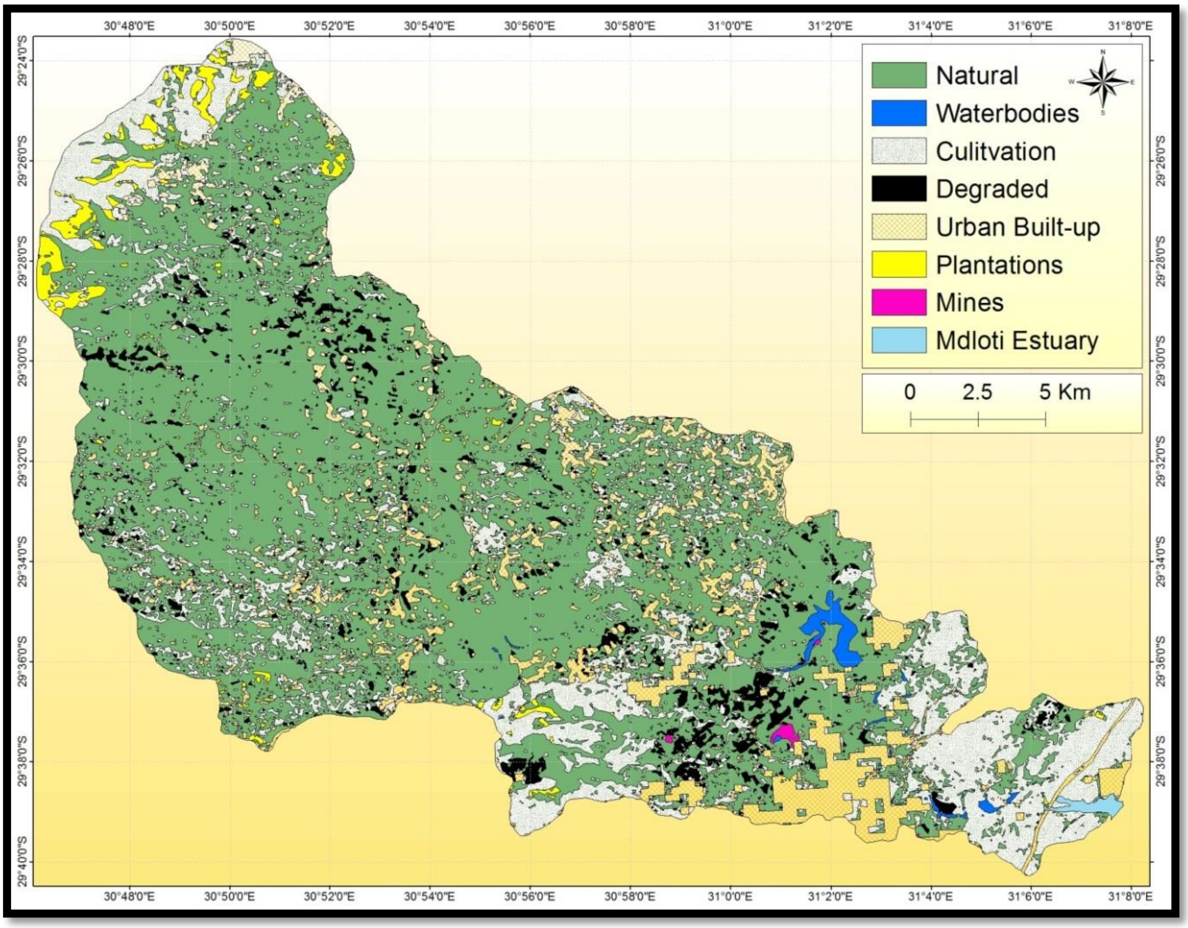

Figure 5.5: Secondary land-cover classes within the Mdloti catchment.

Further analysis was conducted to determine the upper, middle and lower sections of the catchment. This facilitated the isolation of land-cover classes within the lower catchment which, based on Tobler's First Law of geography, would be more likely have a greater influence on the system than land-cover classes in the upper and middle sections (Miller, 2004: 284). A DEM showing the path of the Mdloti River from source to estuary is displayed in Figure 5.6. The longitudinal profile of the river displaying gradient change is shown in Figure 5.7.

The profile indicates that there is a major change in gradient at 100 m (i.e. approximately 65 km from the river source). At this point the major change in river gradient is due to the presence of the Hazelmere Dam. The lower section of the catchment has therefore been classified as all areas of the catchment which do not exceed 100 m.

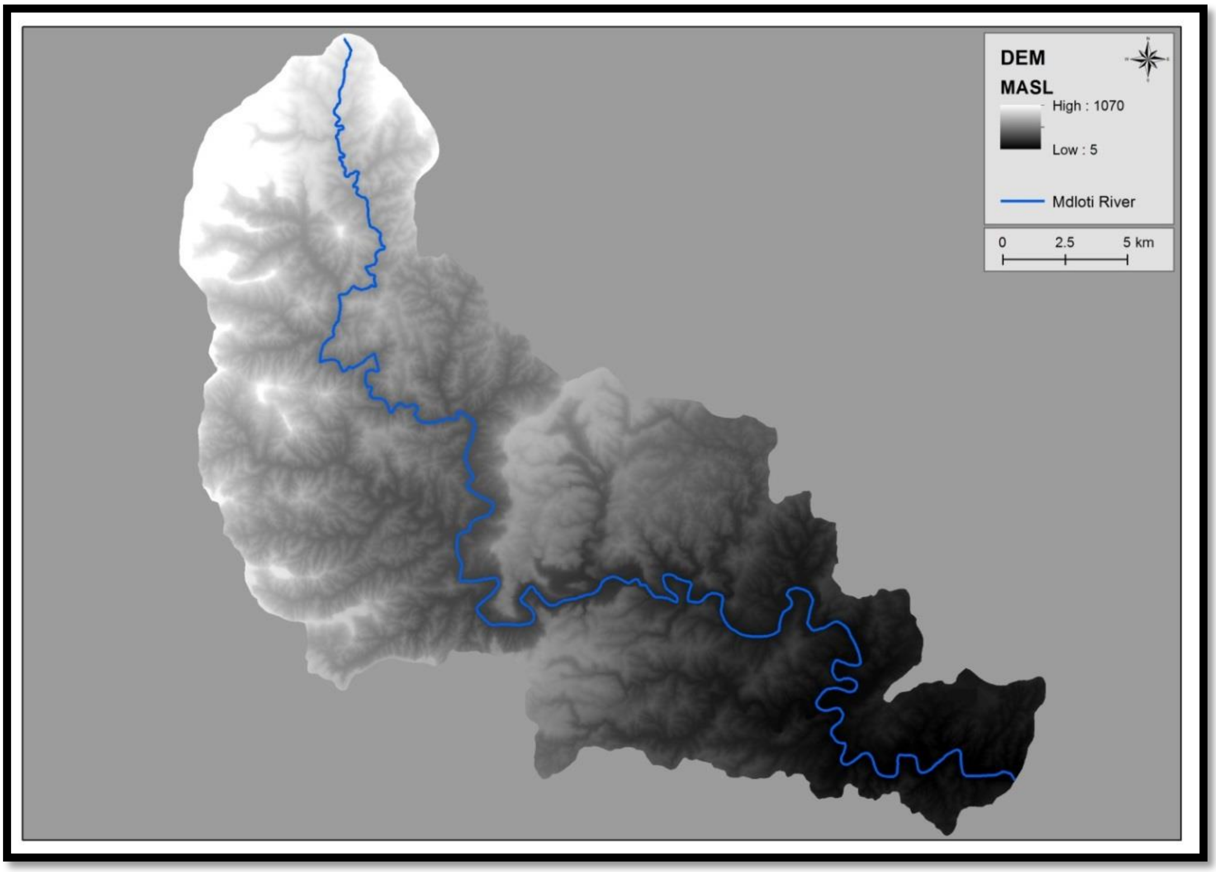

Figure 5.6: Mdloti catchment Digital Elevation Model and river.

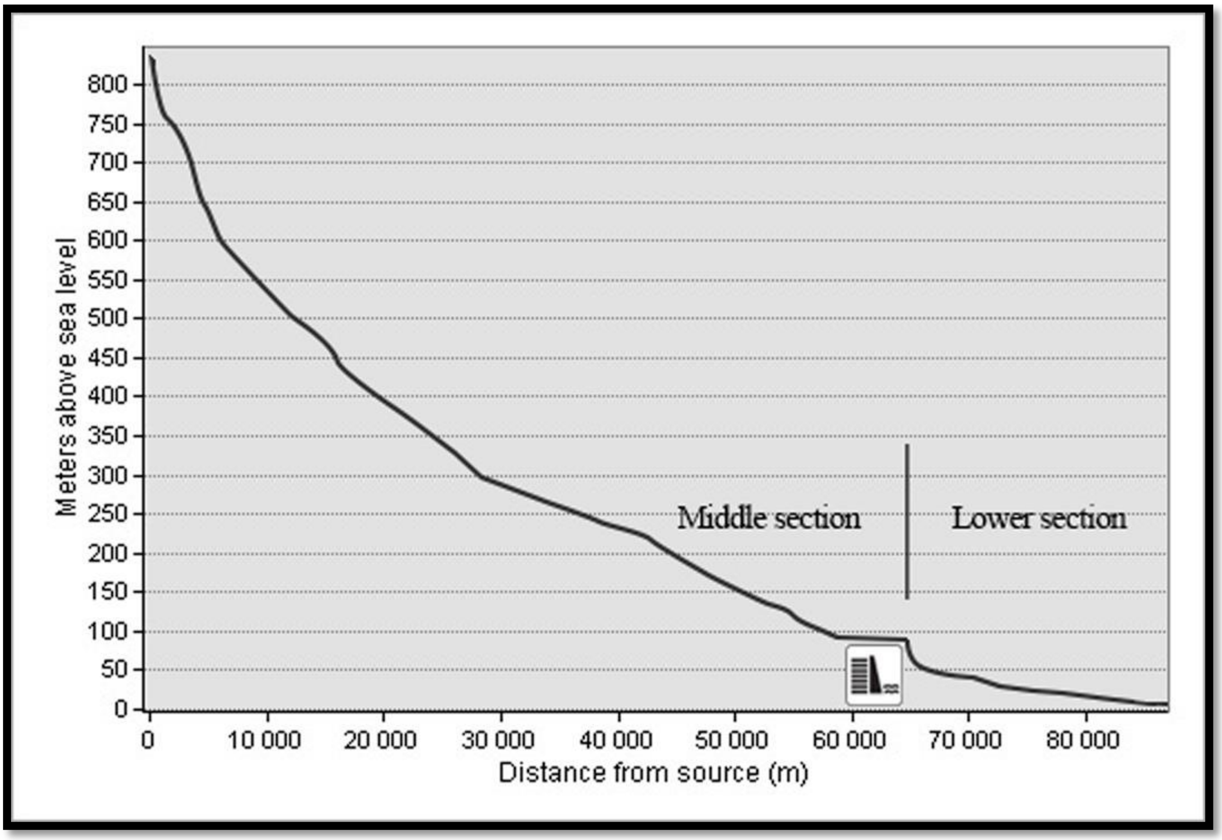

Figure 5.7: Longitudinal profile of the Mdloti River.

Secondary land-cover classes present within the lower reach of the catchment include: natural areas, waterbodies, cultivation, degraded land, urban built-up, plantations, mines and the estuary. Locations of the different land-cover classes are shown in Figure 5.8 and the relative areas and percentage of the catchment are documented in Table 5.10.

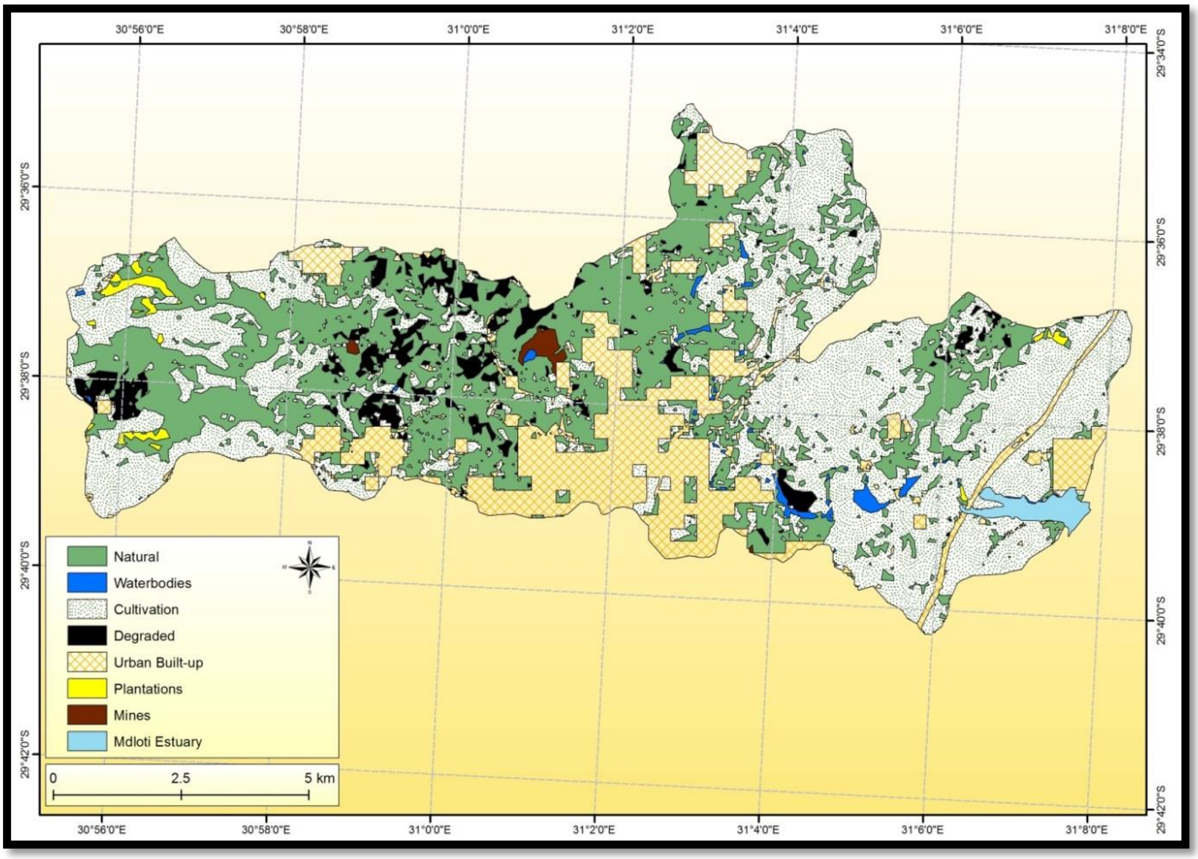

Figure 5.8: Secondary land-cover classes within the lower section of the Mdloti catchment.

The land-cover class occupying the largest part of the lower catchment is cultivated land, accounting for 42.5% of the total area. Cultivated lands are dispersed throughout the lower catchment but are more concentrated in the upper end of this section as well as dominating land-cover nearer the estuary. Area covered by land still in a natural state constitutes the second largest area, accounting for a total of 33% of the catchment. Natural land is more prominent in the upper and middle divisions of the lower section of the catchment. Scattered patches of natural land are also present close to the estuary, with a dense cluster situated just north of the head of the estuary. Urban development occupies 16.7% of the lower section constituting the next largest category. Areas of urban development are seen throughout the catchment, but are more prominent in the middle of the lower section of the catchment. One area of urban development is also present in close proximity to the estuarine functional zone. Out of the remaining land-cover classes, degraded land is the only class which occupies an area >1% of the catchment. The largest area of degraded land is visible in the middle of the lower section of the catchment, often in-between natural land. Smaller degraded areas are also present in close proximity to the west and north of the head of the estuarine functional zone.

Table 5.10: Secondary land-cover classes within the lower section of the Mdloti catchment.

Class	Area (ha)	Catchment (%)
Estuary	99.49	0.93
Natural	3552.34	33.05
Cultivation	4569.27	42.51
Degraded	543.99	5.06
Urban Built-up	1791.76	16.67
Waterbodies	79.90	0.74
Plantations	68.99	0.64
Mines	43.63	0.41
Total	**10749.38**	**100**

The remaining land-cover classes collectively account for 2.7% of the lower catchment section. Land-cover classes include: waterbodies, plantations, mines and the estuary. Waterbodies are scattered through the catchment, with two of the largest waterbodies located within 5 km of the upper reach of the estuarine functional zone. Plantations are located at the top end of the lower catchment, with one small area positioned north of the estuarine functional zone. At this scale two mine areas can be identified, both situated in the middle of the catchment. The largest mining area is in close proximity to the largest urban area. Further analyses using a 1 km buffer around the estuarine functional zone revealed three land-cover classes (Figure 5.9).

Cultivated land occupies the largest area (Figure 5.9), comprising 65.8% of the 1 km buffer zone draining directly into the estuary. Natural land-cover and urban built-up constitute the remainder of the buffer area, with urban development being the second largest land-cover class overall and accounting for 19.9% of the total area. Urban developments are scattered within cultivated lands and a large urban area is also located just north of the estuary mouth. Natural land-cover accounts for 14.2% of the total area and occupies the surrounds of the river entering the estuary as well as a large covering of natural land bordering the south periphery of the estuary.

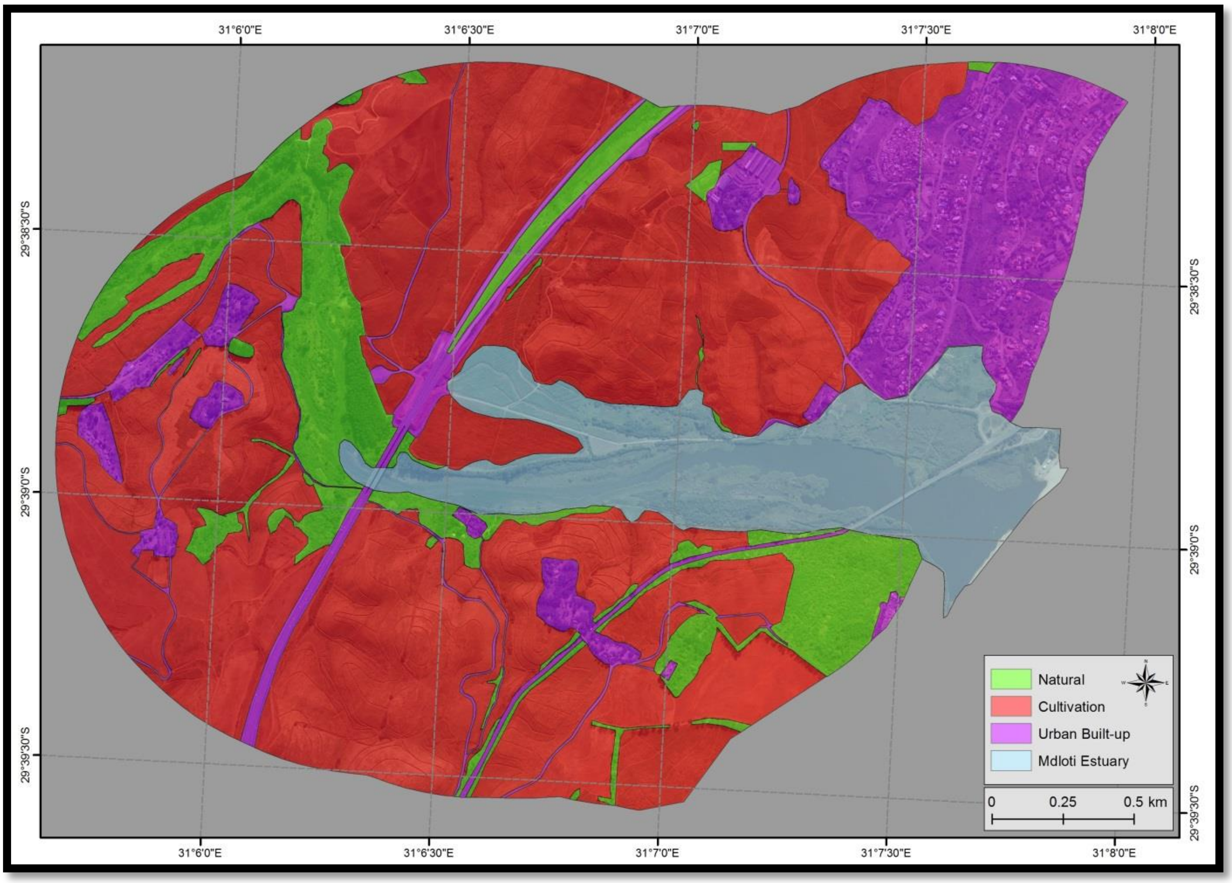

Figure 5.9: Secondary land-cover classes within a 1 km buffer of the Mdloti Estuary.

Additional analysis was conducted creating a 100 m buffer around the functional zone of the estuary and within this buffer zone the same three previous land-cover classes are present (Figure 5.10).

Cultivation accounts for nearly half this buffer area, with the largest cultivated area located within the buffer bordering much of middle and upper reaches of the estuarine functional zone. The percentage area occupied by natural land and urban developments is very similar, 26.7% and 24.3% respectively. Urban areas include a road crossing the head of the estuary and on the northern periphery of the estuarine functional zone at the mouth of the estuary. Natural land within the buffer zone is located near the confluence of the river and estuary as well as large portions of the southern periphery of the estuarine functional zone.

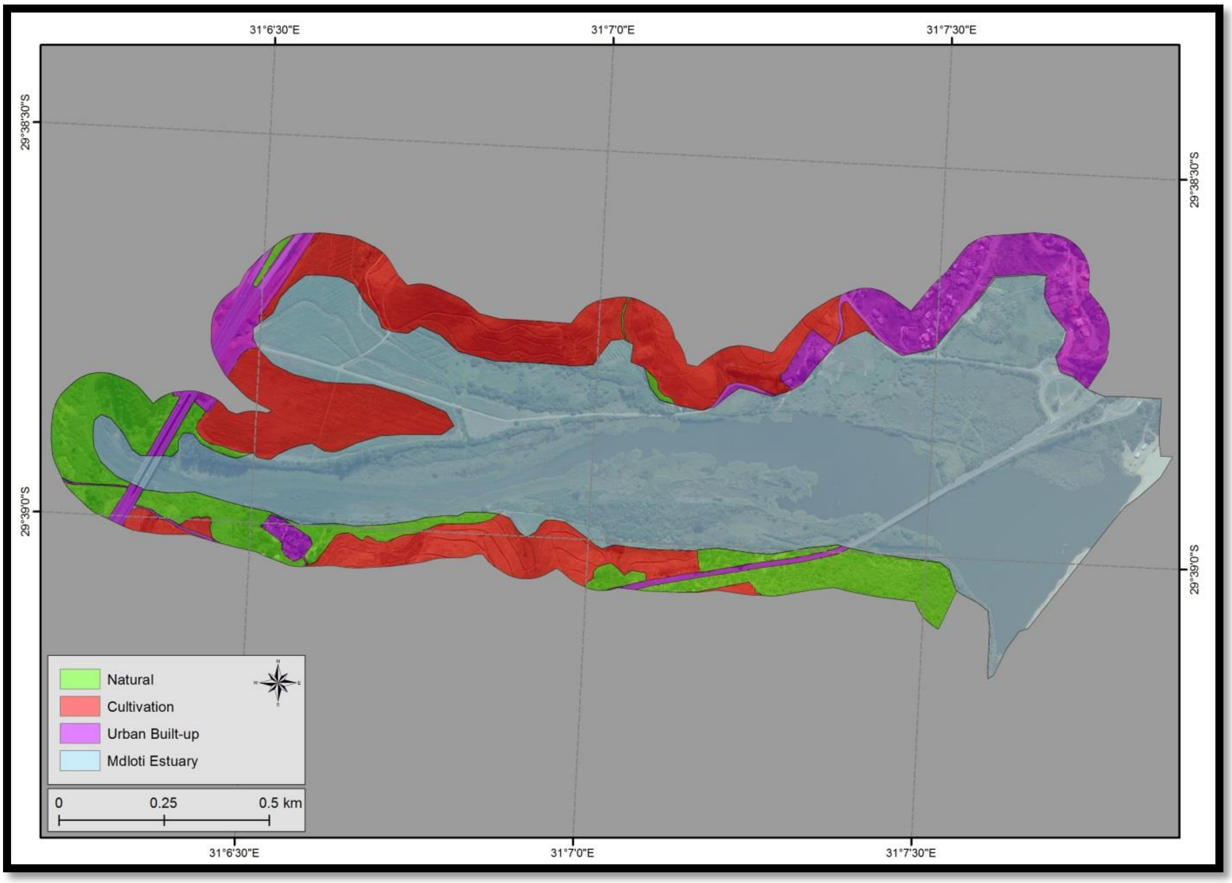

Figure 5.10: Secondary land-cover classes within a 100 m buffer of the Mdloti Estuary.

The last assessment included evaluating transformed and natural land-cover classes within the estuarine functional zone. The two transformed land-cover classes that feature are cultivation and urban built-up (Figure 5.11). Cultivation (12.7%) occupies a greater area than urban development (5.2%) and dominates an area in the upper reach of the functional zone. Other smaller areas of cultivation are also present but scattered around the functional zone. Urban developments within the functional zone primarily constitute roads crossing the system as well as adjacent areas cleared of vegetation.

5.4 Anthropogenic activities affecting the current state of the system

In the study conducted by Demetriades (2007a) the author outlines influences which are currently having a negative effect on the Mdloti Estuary. Demetriades (2007a: 41) concluded that the influences negatively affecting the PES of the Mdloti estuarine system include: reductions in freshwater inflow, floodplain development, sedimentation, bridge construction and other anthropogenic disturbances. The primary negative influence resulting in the current PES for the system is a reduction in freshwater inflow (Demetriades, 2007a: 41). Influences negatively affecting the health of the estuary can be divided into two categories that are derived from both the catchment and the estuary.

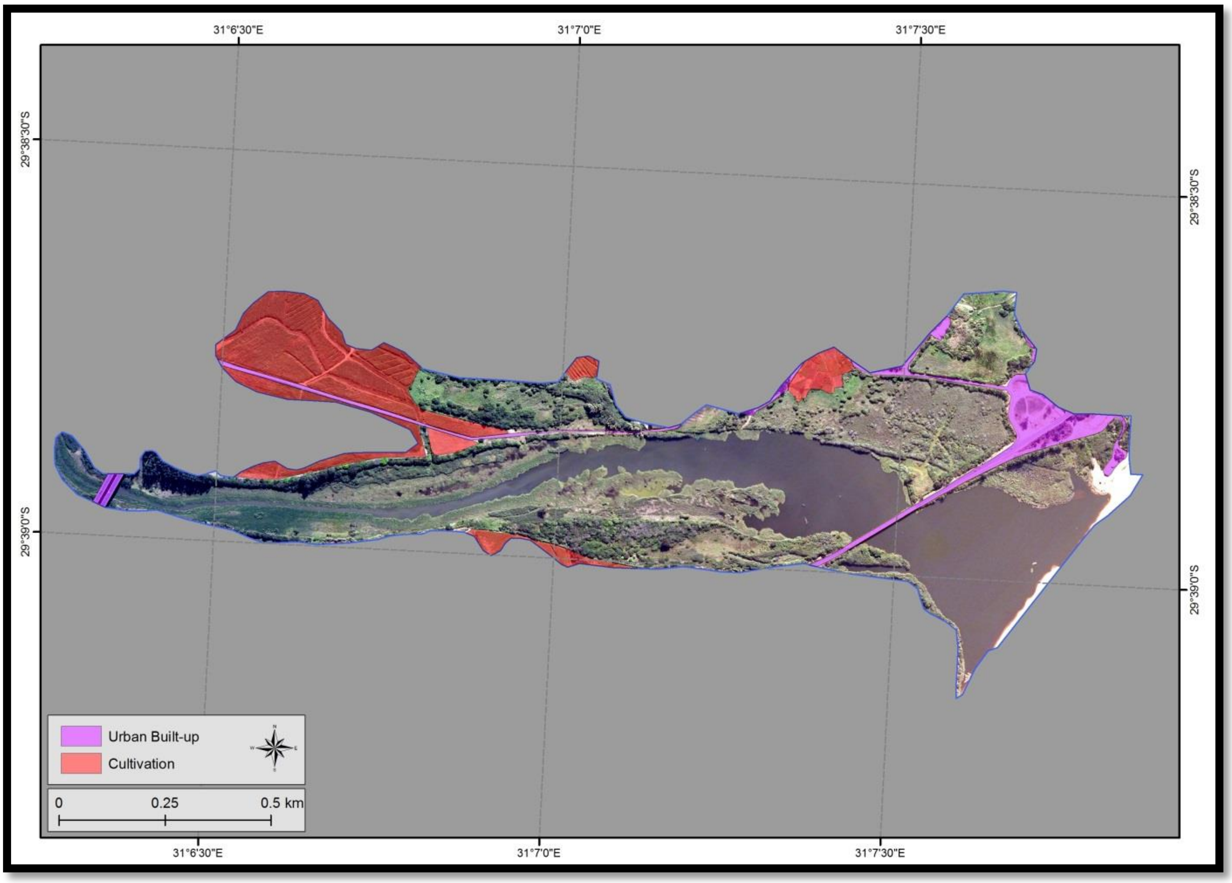

Figure 5.11: Secondary land-cover classes within the Mdloti Estuary.

5.4.1 Catchment activities

Negative influences from the catchment include: a reduction in freshwater inflows, flood plain developments, sedimentation and other anthropogenic influences. The present flood regime within the catchment is still relatively similar to that under Reference Conditions. It has been documented that there has only been a decrease of 1.4% in flood waters entering the estuary. This would also infer that the ability of flood waters to flush sediments from the estuary has also been slightly reduced. Sedimentation within the catchment can be attributed to land transformation from natural habitat to the cultivation of sugar cane, as well as urban developments (Demetriades, 2007a: 12). According to Demetriades (2007a: 12) another deviation in sedimentation rates can be attributed to the presence of the Hazelmere Dam which captures much of the sediment originating from higher up within the catchment.

Other anthropogenic activities occurring within the catchment, which may currently affect the health of the estuary, are nutrient rich discharges occurring from various land-use practices. Nutrient rich waters entering the estuary is purported to be derived mainly from waste water discharges and runoff from agricultural activities (Demetriades, 2007a: 15).

5.4.2 Estuary activities

Within the estuary, negative influences can be mainly attributed to changes in sedimentation due to the presence of structures, sand winning operations and artificial mouth breaching. In terms of structures affecting the estuary morphology, construction of the bridge near the estuary mouth has contributed the greatest effect decreasing the natural habitat area within the estuary (Demetriades, 2007a: 15). According to Demetriades (2007a: 15), sand winning operations that occur within the upper reaches of the estuary are also affecting the integrity of the estuary. Lastly, artificial mouth breaching is still practised within the estuary and occurs when the mouth is closed and back flooding threatens land-use activities as well as infrastructure on the estuary floodplain (Demetriades, 2007a: 15).

5.5 Discussion

The Mdloti Estuary is regarded as an important estuary in terms of its functional importance, but according to its PES the ecosystem has been largely modified. The estuary scored poorly in terms of estuarine health and placed within an ERC of D. The bottom third of the Mdloti catchment exhibits largely transformed land-cover, thus inferring this section of the catchment has greatly changed from Reference Conditions.

Modifications or transformation of natural land within the Mdloti catchment can mainly be attributed to cultivated and urban areas. The areas represented by cultivated lands increase in proportion area occupied in closer proximity to the estuarine functional zone and this land-cover has been found dominating the 1 km buffer around the estuary. Cultivation is also present within the estuarine functional zone, having transformed approximately 13% of the area. Once again the proportion area occupied of each scale of assessment for urban areas increases in closer proximity to the estuarine functional zone and is represented at its greatest proportion area occupied within the 100 m buffer zone around the estuarine functional zone. Within the sensitive estuarine area represented as the estuarine functional zone, urban development has transformed approximately 5% of the natural land-cover.

In conclusion, there is a relationship between the state of the catchment and the health of the estuary as both have been largely modified. In accordance with the ICMA regulations, transformation of land-cover from a natural state within these buffers zones should be minimal. The land-cover characteristics for this system show that the buffer areas have largely been transformed, with natural land accounting for roughly 20% of the land-cover. Without a natural vegetation buffer surrounding the estuarine functional zone it is expected that the estuary would be susceptible to poor health.

CHAPTER 6: TONGATI ESTUARY

6.1 Study area

6.1.1 Estuary

The Tongati Estuary is situated in the Province of KwaZulu-Natal, located north of Durban and the town of Umhlanga (Figure 6.1). The geographic location of the estuary mouth is 29° 34" 19' S and 31° 11" 6' E.

Figure 6.1: Location of the Tongati Estuary and associated catchment (inset image from WISA, 2007b).

The Tongati Estuary is classified as a TOCE (Demetriades, 2007d: 11) and the delineated functional area 1.5 km^2. The length of the estuary is approximately 5 km and it is approximately 0.7 km at its widest point. Over the past 20 years the depth of the estuary has been reduced due to increased siltation (Forbes and Demetriades, 2009: 26). According to Blaber *et al*. (1984: 224) the estuary mouth is often artificially breached when sugarcane lands on the floodplain become flooded. A large scale map of the estuary and delineated functional estuarine area is shown in Figure 6.2.

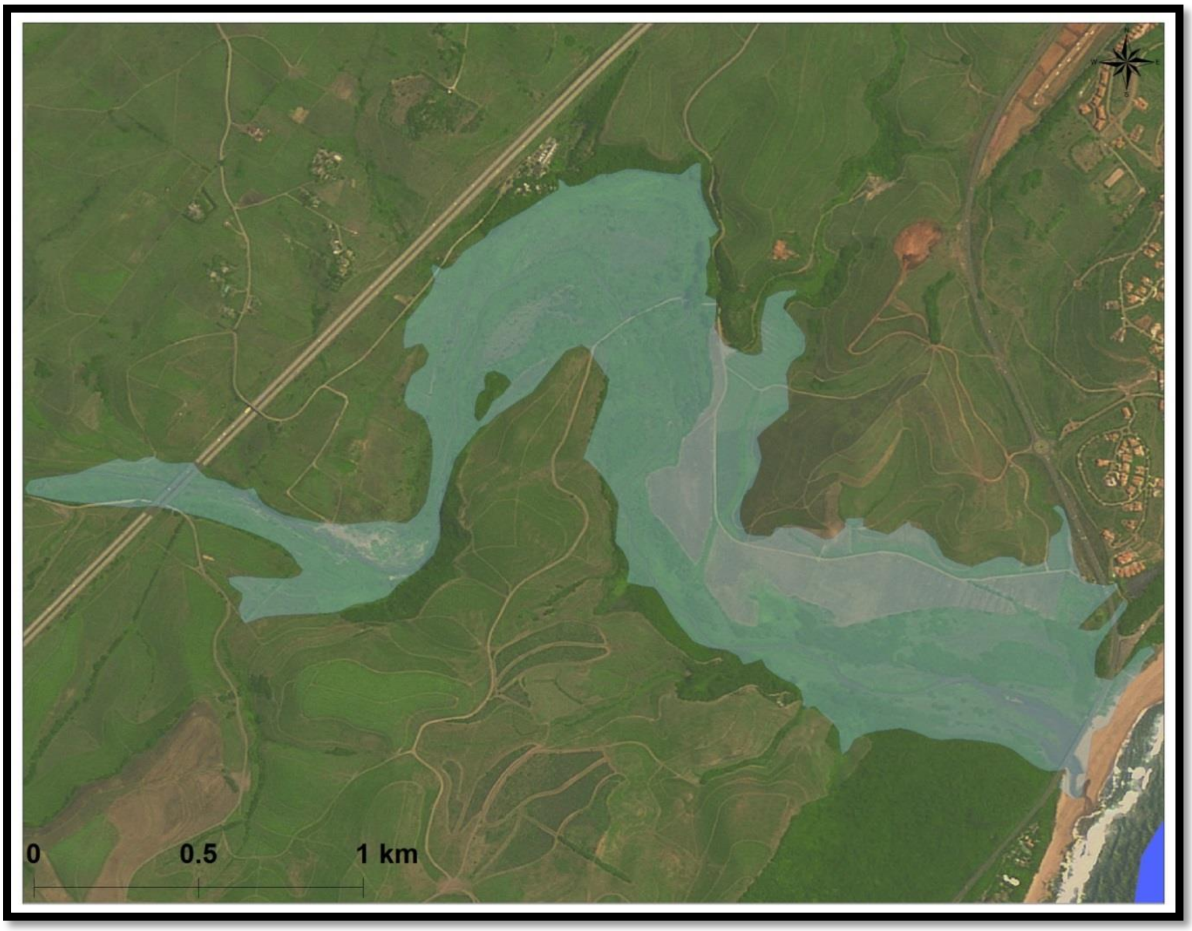

Figure 6.2: Tongati Estuary with overlaid estuary functional zone delineation.

Extensive cultivated lands surround the actual estuary, as well as occupying large areas within the delineated estuary functional zone (Figure 6.2) (Forbes and Demetriades, 2009: 26). Small patches of natural land occur within the estuary functional zone, as well as to the south-west of the estuary mouth.

Other anthropogenic disturbances within and around the estuary include urban settlements as well as constructed roads. Urban settlements occur directly north and south of the estuary mouth, and bridges have been constructed across the system. Two major roads cross the upper and lower parts of the estuary and smaller agricultural roads can be seen within the estuary functional zone.

6.1.2 Catchment

The Tongati catchment is approximately 412 km^2 (Figure 6.3). Rainfall patterns within KwaZulu-Natal are seasonal with much of the precipitation occuring during the summer months (Perrissinotto *et al*., 2004: 62). According to Demetriades (2007c: ii) this catchment area has a natural mean annual runoff (MAR) of 70.79 x 10^6 m^3 which equates to an average flow of 2.25 m^3 s^{-1} into the estuary. It has been determined that the deviation of natural MAR entering the estuary presently compared to Reference Conditions equates to a decrease of 16% (Forbes and Demetriades, 2009: 28).

The delineated catchment (Figure 6.3) can be characterised into various different land-cover classes. There are two dams present, including the Dudley Pringle (2.31 x 10^6 m^3) and the Siphon (0.35 x 10^6 m^3). Both these waterbodies are located approximately 5 km inland in a north-easterly direction from the top of the estuary. Areas of urban development are also present within the catchment, but predominately occur within the bottom half of the catchment. The large town of Tongaat is located in close proximity to the top of the estuary. Another large urban development within the catchment is the King Shaka International Airport which can be seen in the southern most part of the catchment (Figure 6.3), approximately 4 km from the estuarine functional zone.

A large portion of the catchment has been transformed into cultivated lands, which primarily consists of sugarcane farms. As shown in Figure 6.2, the cultivated areas are present on the peripheries as well as within the actual estuary functional area. Plantations also occupy a considerable area within the catchment although this land-cover is not visible at the scale depicted in Figure 6.3.

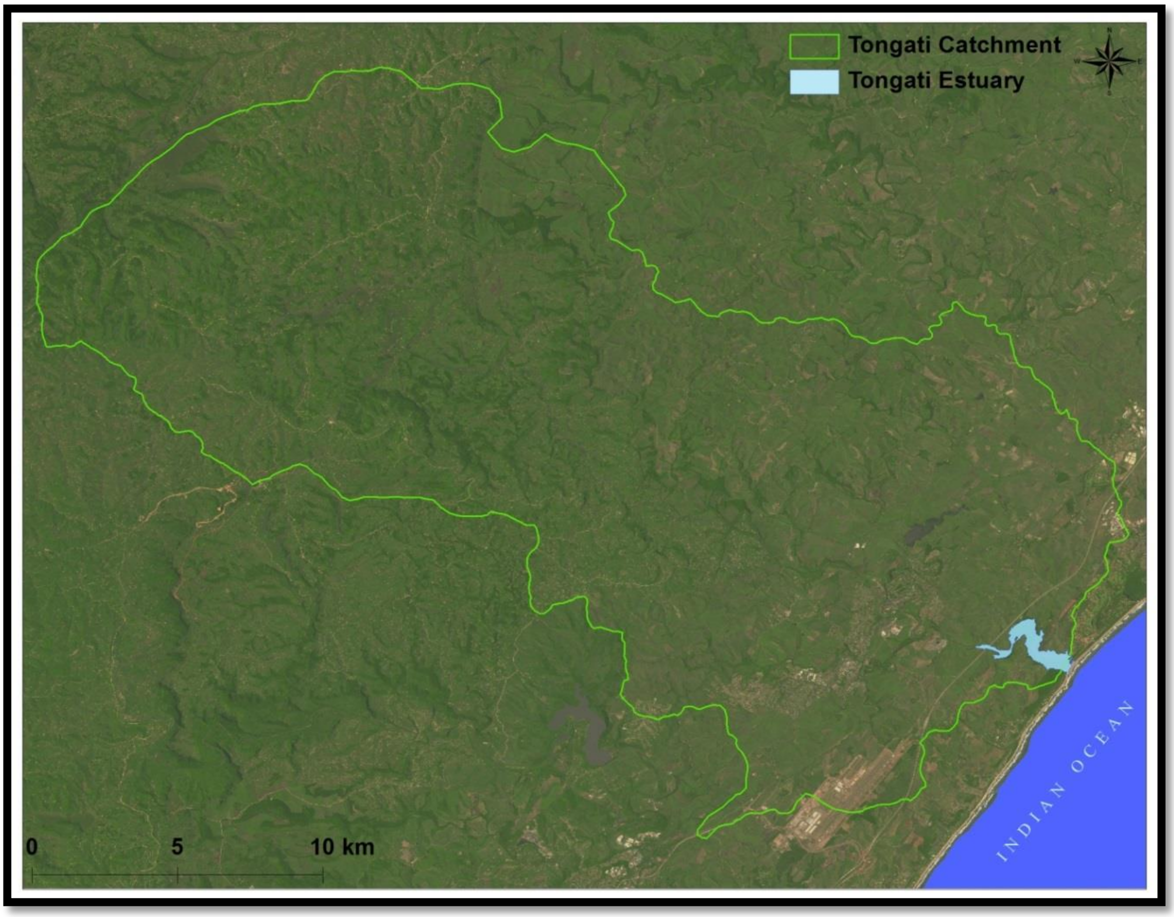

Figure 6.3: Tongati Estuary functional zone and catchment boundary delineations.

6.2 Current state of the system

The Ecological Reserve determination study for the Tongati Estuary was conducted by Demetriades (2007c). Table 6.1 shows the score attained for each EHI variable.

The Habitat Health of the Tongati Estuary has been scored 63 out of 100. The two abiotic variables showing the greatest loss of integrity were water quality and physical habitat alteration, with water quality in the system most effected and only scoring 16 out of 100. The second most degraded variable was physical habitat alteration which also scored less than 50%, showing high levels of change from its Reference Condition. The Biotic Health Score component of the EHI for the Tongati scored 36 out of 100, with the two lowest scoring variables being birds and invertebrates. The highest scoring biotic variable was microalgae, which was surprising with such a low water quality score. The overall Estuarine Health score for the Tongati is 49 out of 100. This means that the PES of the Tongati is determined to be a Category D (Table 6.2) which indicates that the system has been largely modified and degraded from its Reference Condition.

Table 6.1: Estuarine Health Index scores for the Tongati Estuary (adapted from Demetriades, 2007c: iii).

Variable	Weight (%)	Score	Weighted score
Hydrology	25	98	25
Hydrodynamics and mouth condition	25	95	24
Water quality	25	16	4
Physical habitat alteration	25	42.5	11
Habitat Health score			**63**
Microalgae	20	65	13
Macrophytes	20	58	8
Invertebrates	20	25	5
Fish	20	30	6
Birds	20	20	4
Biotic Health score			**36**
Estuarine Health score			**49**

Table 6.2: Present Ecological Status classification of the Tongati Estuary based on the Estuarine Health Index (adapted from Demetriades, 2007c: iii).

Estuarine Health Index	Present Ecological Status	General Description
91 – 100	A	Unmodified, natural
76 – 90	B	Largely natural with few modifications
61 – 75	C	Moderately modified
41 – 60	**D**	**Largely modified**
21 – 40	E	Highly degraded
0 – 20	F	Extremely degraded

The Tongati Estuary has a Functional Importance score of 65 **(**Table 6.3) based on its role as a nursery for marine associated fish and crustaceans (Demetriades, 2007: 44). The EIS for the Tongati Estuary was 61 out of 100 (Table 6.4) which classifies the estuary as being "Important" (Table 6.5).

Table 6.3: Functional Importance of the Tongati Estuary (adapted from Demetriades, 2007c: 44).

Functional Importance	Score
(a) Export of organic material generated in the estuary (regional scale)	45
(b) Nursery function for fish and crustaceans (marine/ riverine)	65
(c) Movement corridor for river invertebrates and fish breeding in sea	40
(d) Roosting area for marine or coastal birds	40
(e) Catchment detritus, nutrients and sediments to sea	50
Functional importance score (maximum score of (a) to (e))	**65**

Table 6.4: Estuarine Importance Scores for the Tongati Estuary (adapted from Demetriades, 2007c: iv).

Criterion	Weight	Score	Weighted Score
Estuary Size	15	70	11
Zonal Rarity Type	10	10	1
Habitat Diversity	25	80	20
Biodiversity Importance	25	51	13
Functional Importance	25	65	16
Estuarine Importance Score			**61**

Table 6.5: Estuarine Importance Score based on Present State (Demetriades, 2007c: iv).

Importance Score	Description
81 – 100	Highly important
61 – 80	**Important**
0 – 60	Of low to average importance

The EHI and PES of the Tongati Estuary has been established to be 49 and D respectively, this places the estuary in an ERC of D (Table 6.6). This classification represents the lowest ERC allowed for this system.

Table 6.6: Ecological Reserve Category as applied in the estuaries RDM process (Demetriades, 2007c: iv).

Estuarine Health Index	Present Ecological Status	Description	Ecological Reserve Category
91 – 100	A	Unmodified, natural	A
76 – 90	B	Largely natural with few modifications	B
61 – 75	C	Moderately modified	C
41 – 60	**D**	**Largely modified**	**D**
21 – 40	E	Highly modified	-
0 - 20	F	Extremely degraded	-

The Tongati Estuary has been classified an important estuary, the recommended ERC for the system is PES + 1, i.e. a minimum of a C (Table 6.7).

Table 6.7: Recommended Ecological Reserve Category based on level of protection and importance of an estuary (Demetriades, 2007c: v).

Current/desired protection status and estuary importance	Recommended Ecological Reserve Category	Policy basis
Protected area	A or Best Attainable State	Protected and desired protected areas should be restored to and maintained in the best possible state of health
Desired Protected Area		
Highly important	PES + 1, min B	Highly important estuaries should be in an A or B class
Important	PES + 1, min C	Important estuaries should be in an A, B or C class
Of low to average importance	PES, min D	The remaining estuaries can be allowed to remain in a D class.

6.3 Catchment land-cover analysis

The Tongati Estuary drains an area that spreads over two quaternary catchments. The size of the catchment that feeds the estuary is approximately 412 km^2 (Table 6.8). A comparison between estuarine functional zone size and catchment size shows that the estuary occupies <0.5% of the entire catchment. The representative sizes and percentage of the whole catchment occupied by natural and transformed land-cover classes are shown in Table 6.8.

Table 6.8: Primary land-cover classes in the Tongati catchment

Class	Area (ha)	Catchment (%)
Natural	16048.65	38.99
Transformed	24957.88	60.64
Estuary	150.76	0.37
Total	**41157.29**	**100**

Within the Tongati catchment the area that is representative of land still in its natural state constitutes 39% of the total catchment cover. Transformed land occupies the remaining 60% of the total catchment cover. The division of the catchment area between natural and transformed land is not uniform and the distribution between the two classes can be seen in Figure 6.4. There are a few trends that can be noted in the distribution of natural and transformed land within the catchment. Firstly the majority of the area represented by natural land is located in the upper half of the catchment, with smaller areas of transformed land scattered between. Conversely, the majority of the bottom half of the catchment is transformed land with scattered areas of natural vegetation in-between. Much of the land around the estuary has been transformed, but there is still a small strip of natural land towards the mouth of the estuary along the coast.

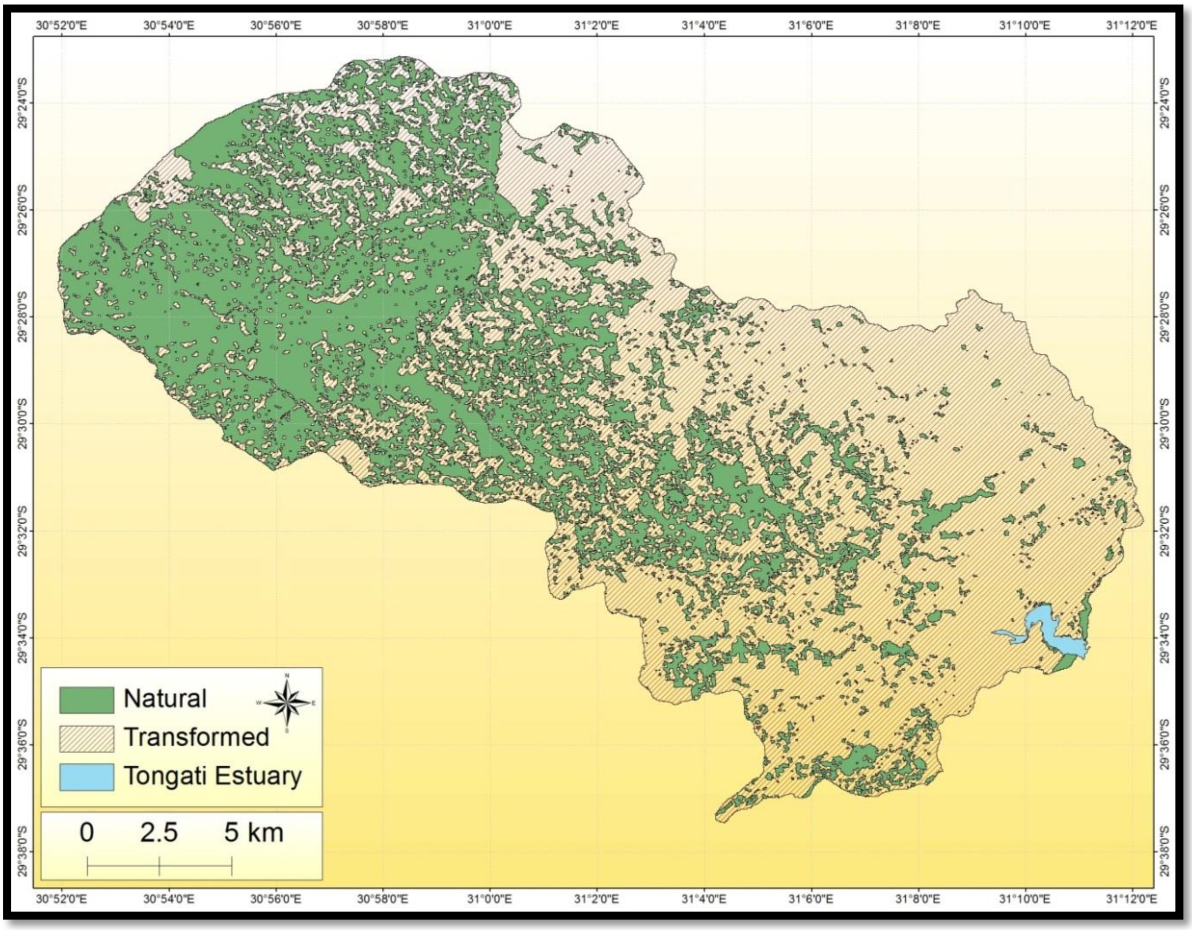

Figure 6.4: Primary land-cover classes within the Tongati catchment.

The second catchment analysis further classifies the category of 'transformed' land into various land-cover types. The land-cover types that can be seen within the Tongati Estuary's catchment include: waterbodies, cultivated land, degraded land, urban built-up, plantations and mines. The relative area and percentage catchment occupied by each land-cover type is shown in Table 6.9 and the geographic locations and distribution of the classes in Figure 6.5.

The three land-cover classes occupying the largest area are cultivated land, natural land and urban built-up. Cultivated land, occupying the greatest area, covers approximately 47.2% of the total catchment, of which appear in greater magnitude in the bottom half and along the north-eastern portion of the catchment. There are also patches of cultivated land in the upper half of the catchment in amongst natural areas. Cultivated land is also present on the floodplain of the estuary.

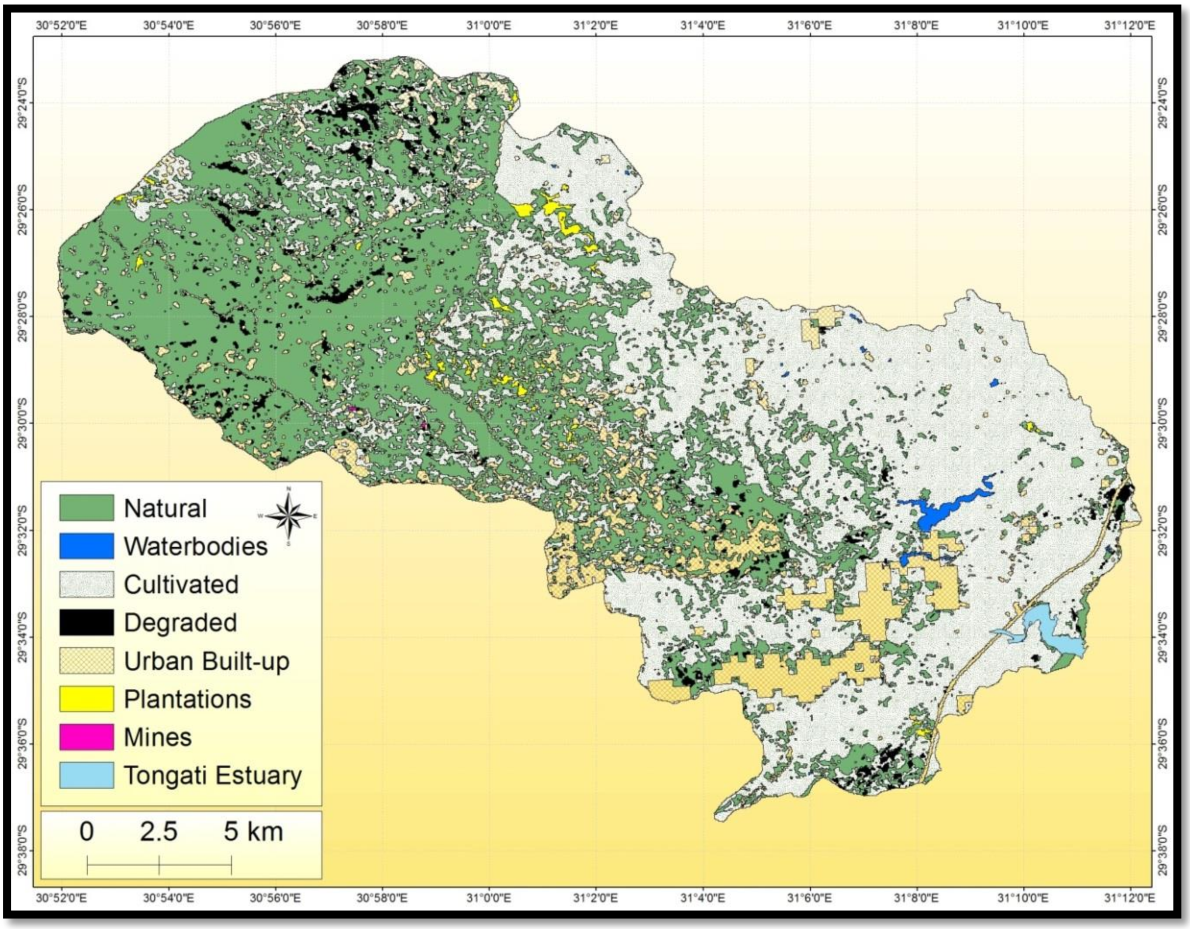

Figure 6.5: Secondary land-cover classes within the Tongati catchment.

Table 6.9: Secondary land-cover classes in the Tongati catchment

Class	Area (ha)	Catchment (%)
Estuary	150.76	0.37
Waterbodies	145.04	0.35
Natural	15903.61	38.64
Cultivated	19435.02	47.22
Urban Built-up	4328.29	10.52
Plantations	278.73	0.68
Degraded	912.15	2.22
Mines	3.69	0.01
Total	**41157.29**	**100**

The second largest area of land-cover is that of natural vegetation, which as previously mentioned is more densely located in the top half of the catchment. Natural land-cover becomes more sporadically spread out in the lower half of the catchment, with only small patches in close proximity to the estuary. Urban development accounts for the third largest area, occupying 10.5% of the total catchment area. The largest urban area is situated in the bottom third of the catchment near to the estuary, with smaller settlements scattered across the catchment.

Out of the remaining land-cover classes, degraded land is the only class which occupies an area >1% of the total catchment. Degraded areas account for approximately 2.2% of the catchment and are located mainly in the top third of the catchment amid natural vegetation and smaller areas of cultivated land. Small, localised patches of degraded land are also present in the bottom half of the catchment, with some patches located near to the periphery of the estuary.

Plantations, waterbodies and mines are also present within this catchment. These land-cover classes occupy 0.6%, 0.4% and 0.01% of the catchment respectively. Small plantations are located near the upper reach of the estuarine functional zone, as well as a few scattered mines. Small waterbodies can be seen amongst the areas of cultivated land and a larger waterbody north-east of the urban area and north-west from the inlet to the estuary. Due to the location of these waterbodies they probably supply the urban areas with drinking water and irrigation water for the cultivated areas.

Further analysis was conducted to divide the catchment into upper, middle and lower sections. This enabled the isolation of land-cover classes within the lower section of the catchment which, based on Tobler's First Law of geography, would be more likely to have an influence on the estuary than land-cover classes in the middle and upper sections of the catchment (Miller, 2004: 284). A DEM showing the path of the Tongati River from source to estuary is displayed in Figure 6.6. The longitudinal profile of the river displaying gradient change is shown in Figure 6.7.

Without any major changes in river morphology closer to the estuary, it was difficult to distinguish the exact point of change from the middle to lower section. The gradient of the river starts to flatten approximately 45 km from the river source at 40 m, and for the purpose of this assessment all land below this altitude will be classified as part of the lower section.

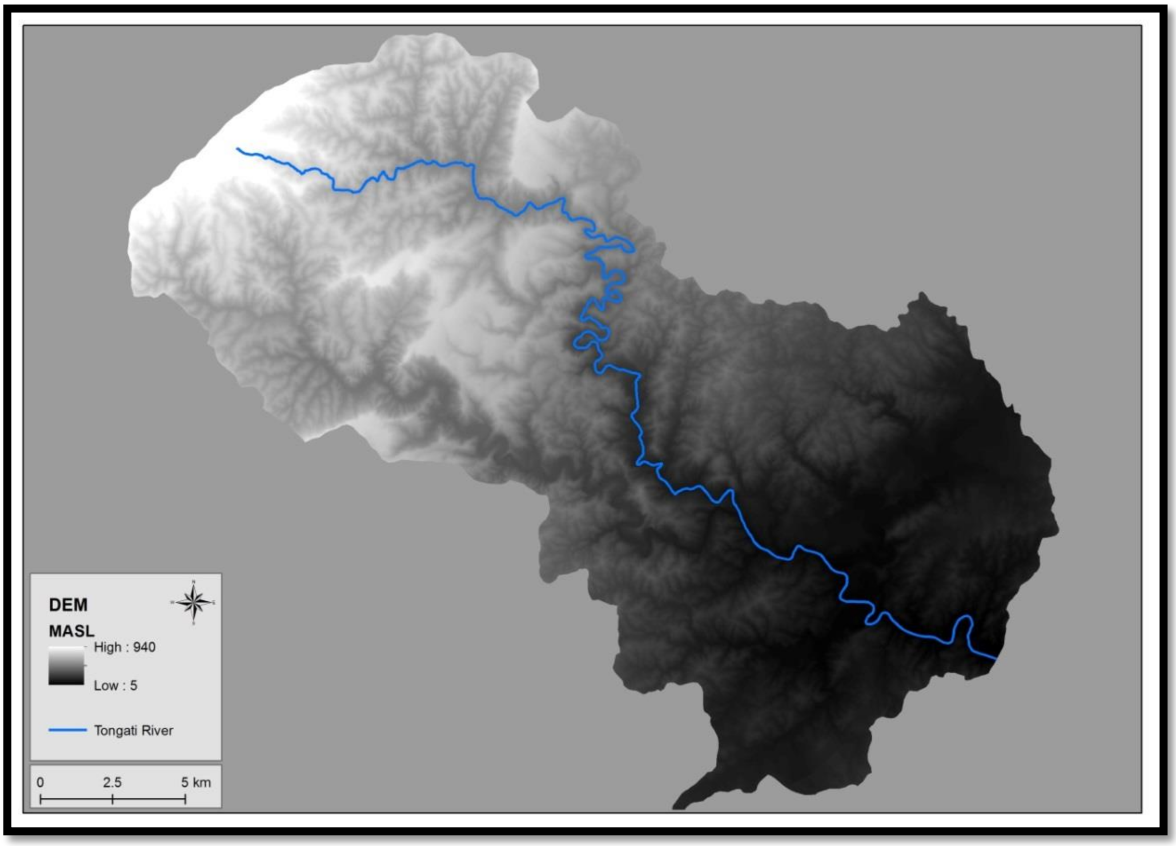

Figure 6.6: Tongati catchment Digital Elevation Model and river.

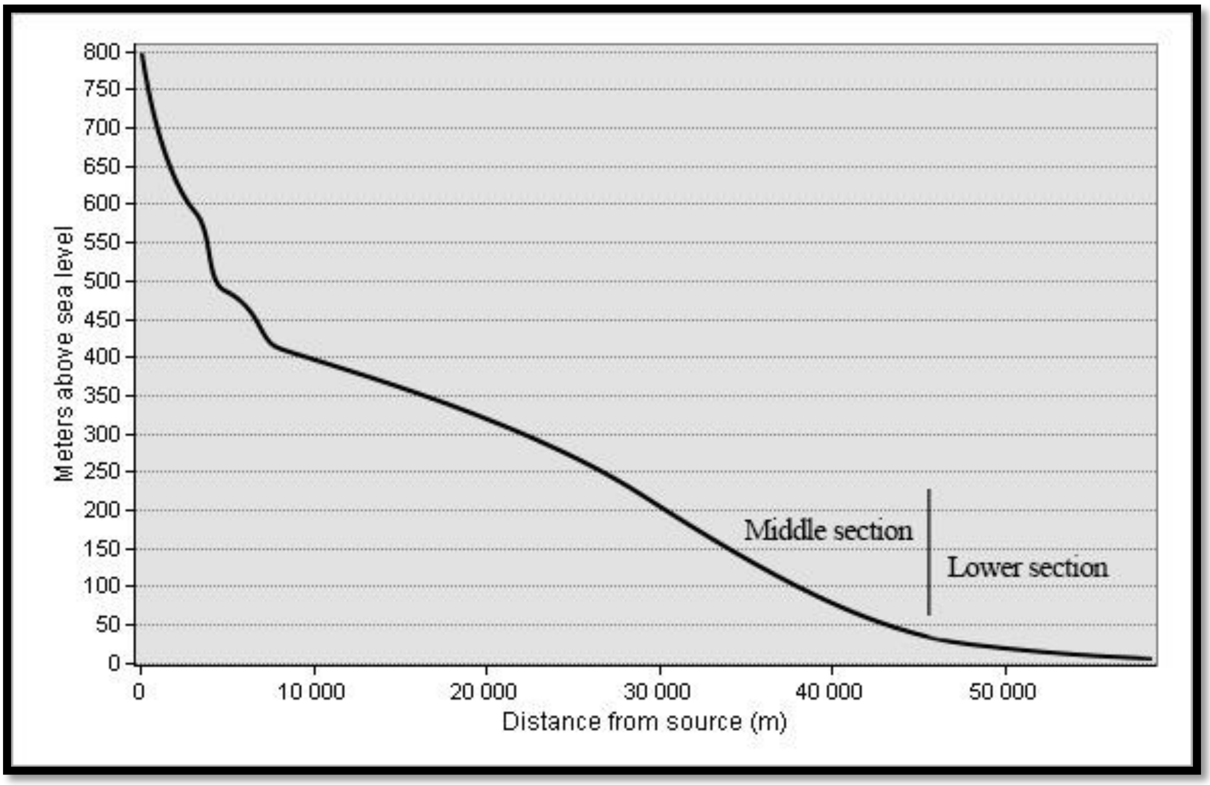

Figure 6.7: Longitudinal profile of the Tongati River.

Secondary land-cover classes present within the lower section of the Tongati catchment include: natural vegetation, cultivated areas, degraded land, urban built-up, waterbodies, plantations and the estuary. The locations of the land-cover classes are shown in Figure 6.8 and their representative areas occupied and percentage of the catchment can be seen in Table 6.10.

The lower section of the Tongati catchment reflects a heavily cultivated zone. Cultivation is visible throughout the catchment, accounting for 73.7% of the total catchment area. The second and third largest land-cover classes are natural vegetation and urban areas, occupying 12.4% and 10.8% of the catchment respectively. Areas representing natural vegetation are scattered throughout the catchment, with larger portions located in close proximity to urban areas. Concentrated areas of natural land also exist in the southern section of the catchment, as well as along the coast adjacent to the estuary mouth. Urban areas are also scattered throughout the catchment but occupy a larger area in the southern half of the catchment in close proximity to the upper section of the estuarine functional zone. Much of the northern periphery of the estuarine functional zone is dominated by urban developments.

The remaining land-cover classes collectively only occupy 3.1% of the total catchment area. Degraded land, occupying 1.3% of the total catchment contributes the largest area, is scattered around the catchment but predominantly situated between areas of natural habitat. At this scale, small areas of plantations are visible, but collectively only account for 0.1% of the total catchment area. In the middle catchment section, two waterbodies are present and collectively represent 0.8% of the total catchment, which is similar to the area occupied by the estuarine functional zone.

A 1 km buffer was created around the estuary functional area delineation for further analysis of the associated catchment land-cover and within this buffer zone, four land-cover classes are present (Figure 6.9).

The largest land-cover class is cultivation which is clearly visible dominating the catchment cover and constitutes 77.4% of the catchment area. The second largest land-cover is natural habitat which accounts for 15.9% of the catchment. Natural vegetation is seen in greater magnitude on the coast on either side of the estuary mouth, as well as in some of the waterways draining into the estuary. Urban land-cover constitutes 6.5% of the total catchment area and is dispersed throughout the lower catchment, but is most prevalent north of the estuarine functional zone. Degraded lands are present within the buffer zone, but only account for 0.2% of this area. The three areas of degraded land are all in close proximity to the estuarine functional zone.

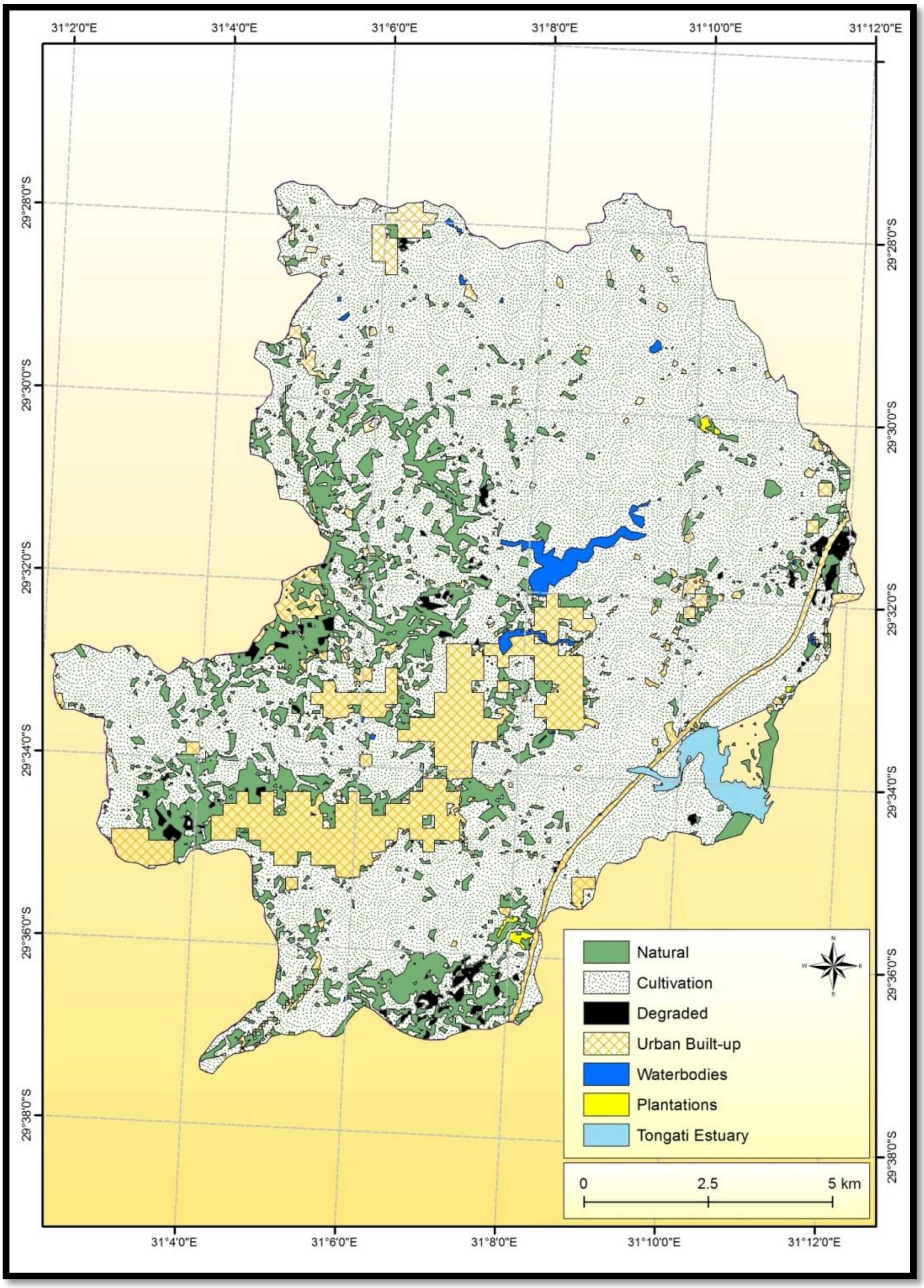

Figure 6.8: Secondary land-cover classes within the lower section of the Tongati catchment.

Table 6.10: Secondary land-cover classes within the lower section of the Tongati catchment.

Class	Area (ha)	Catchment (%)
Estuary	150.76	0.89
Natural	2095.88	12.38
Cultivation	12482.96	73.74
Degraded	216.65	1.28
Urban Built-up	1819.58	10.75
Waterbodies	140.85	0.83
Plantations	20.80	0.12
Total	**16927.48**	**100**

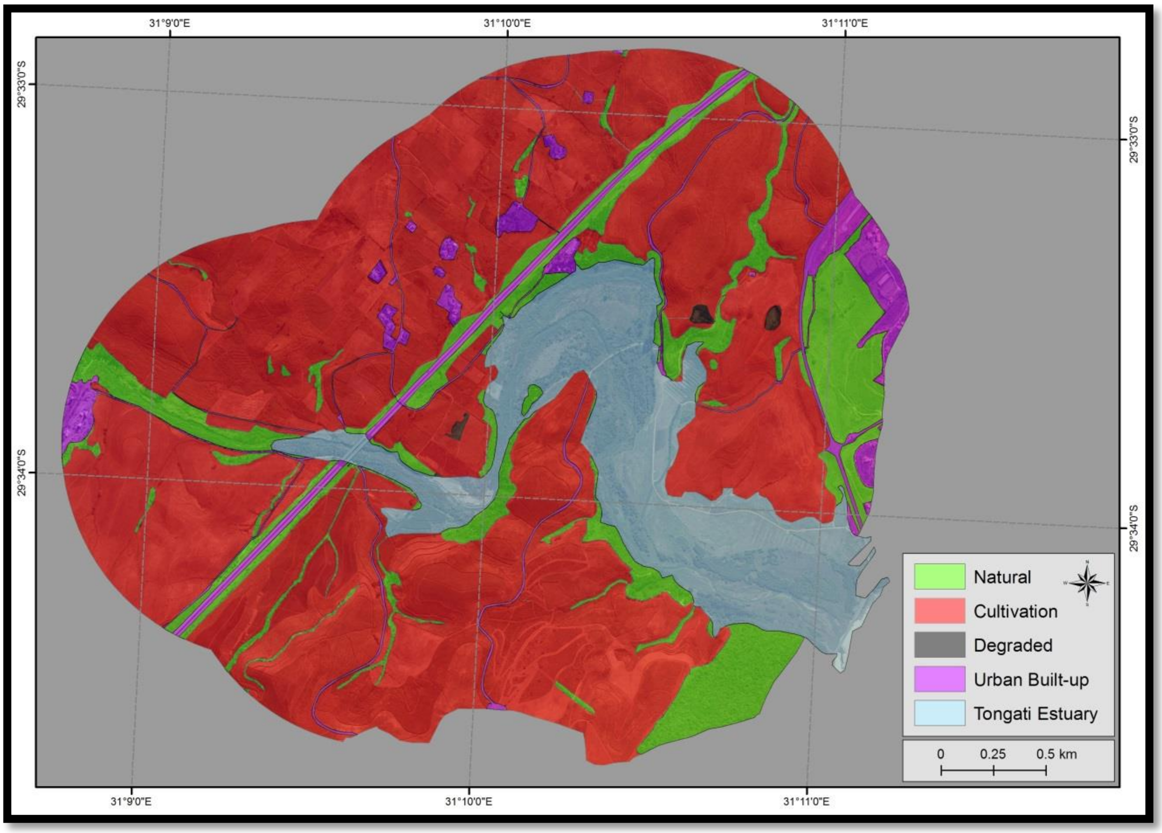

Figure 6.9: Secondary land-cover classes within a 1 km buffer of the Tongati Estuary.

Within a 100 m buffer of the estuarine functional zone, four land-cover classes are visible including: natural areas, cultivated land, degraded land and urban areas (Figure 6.10). Cultivated land once more dominates the buffer by occupying 59.2% of the total area. The second largest land-cover is natural vegetation, accounting for 34.5% of the buffer zone. Urban developments appear in the buffer zone primarily as roads around the estuarine functional zone and constitutes 6.5% of the buffer zone. Finally, degraded land is also present but accounts for <0.5% of the buffer zone.

Within the Tongati Estuary delineation, the previous four land-cover classes remain visible (Figure 6.11). The estuarine functional zone remains largely natural (exhibiting 78.9% natural land-cover) but land-cover transformations have occurred. Cultivation, urban development and degraded land make up the remainder of the area, with cultivation dominating by constituting 18% of the total area. Urban developments and degraded land constitutes 2% and 1.2% of the estuarine functional zone respectively.

6.4 Anthropogenic activities affecting the current state of the system

In the study conducted by Demetriades (2007c) the author outlines activities which are currently affecting the Tongati Estuary negatively. The activities include: floodplain development, additional sedimentation, the construction of illegal causeways and nutrient enrichment resulting from treated water outflow from a sewage works. Influences negatively affecting the estuary can be divided into two categories, namely those originating from the catchment and those within the estuary.

6.4.1 Catchment activities

Influences originating from catchment activities include: sedimentation and nutrient enrichment, with accelerated sedimentation occurring within the estuary as a result of land-use changes within the catchment (Demetriades, 2007c: 20). It is also proposed that the causeways in the estuary have increased the rate of sedimentation due to the reduced tidal exchange and the limiting of flood scouring due to the concrete base created for the causeways (Demetriades, 2007c: 20). The N2 road bridge has also had an impact on the on the river bed, extensively changing it from Reference Condition (Demetriades, 2007c: 23).

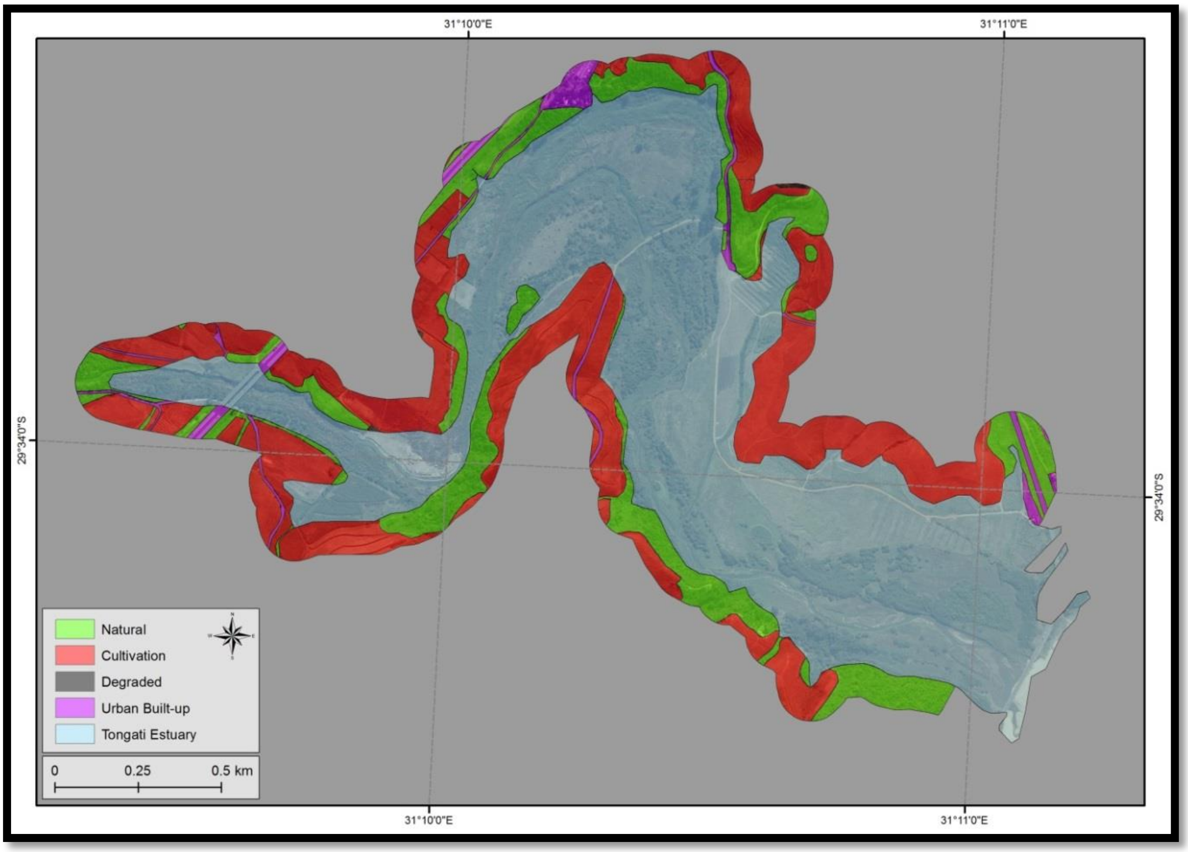

Figure 6.10: Secondary land-cover classes within a 100 m buffer of the Tongati Estuary.

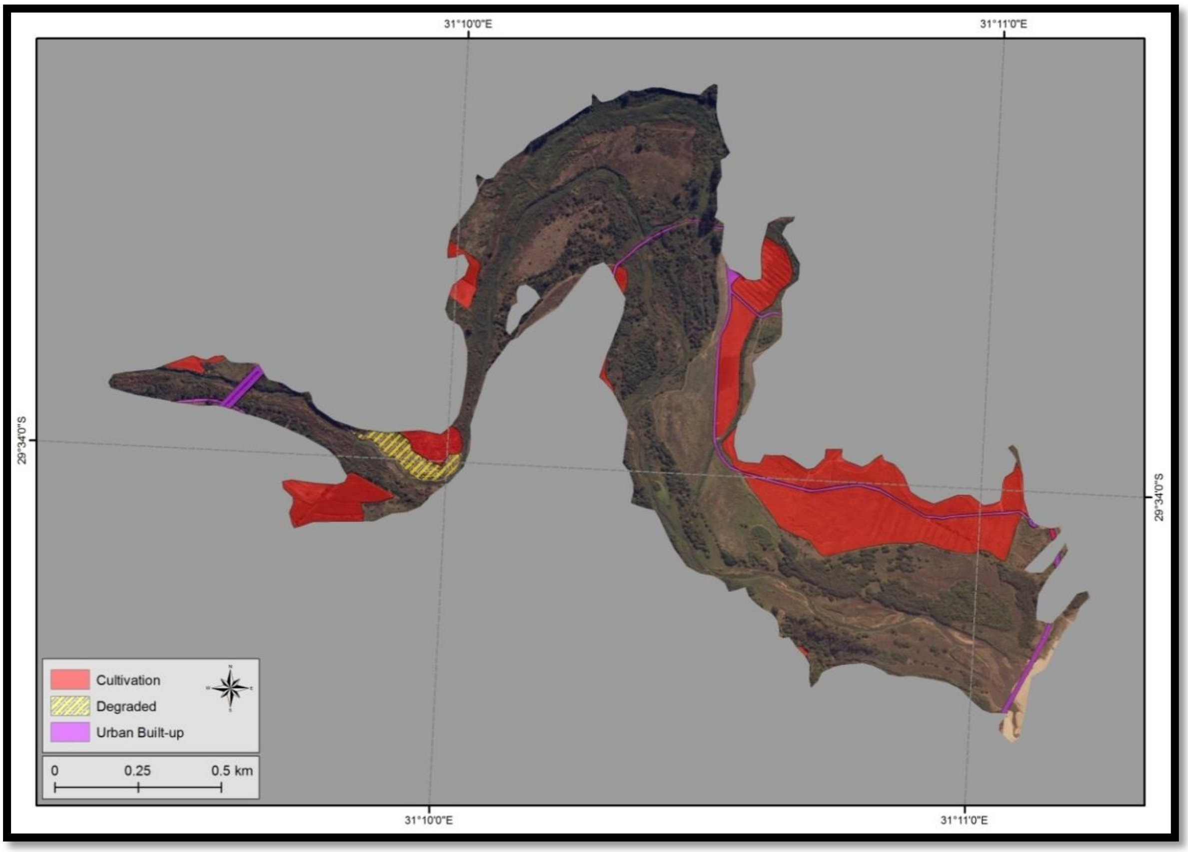

Figure 6.11: Secondary land-cover classes within the Tongati Estuary.

Increased nutrient enrichment of the estuary can be attributed to various different land-uses within the catchment. A large portion of nutrient loading within the estuary can be attributed to sewage works and waste water discharges into the watercourses. Previously the estuary also used to receive industrial effluent from textile mills (Blaber *et al*., 1984: 224), but discharges affecting water quality can also be attributed to runoff from both urban and industrial sectors within the catchment, as well as agricultural runoff (Demetriades, 2007c: 23).

6.4.2 Estuary activities

Direct negative influences, which have modified the estuary profile, can be attributed mainly to the construction of two causeways illegally within the upper reaches of the estuary. The furthest from the mouth is approximately 2.5 km upstream and is now deemed to be the upper limit of the tidal influence in the estuary (Demetriades, 2007c: 23). Although the upper causeway has raised pipes to allow the passage of water, the lower causeway is a solid structure that forces any flow over the top of this barrier (Demetriades, 2007c: 23).

6.5 Discussion

The Tongati Estuary is regarded as an important ecosystem, but it has been determined to be highly modified in accordance with its PES. The estuary scored poorly in terms of estuarine health and has been placed in an ERC of D. The Tongati estuary catchment has similar characteristics as the catchment area has been largely transformed from a natural state and is currently portraying a highly cultivated catchment.

Many of the pressures present negatively influencing the health of the system have been associated with land-cover change from natural to cultivation and urban developments. It was found that for each level of assessment excluding within the estuarine functional zone, cultivated land occupied the greater proportion of the total catchment area. This potentially creates a significant threat for the integrity of the estuary as natural buffers have been diminished within the catchment and associated effects have been documented in the RDM assessment. Urban development appears throughout the catchment, but primarily resides within the bottom section of the catchment. This land-cover is present within the CPZ, as well as within the estuarine functional zone. Within the estuarine functional zone urban development only represents approximately 2% of the total land-cover, but these structures are affecting the health of the estuary. As sedimentation is a large contributor to the decrease in estuarine health for this system, it is important to note that some areas of degraded land have been identified within the CPZ and within the estuarine functional zone. These bare areas are potentially at risk of accelerated erosion which could further exacerbate the current sedimentation issues.

In conclusion, there is a relationship between land still in a natural state and the health of the Tongati Estuary. The majority of the natural vegetation is located in the top half of the catchment, with land in closer proximity to the estuary having exhibiting transformation. Within the CPZ natural land-cover only occupies 16% of the surface area, potentially decreasing the effect of natural buffers and increasing negative attributes from near land-use activities entering the system. Therefore with a heavily transformed catchment and lack of natural vegetation it could be inferred that the EHI given to the system is justified from a catchment perspective.

CHAPTER 7: SUMMARY OF RESULTS, GENERAL DISCUSSION AND CONCLUSIONS

7.1 Summary of results

7.1.1 Estuary ranking and noted trends between study sites

The health status of the study estuarine systems, as outlined by the RDM outcomes allowed for a ranking of the estuaries in terms of established estuarine health scores. Out of the small sample size of only four assessed systems, only one estuary, the East Kleinemonde, was categorised as having an ERC of B and the remaining three were classed as having an ERC of D. The Groot Brak Estuary had the highest EHI out of the category D estuaries, followed by the Tongati and lastly the Mdloti Estuary. For the purpose of this thesis the estuaries were assigned a ranking according to the determined health for each system and thus the East Kleinemonde Estuary was the healthiest, with the Mdloti Estuary exhibiting the poorest health.

Table 7.1: Estuarine Health Index and assigned estuary rank.

Estuary	East Kleinemonde	Groot Brak	Mdloti	Tongati
Final EHI	87	58	41	49
Estuary rank	1	2	4	3

In the RDM assessments conducted by van Niekerk *et al*. (2008, 2009) and Demetriades (2007a, 2007c) the authors outlined the pressures that have resulted in poor estuarine health (see individual study chapters for details). These pressures have been identified through complex and in-depth analysis, and from a catchment perspective many of these pressures are hard to identify and quantify. Also, many of these pressures are interlinked due to the hydrological continuity within catchment landscapes and the connectivity between land-cover types (Booth, 1991; Gergel *et al*., 2002; Tong and Chen, 2002). The common pressures found within all four systems include: riparian developments, structures within the estuarine functional zone, nutrient input from agricultural activities and urban areas, excessive erosion and sedimentation, and deteriorating estuarine water quality. As highlighted in the literature, these pressures are inherent in the nature of urban built-up and cultivation land-cover classes and can have severe impacts on aquatic ecosystems (Stein *et al*., 2002: 13). These two land-cover classes have been utilised in research to assess aquatic ecosystem health (Amiri and Nakane, 2008; Bierschenk *et al*., 2012; Mamoun *et al*., 2013; Sliva and Williams, 2001; Viaud *et al*., 2004) and have been found to be a good indication of anthropogenic disturbance levels (Gergel *et al*., 2002: 125). Thus, the extent and magnitude of natural vegetation, urban and cultivated areas within each study catchment could be used to infer links between catchment land-cover and estuarine health.

Some of these pressure are also closely associated with major impoundments within catchments (Marques *et al*., 2004; Snoussi *et al*., 2007) and these impoundments greatly impact on the ecological functioning of aquatic ecosystems (Stein *et al*., 2002: 13). Large impoundments are present within three of the study catchments (Groot Brak, Mdloti and Tongati), and may have influenced the decreased EHI scores received for these systems. Another trend which was noted, is that the two estuaries with the poorest health have WWTWs (point source of nutrients) discharging directly into their rivers, which also heavily impacts on downstream aquatic ecosystems (Stein *et al*., 2002: 12). Unfortunately, influences from WWTWs cannot be quantified from a catchment perspective.

7.1.2 Catchment land-cover

The composition of catchment land-cover for the four study systems was analysed at various scales, including the whole catchment, lower section of the catchment, within buffers of 1 km and 100 m of the estuarine functional zone and within the estuarine functional zone itself. Analysis of the entire catchment areas identified that the prominent land-cover types were natural, waterbodies, cultivation and urban built-up. This scale of analysis also identified that the three estuaries with the poorest rated health also contained high proportions of plantations, degraded lands and mines within their associated catchments. The East Kleinemonde catchment was the only catchment with relatively low levels of natural land transformation, and this could be related to the high estuarine health score received (Table 7.2) (Brooks *et al*., 2004; Bierschenk *et al*., 2012; Mamoun *et al*., 2013).

Table 7.2: Natural land-cover extent and estuary rank within the entire catchments.

Estuary	East Kleinemonde	Mdloti	Tongati	Groot Brak
Natural land-cover (%)	81.3	60.3	38.6	33.1
Estuary rank	1	4	3	2

The lower section catchment analysis yielded similar results to that of the whole catchment but aided identification of land-cover classes in closer proximity to the estuary, i.e. facilitated a focus on land use that would more likely have a larger effect on the integrity of the estuary (Miller, 2004). Again, the main land-cover classes present within this scale of assessment were natural, cultivation and urban built-up. A trend visible at this scale within the category D estuaries is that they all exhibit highly transformed land-cover, with cultivation accounting for the greatest area. Associated waterbodies were also present but accounted for less than 1% of the total area of each system's lower catchment section. Within the lower Mdloti and the Tongati catchments, degraded lands were visible, and within the Mdloti lower catchment some land-cover associated with mining was also present (Table 7.3).

Table 7.3: Natural land-cover extent and estuary rank within the lower catchment sections.

Estuary	East Kleinemonde	Mdloti	Groot Brak	Tongati
Natural land-cover (%)	83.1	33.1	12.7	12.4
Estuary rank	1	4	2	3

Within the CPZ for rural areas (as delineated by a 1 km buffer around the estuarine functional zone) similar trends were noted. The land-cover classes present within this scale of assessment were natural, cultivation and urban built-up areas. Urban areas were seen occupying land within 1 km of all the study systems and cultivation was only absent from the East Kleinemonde buffer. The CPZ is a sensitive area for the ecological functioning of coastal processes (Republic of South Africa, 2009). At this scale, pressures associated with particular land-cover and associated land-uses are likely to have direct impacts. Areas of cultivation are prevalent in the KwaZulu-Natal catchments, with the Groot Brak catchment containing a relatively small area of cultivation and the East Kleinemonde catchment being without formal cultivation. Of particular importance was the percentage land-cover represented by natural land within the 1 km CPZ catchments of each study area correlating with the estuary rank in terms of established health (Table 7.4).

Table 7.4: Natural land-cover extent and estuary rank within the 1 km buffers.

Estuary	East Kleinemonde	Groot Brak	Tongati	Mdloti
Natural land-cover (%)	85.6	66.1	15.8	14.2
Estuary rank	1	2	3	4

Within a 100 m buffer of the estuarine functional zone, which is classified as the CPZ for urban areas, the three main land-cover classes were natural, cultivation and urban built-up. Again, within the KwaZulu-Natal systems, cultivation was most prevalent in the estuary surrounds and practically absent from the two Cape catchments. Urban development accounted for a relatively large percentage of the CPZ catchments, with the Groot Brak system exhibiting the greatest area of urban development and the Tongati the least. Similarly, as was the case with the 1 km buffer analysis, the percentage area of natural land within this buffer also relates with the estuary rank in terms of health (Table 7.5).

Table 7.5: Natural land-cover extent and estuary rank within the 100 m buffers.

Estuary	East Kleinemonde	Groot Brak	Tongati	Mdloti
Natural land-cover (%)	69.7	57.4	34.5	26.7
Estuary rank	1	2	3	4

The largest scale of assessment involved analysing the land-cover within the estuarine functional zones. The three main land-cover classes were natural, cultivation and urban built-up. All the study estuaries have been transformed to some degree from their Reference Condition. Cultivation was more prevalent in the KwaZulu-Natal estuarine functional zones, and urban developments in the other two estuaries, with the Tongati Estuary having the greatest proportion of cultivation and the Groot Brak Estuary having the greatest proportion of urban development. Unlike the 1 km and 100 m buffer analysis, the percentage area of natural land does not relate to the assigned estuary health ranking, with the Mdloti Estuary remaining largely natural and the Groot Brak Estuary showing the greatest deviation from its natural state (Table 7.6). This result may be partially due to the relatively high proportion of natural land-cover in all four estuaries, with no system having less than 64% natural cover.

Table 7.6: Natural land-cover extent and estuary rank within the estuarine functional zones.

Estuary	East Kleinemonde	Mdloti	Tongati	Groot Brak
Natural land-cover (%)	89.4	82.1	78.9	64.2
Estuary rank	1	4	3	2

7.2 General discussion

To reiterate, the primary aim of this research was to examine the relationship between catchment land-cover and the health status of associated TOCEs. The research hypothesis proposed was: "Estuarine health is directly related to catchment land-cover, with increasing alteration from a natural state being associated with a decline in estuarine health". The analysis was accomplished through selecting sites for comparison based on a review of the literature, collation and manipulation of existing spatial and raster datasets, examining the PES and EHI for each system, identifying and collating associated pressures on the study systems, conducting land-cover assessments at various scales on the study catchments, and finally identifying potential relationships between land-cover and the health of each system.

The examination of the PES and EHI for each system provided an understanding of the current state of each estuary. This highlighted the magnitude of deviation from the Reference Condition that each of these estuarine ecosystems have been subjected to. It was found that the two estuaries in the subtropical biogeographic region (Mdloti and Tongati) exhibited the greatest health deterioration. The two estuaries within the warm temperate biogeographic region (Groot Brak and East Kleinemonde) were in a better state of health than the subtropical systems, thus supporting the general estuarine health trends outlined by Whitfield and Baliwe (2013).

As stated by Allanson and Baird (1999: 292), Wolanski (2007: 11) and Whitfield and Cowley (2010), the increase in anthropogenic activities and their associated pressures are becoming more noticeable within the catchments of most South African estuaries, which is resulting in a decrease in estuarine health and a decrease in the capability of these ecosystems to provide adequate goods and services. The RDM assessments enabled the collation and comparison of associated pressures exerted on the study estuaries to be undertaken using the same GIS methodology. The pressures associated with the decline in health of these four estuaries are aligned to the key pressures outlined within the NBA report by van Niekerk and Turpie (2012). The primary pressures exerted on the four study systems (as identified in the study chapters) originated from within the immediate estuary catchments (including the peripheries of the estuaries) and were mainly associated with agricultural land and urban developments (urban areas and construction such as dams, roads and WWTWs). It was also noted that each estuarine functional zone assessed showed some degree of transformation from natural land-cover, with the predominant land-cover classes comprising cultivation and urban built-up.

Identification, quantification and determination of the locations of land-cover classes present in each catchment were achieved through catchment and buffer zones delineations using GIS software, and following published methods that have applied to similar types of studies (Amiri and Nakane, 2008; Bierschenk *et al*., 2012; Brooks *et al*., 2004; Mamoun *et al*., 2013; Sliva and Williams, 2001; Stein *et al*., 2002; Tiner, 2004). The GIS procedures utilised were aligned with general procedures outlined in the literature, and the spatial data that was generated facilitated a comparison between the study estuaries and their catchments.

The first level of assessment evaluated land-cover classes within the whole catchment. One major trend noted was that the three estuaries with the poorest estuarine health scores all had major impoundments within their associated catchments. No other significant trends were noted between land-cover classes at this scale. What was apparent, though, was that the East Kleinemonde catchment had mostly natural land-cover (81%) and the estuary had the highest rating in terms of health when compared to the other three systems. The estuary with the second most natural catchment (60%) was represented by the Mdloti, which had the poorest health rank, thus indicating that within this small sample of study sites, at lower percentages of natural land-cover the relationship between natural land-cover and estuarine health breaks down.

In the case of the Mdloti catchment, although more than half the catchment area is delineated as natural land, minimal natural land-cover is present within close proximity to the estuary, which, if comprised of natural vegetation, would mitigate negative effects derived from catchment activities (Tiner, 2004; Viaud *et al*., 2004). This level of analysis, however, did provide useful information in terms of the locations of various land-uses in relation to their proximity to the estuarine functional zone, and thus their potential effects on the aquatic ecosystem.

The next level of analysis identified land-cover classes present within the lower sections of the estuary catchments, but once again did not reveal any significant trends (Table 7.3). What was highlighted, however, was that the predominant land-cover classes within this delineation included natural, cultivation and urban built-up areas. This delineation should primarily constitute natural vegetation but this was only the case in the East Kleinemonde catchment. The other three estuarine catchments all exhibited highly transformed land-cover, with the maximum magnitude of natural land in these systems occupying only 33% of the total area. The dominant land-cover at this scale was that of agricultural land which, as outlined by the literature, is expected to be highly detrimental to the ecology of estuaries.

Based on ICMA regulations, two buffers (1 km and 100 m) around the estuarine functional zones were analysed, similar to buffer zone delineations used in this type of research (Brooks *et al*., 2004; Mamoun *et al*., 2013; Slaiva and Williams, 2001). The ICMA was created to "promote the conservation of the coastal environment, and maintain the natural attributes of coastal landscapes and seascapes, and to ensure that development and the use of natural resources within the coastal zone is socially and economically justifiable and ecologically sustainable" (Republic of South Africa, 2008: 2). Thus this act was passed to ensure the integrity of coastal land which plays a significant role in coastal ecosystems. Analysis of land-cover in both buffer zones portrayed similar land-cover trends and highlighted the immediate surrounds of the Mdloti and Tongati estuaries as heavily cultivated zones, with the Groot Brak and East Kleinemonde buffer zones having a relatively large area under urban development. Within the East Kleinemonde and Groot Brak buffer zones a relationship is noticed between the levels of urban development and established estuarine health (in the absence of significant cultivation), leading to the conclusion that in these two estuaries, the greater the extent of urban development within this zone, the poorer the estuarine health might be (Bierschenk *et al*., 2012; Rothwell *et al*., 2010). In contrast, within the buffer zones of the Tongati Estuary there is a greater extent of cultivation than the nearby Mdloti Estuary, but the former has the better estuarine health.

Of particular interest was the magnitude of natural habitat portrayed within the CPZs surrounding the estuaries. It was found that with an increase in land-cover transformation away from the natural state, there is deterioration in estuarine health, thus supporting research which utilises percentage natural land-cover to infer aquatic ecosystem health (Table 7.4 and Table 7.5) (Bierschenk *et al*., 2012; Brooks *et al*., 2004; Mamoun *et al*., 2013; Tiner, 2004). The two KwaZulu-Natal systems had extensively transformed natural areas used for agriculture when compared to the two Cape temperate systems. However, the latter two estuaries had major urban transformations, with the percentage area occupied by natural land within each catchment being related with the assigned estuary rank. It is within the CPZs that natural land plays an important role in mitigating many of the negative effects derived from surrounding catchment activities on the aquatic ecosystem (Tiner, 2004; Viaud *et al*., 2004; Walmsley, 2002). Therefore the extent of natural vegetation within CPZs may be a good measure for inferring estuarine health, especially if this habitat extends into the greater catchment.

The last scale of analysis entailed evaluating and calculating the magnitude of land-cover classes that appeared within the estuarine functional zone. The estuarine functional zone is classified as a sensitive area necessary for estuarine function and health (van Niekerk and Turpie, 2012: 28) and one would expect that the greater the transformation that this zone has undergone, the poorer the health of the estuary. Each estuary analysed showed some degree of transformation, but no definitive trend could be established. The Mdloti Estuary (poorest health) portrayed the second least transformed area and the Groot Brak Estuary (the second best health) had the least natural area. This could mean that the pressures exerted on these systems largely originate from catchment activities rather than originating from within the estuarine functional zone, but the degree to which the estuarine functional zone has been altered may also hinder the ecosystem's ability to recover.

A possible relationship between catchment land-cover and health of the estuary is that the pressures derived from urban land-cover seem to be less detrimental than pressures associated with cultivation (or the management thereof), as the two catchments that are most heavily cultivated are also in the poorest health. This statement is made using broad assumptions about LULC impacts, as urban land-cover varies in nature (i.e. urban residential or urban industrial), as well as different types of agriculture (pineapple farming or sugarcane) occurring within the different catchments. Although a small sample size of only four estuaries was assessed, based on the results of this project, urban built-up and cultivation land-cover classes individually do not appear to be good indicators of estuarine health. Instead, natural land-cover within the CPZ buffers appears to be the best predictor of estuarine health. Thus, the hypothesis that an alteration from the natural state is associated with a decline in estuarine health within these zones is supported by the results from this study.

As this project primarily uses available GIS spatial datasets, and standard desktop GIS techniques, the methods used can be easily duplicated and applied to other TOCEs in South Africa. The findings indicate that there is a relationship between natural land-cover extent within the CPZ delineations and estuarine health, and therefore supports the rationale for the implementation of ICMA regulations. Thus a method of rapidly assessing CPZ status to infer TOCE condition and to prioritise TOCEs for rehabilitation and/or conservation was developed (see sub-chapter 2.5 in methods). This result could prove to be an effective basis for prioritising TOCEs for conservation, based on the degree to which their associated CPZs have been altered from a natural state. This method of assessing buffer zone (as stipulated by local legislation elsewhere) integrity, or alteration from a natural state, has been employed successfully in studies by Brooks *et al*. (2004) and Mamoun *et al*. (2013) to prioritise aquatic ecosystems for conservation. Based on the results from the current study, the Mdloti and Tongati estuaries are the most in need of prioritised rehabilitation attention.

7.2.1 Limitations

Some limitations imposed on this project are associated with the NLC data used, difficulties with ground truthing of the spatial data, as well as the poor data, available literature sources and statistical analysis which could have been done. Limitations of the NLC data were discovered when it was found to lack accuracy for smaller study sites due to the scale at which the data was mapped. The generalised, aggregated land-cover classes often made it difficult to discern specific land-uses of the land-cover. The NLC data was found to be fairly accurate with regards to all of the assessed land-cover classes except for plantations. It is recommended that the data should be updated with ground truthed measurements before using this dataset to determine present catchment state and condition.

Ground truthing of the spatial data also proved difficult due to time constraints, accessibility issues and the topography of the catchments. Access to some sample sites proved difficult due to privatisation of the land and/or lack of roads within the catchment. Another limitation, particularly in KwaZulu-Natal, was poor visibility of the sample blocks due to tall vegetation and/or hilly terrain. Ground truthing was also based on broad scale analysis of the catchments and the CPZs and estuaries should have also been ground truthed.

Another major limitation concerns the results of this project, as the findings have been based on the assessment of only four TOCEs which made it difficult to identify any real patterns, but these were the only systems which had intermediate level RDM assessments.

This thesis only focused on the relationship between the overall health scores of each system and land-cover types within the catchments. If statistical correlation/regression analysis had been performed, it may have provided insight into the effects of individual land-cover type's on the individual components of estuarine health (i.e. water quality), thus potentially showing a correlation between individual components and land-cover.

Within the assessed study sites, the use of natural land-cover did not take into consideration the presence of alien invasive vegetation within these areas. A time series analysis of natural land-cover from aerial photographs may have provided insight into the condition of the reported 'natural' land-cover and ultimately changed the results.

7.2.2 Future studies

This study provides a preliminary assessment of TOCEs catchments and the associated pressures of catchment transformation on these systems. Once more TOCEs have had a RDM assessment conducted at an Intermediate level, this will provide a larger data pool to compare against the results from this thesis and therefore provide a higher level of confidence in the results. An important future study could also, instead of using an overall integrative measure of health, focus on the individual components of the EHI to try ascertain the effects of different land-uses on the health of TOCEs. As identified in the limitations, further studies could also employ the use of statistical analysis to ascertain principle land-cover types affecting TOCE health in South Africa. Another potential study could entail the digitising of more TOCE catchments to provide a higher accuracy level of data for all disciplines to utilise and to provide higher accuracy land-cover and land-use data of the estuarine functional zones and associated catchment areas.

7.3 Conclusions

This thesis has shown that the hypothesised relationship between altered natural land-cover and decreased estuarine health is true within the assessed CPZs. Concurrent use of available estuary data, catchment land-cover data, and newly created land-cover data, identified that there is a relationship between the magnitude of natural land within a 1 km and 100 m buffer around the estuarine functional zone and the health of the associated estuary. The two land-cover classes encompassing many of the associated pressures on estuaries have been identified as originating from agriculture and urban development, but these two land-cover classes were not good individual predictors of TOCE health. Based on the results of this study, a method for rapidly assessing CPZ status to infer TOCE condition and prioritise TOCEs for rehabilitation and/or conservation was developed. This thesis has also shown the advantages of using GIS techniques to undertake spatial analysis for resource protection and management, and can be easily replicated for other TOCEs in South Africa if the relevant data at the right accuracy level is available. The major findings of this thesis are shown in Table 7.7.

The parliamentary laws and acts within South Africa have been created to protect the integrity of estuarine functions, services and natural resources for future generations. It has been illustrated in this study that estuarine ecosystems are influenced by catchment activities and that it is of paramount importance to uphold and enforce the legislation to minimise further transformation of these crucial areas. This study has also demonstrated the importance of having recent data available to assess the current state of ecosystems, which will benefit those involved in the management of these resources.

For this reason, it is of utmost importance that future studies involving the evaluation and monitoring of estuary catchment land-cover is conducted to further contribute to the understanding of the relationship between land-cover and associated land-uses on estuarine ecosystems. Since this study focuses only on TOCEs, it is hoped that further studies on other types of estuaries along the South African coast will be initiated, thus assisting with the management and protection of these valuable ecosystems for future generations.

Table 7.7: Major findings of the study on four South African TOCEs.

Major findings
Natural land-cover class was the best predictor of estuarine health, with urban built-up and cultivation land-cover classes not representing effective predictors.
There is a relationship between natural land-cover extent within both 1 km and 100 m buffer zone assessments and estuarine health.
There was no relationship between natural land-cover extent within whole catchment, lower catchment or within estuarine functional zone assessments and estuarine health.
The three estuaries with the poorest health all had major dams/impoundments within their associated catchments.
Methods used in this thesis are effective and can be easily duplicated using GIS software.
The method developed for rapidly assessing the condition of South African TOCEs could be effective for prioritising TOCEs for rehabilitation and/or conservation.

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