AN ANALYSIS OF THE SPATIAL AND TEMPORAL CHANGES IN THE RIPARIAN ZONE OF THE BERG RIVER IN THE VICINITY OF HERMON: IMPLICATIONS FOR GOVERNANCE

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Abstract

Riparian zones broadly refer to the interface between terrestrial and aquatic systems. It is widely acknowledged that riparian zones provide a number of services including that of an ecological corridor for migration of animal species; a habitat; food for aquatic macro invertebrates in the form of organic matter; stabilising river banks; filtering nutrients and sediments from water that discharges off surface slopes and land; and protecting and improving water quality of river systems. This study examines how the Berg River riparian zone has changed over the past few decades and then considers the implications for governance of these zones in South Africa. The study identifies changes in vegetation composition and spatial extent of the riparian zone. The study site is a stretch of the Berg River in the Hermon area. Changes in vegetation and the spatial extent of the riparian zone over time were identified and mapped using aerial photographs of the study area spanning a period from 1955 to 2012. The results of the study showed that the spatial extent of the riparian zone decreased by 29.3% from 55 ha in 1955 to 39 ha in 2012. At the same time the area covered by trees (*Eucalyptus globules)* increased from 3.84 ha in 1955 to 35.94 ha while the area covered by shrubs that could be detected from the sources, decreased from 46.10 ha in 1955 to close to zero in 2012. The results of this study reveal a lack of governance in the river system. The lack of governance is attributed to the fact that the Berg River Catchment Management Agency is not operational. In South Africa weak governance in the management and responsible care in safeguarding riparian zones has compromised water quality, ecological integrity and habitat of the river system.

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Contents

List of Acronyms

BOCMA	Breede Overberg Catchment Management Agency
CARA	Conservation of Agricultural Resources Act
CMA	Catchment Management Agency
EIA	Environmental Impact Assessment
ERDAS	Earth Resources Data Analysis System
GIS	Geographical Information Systems
NEMA	National Environmental Management Act
NGOs	Non Governmental Organisations
SANBI	South African National Biodiversity Institute
WfW	Working for Water

CHAPTER 1: Introduction

Introduction

Worldwide human activities have significantly modified river processes as well as aquatic and riparian ecosystems (Merritt *et al*., 2009). In many cases these activities have resulted in the loss of riverine ecosystems' productive capacity (Holmes *et al*., 2005). The damage is caused by a multiplicity of activities including: high nutrient loading being discharged into aquatic environments from the release of surface runoff from agricultural land; the channelling and straightening of streams in order to use the land for other purposes such as farming and boating (Baudry & Thenail, 2004); the construction of infrastructure such as dams and canals (Merritt *et al*., 2009); and the encroachment of human settlements, livestock trampling and grazing as well as the planting of alien species (Holmes *et al*., 2005).

In general, the impacts of human activities on aquatic and riparian systems in urban streams are well known (Gift *et al*., 2008). In urban streams the resultant degradation and impacts are collectively termed "the urban stream syndrome" which is characterised by hydrologic flash flooding and channel erosion (Gift *et al*., 2008; Imberger *et al*., 2011).

In South Africa the riparian zone of most river systems has been negatively impacted largely by farming activities, expansion of human settlements, as well as the invasion of alien plants (Holmes *et al*., 2005) with the former resulting in the clearing of riparian vegetation as well as livestock grazing and trampling along water courses *(ibid*).

In a study conducted in the KwaZulu-Natal midlands region it was found that riparian zones were susceptible to exploitation by commercial forestry companies (Everson, 2007). Commercial forestry in riparian and upstream areas that were planted with black wattle (*Acacia meansii*) had the effect of reducing stream flow by between 0.8 and 2 litres per second per annum in the catchment *(ibid*). Other studies have shown that riparian areas in the Western Cape Province of South Africa are no longer intact as a result of the impoundment along the rivers (Everson, 2007). The Berg River has not been spared from substantial modification along the river banks as a result of agricultural intervention, and the near total invasion by alien invasive plants along the riparian zone (Clark, 2009).

1.1 Riparian zone definition

Riparian zones are complex environments that are not easily understood (IIhardt *et al*., 2000). According to these authors the definition of riparian zones varies depending on site, situation and what should be included and excluded in attempting to designate the zone. Some authors and resource managers argue that the riparian zone includes the aquatic environment and the transition zone between the aquatic and terrestrial environment (*ibid*). Others argue that the riparian zone includes the transition area between the aquatic and terrestrial environment only (*ibid*). In addition, there is also a debate on whether the transition zone comprises only land with soils that are saturated or seasonally saturated or land that is influenced by or influences the aquatic environment *(*IIhardt *et al*., 2000). The United States Department of Agriculture-Forest Project describes the riparian zone as that which comprises the aquatic system, riparian ecosystems, and wetlands where the riparian ecosystem is limited to areas with soil and vegetation types that require the free flow of water (*ibid*).

The term riparian originates from the Latin word *riparius* which refers to the banks of a stream or land adjoining a body of water (IIhardt *et al*., 2000; Naiman & Decamps, 1997). Thus, some authors have excluded the aquatic component of the riparian zone (IIhardt *et al*., 2000). Others describe the riparian zone more broadly by taking into account the important functional linkages of the riparian area using energy and material flows in the associated food webs including the aquatic component (*ibid)*.

There is a general lack of understanding of appropriate spatial boundaries that delineate riparian zones (Burcher, 2009). According to Gregory *et al*. (1991) the range of definitions for riparian zones can be based on vegetative, hydrologic, soil type and topographic criteria. Criteria such as topographic aspects, periodic flood boundaries and distinctive vegetation are normally used by policy decision makers, researchers and land managers to define riparian zones (Burcher, 2009).

Riparian zones are commonly defined as the transition zone between the terrestrial and aquatic ecosystems (Burcher, 2009; Richardson *et al*., 2007; Broadmeadow & Nisbert 2004; Groffman *et al*, 2000; Hancock *et al*., 1996; Gregory *et al*., 1991). The zone consists of sharp gradients of ecological processes, vegetation and environmental features such as hydrology, soils and topography (Gregory *et al*., 1991). This is a transition zone that encompasses the characteristic species of both the aquatic and terrestrial ecosystems (Groffman *et al*, 2000; Gregory *et al*., 1991). Consequently the spatial extent of the riparian zone is difficult to delineate (Burcher, 2009; Gregory *et al*., 1991). According to Naiman and Decamps (1997), it is difficult to delineate the width of the riparian zone as it varies depending on the size of the stream, context of the landscape and the hydrological dynamics in the area.

However, geomorphic structures and the distribution of typical riparian plant communities can be used to delineate riparian zones (*ibid*). Burcher (2009) added that spatially continuous and ecologically relevant riparian zones can be identified by quantifying the hydrological patterns from the stream to the upland terrestrial areas. Moreover the composition of the riparian zone is a function of the surrounding landscape's disturbance regimes (Holmes *et al*., 2005). The disturbances include wind, fire, flooding, debris flows, as well as sedimentation process (*ibid*). As a result the vegetation species found in the riparian zone are unique to the zone and are able to adapt to the flood regimes, elevated water tables and soil types (Naiman & Decamps, 1997; Hancock *et al.*, 1996).

Other studies have defined riparian zones as terrestrial habitats that surround wetlands (Semlitsh & Bodie, 2003). The authors added that these habitats include the banks or edge and the shores of any permanent or temporary lotic and lentic systems. In another study the riparian zone is described as the interface between water and land ecosystems structured within networks in the landscape (Nilsson & Svedmark, 2002). The characteristics of natural riparian zones depend on the stream size (*ibid)*. They range from simple narrow strips of land adjacent to rivers to wide flood plains in the lower reaches (*ibid*).

Riparian zones are also described on the basis of their functions as a zone of three dimensional interactions involving the aquatic and terrestrial systems (Gregory *et al*., 1991). The author added that riparian zone boundaries extend laterally to the confines of inundation and upward into the streamside vegetation canopy. The specific temporal dynamics and spatial patterns of a given ecological process in the riparian zone determine the dimensions of its zone of influence (*ibid*).

In addition, riparian zones can be described by the temporal and spatial patterns of the geomorphic and hydrologic processes as well as the terrestrial vegetation succession in terrestrial and aquatic systems (*ibid*). The hydrological process in the riparian zone connects the aquatic and riparian habitat through over bank and groundwater flows (Bodie, 2001). While geomorphic processes refer to the stratigraphic development of sediments deposited in a river as well as their exposure to shear forces, deposition and scour (Meritt *et al*., 2009).

In addition, Barling and Moore (1994) provide a physical perspective of the riparian zone by defining it as an area situated alongside the river banks that plays a key role in stabilising the banks and the river channel as well as maintenance of the ecological integrity of the stream. The authors list five variables that influence physical processes in the riparian zone, namely: intensity of rainfall and its duration; topography; soil type; vegetation type; and land use within the particular catchment.

In a study on riparian buffers in Australia, it was found that in some cases the riparian zone was viewed as a buffer strip because it was situated along the river banks and played a key role in stabilising the river banks as well as protecting the ecological integrity of the stream (Barling & Moore, 1994). However, Naiman and Decamps (1997) disagree by stating that a buffer strip is a zone established at a specified distance from a water course in which land use activities are controlled to ensure protection of the river. Such zones are usually characterised by undisturbed vegetation that filter sediments and pollutants before they reach the stream (Barling & Moore, 1994). Given these many and varied perspectives in the understanding of riparian zones, IIhardt *et al*. (2000) argue that there is a need to reconcile these different perspectives.

One approach that has gained acceptance recently is one that takes an integrated approach to determining the full extent of the riparian zone as "the three-dimensional ecotones of interaction that include terrestrial and aquatic ecosystems, that extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the water course at a variable width" (Hazlett *et al*., 2008: p. 16). Similarly the riparian zone has been described as "encompassing the stream channel between the low and high water marks and that portion of the terrestrial landscape from the high water mark toward the uplands where vegetation may be influenced by elevated water tables or flooding and by the ability of the soils to hold water" (Naiman & Decamps, 1997: p. 623). Both these discussions on definitions include the aquatic component of the riparian zone, and, as will be explained later, it makes sense to include this in this current study.

1.2 Rationale for the study

The banks of the Berg River have been modified by several factors including the encroachment of agriculture activities, near total replacement of indigenous vegetation by alien invasive plant species, and elevated pollution levels from non-point sources of pollution that all potentially contribute to eutrophication (Clark, 2009). Thus, the functions of the riparian zone are likely to be compromised because of the concomitant loss of diversity of plants in the riparian zone and aquatic systems resulting in a deterioration of water quality (*ibid*). The extent to which this is true of the Berg River is largely unknown. The lack of information on the state and condition of the riparian zone along the Berg River has resulted in a limited understanding, in this instance, of how a riparian zone management strategy could be developed at a catchment level.

This study seeks to contribute to a body of knowledge, using a temporal scale survey of sections of the Berg River, to emphasise the changing state of the riparian zone. In so doing, the study will analyse the changing condition of the riparian zone, and also discuss the current and future riparian zone governance arrangements in South Africa.

1.3 Research Question

How and to what extent has the riparian zone along a selected section of the Berg River changed over time?

Aims and objectives

The aim of this study is to describe the changes to the riparian zone along a selected section of the Berg River over an extended period of time and explore the implications for governance of the riparian zone.

The specific objectives of this research are to:

- Describe the riparian zone in terms of its vegetation composition and spatial extent using aerial surveys, and to map the changing state of the riparian zone of a selected stretch along the Berg River over time
- Identify and describe the changes in the spatial extent and changes in vegetation of a selected stretch of the riparian zone along the Berg River
- Understand the current governance arrangements for the riparian zone.

The use of aerial surveys to map the changing state of the riparian zone over time gives a clear indication of how the zone has been transformed in terms of its vegetation composition and spatial extent. In addition, an improved understanding of how the vegetation composition and spatial extent of the zone has changed over time provides an indication of the past and current riparian zone governance arrangements. Moreover, a better understanding of the current and future riparian zone governance arrangements might help to improve the governance of the resources required to protect the water quality of the river systems.

1.4 Literature discussion

The governance of riparian zones is compromised by the lack of clarity about its definition, lack of knowledge about the state of the riparian zone and the lack of clarity about who is responsible and accountable for the governance of these resources. This study will explore international discussions on riparian zone governance; the multiple perspectives with regards to defining the riparian zone; the important role that the riparian zone plays in the provision of ecological services, and finally, will highlight the importance of ensuring successful governance of these resources.

1.5 The Berg River context

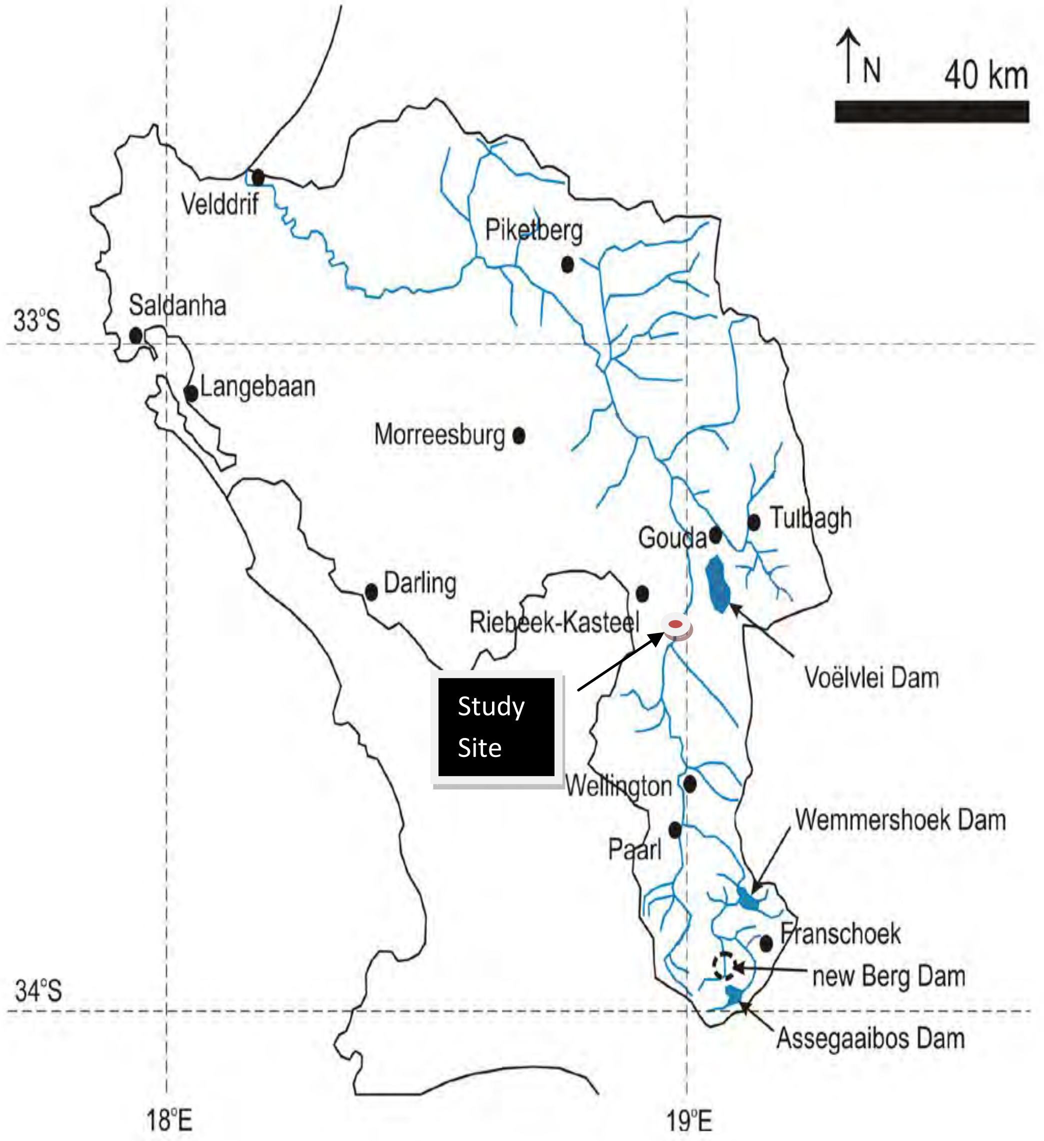
The Berg River in the Western Cape Province of South Africa is the largest catchment in the province spanning an area of approximately 9000 km^2 (Clark, 2009). The river source begins in the Drakenstein and Franschhoek Mountains, and eventually flows into the Atlantic Ocean near Velddrif (Figure 1) (de Villiers, 2007; Clark, 2009). The length of the Berg River is approximately 300km from source to mouth (de Villiers, 2007). It has nineteen major tributaries and numerous small scale canals and furrows that flow into the river (Clark, 2009).

The Berg River catchment falls within a Mediterranean climate which is characterised by cool wet winters and warm dry summers (Clark, 2009). According to the authors, the spatial distribution of vegetation in the catchment is directly linked to the geology of the area as opposed to the climate. In other words, climate has little influence on the distribution of vegetation in the area as the geology of the area shapes the spatial distribution of the vegetation *(ibid*).

The Berg River is the main source of water for household and industrial use in Cape Town metropole and the greater Cape Peninsula area (de Villiers, 2007; Davies *et al*., 1993). The main land uses in the Berg River catchment include agriculture, plantation forestry, livestock farming, nature conservation, commercial industries and residential areas (de Villiers, 2007; Clark, 2009). Agricultural related industries that dominate the area are typically linked to production of wine, canneries and other food processing factories (Davies *et al*., 1993). The larger part to the north of Wellington is dominated by dry land grain and stock farming (*ibid*). At the same time a high density of alien vegetation affects 13% of the total catchment (Davies *et al*., 1993*)*. Only 2% of the total catchment is estimated to remain in a pristine state (*ibid*).

The lower Berg River is an important habitat for a diversity of avifauna (Kading *et al*., 2009; Davies *et al*., 1993). Since the larger part of the west coast of southern Africa is generally arid this makes the lower Berg River a migratory corridor for birds to and from Europe and northern Asia (*ibid*). It is also a major breeding site for wetland birds (Davies *et al*., 1993). Some 127 bird species have been recorded *(ibid*). In addition, the Berg River estuary provides a nursery for high diversity of fish species (Kading *et al*., 2009).

As mentioned earlier, the Berg River is increasingly being degraded (de Villiers, 2007; Davies *et al*., 1993) and is considered amongst the most highly polluted rivers in the Cape Metropolitan-Boland area (Paulse *et al*., 2009). There are multiple causes which include salinisation from irrigation return flows; general nutrient enrichment from agricultural runoff; domestic sewage inflows particularly from the towns of Paarl and Wellington; industrial and wine farm effluents, trout farm effluents, invasion by alien aquatic species, riparian plants and animal species as well as the discharge of polluted water from establishments such as informal settlements and industries (*ibid*). The Berg River is also affected by augmentation schemes such as the building of dams (Clark, 2009).



Key: Study site – ●

Figure 1: Berg River Catchment **(**Adapted from de Villiers, 2007**)**

1.6 Discussion on the methods

A baseline understanding of the study area from 1955 to 2012 was achieved by analysing aerial photographs of the area. This was done to show how the spatial extent and vegetation types of the riparian zone have changed over time. The changes are indicative of the kinds of intervention that takes place on the land. It can be hypothesised that the riparian zone is shrinking and being compromised by agricultural activities as well as the increasing neglect of the zone, and invasion by alien vegetation. Such information will be used to infer the lack of control, accountability and proper environmental governance arrangements of these resources.

1.7 The scope of the study

This study will focus on surveying a section of the Berg River to determine the changing conditions within the riparian zone. The changing conditions in the riparian zone of particular interest to this study will be in terms of the changes in areal extent and vegetation types. In addition, the current legislation and policy for riparian zone governance in South Africa will be discussed. The determination of the extent of degradation in the Berg River riparian zones is outside the scope of this study.

The study is limited largely by a lack of long term data on the historical analysis of the state of the riparian zone along the Berg River. The riparian zone is often a neglected area because there is no baseline data upon which to determine the temporal and spatial changes in the geography of the riparian zone.

1.8 Limitations of the study

This study is focusing on providing baseline information that relate to the changing extent of the conditions in the riparian zones. The changes are mainly in terms of areal extent and vegetation types and the implications of the changes on governance of the riparian systems in the Berg River. It also provides a discussion of the current riparian zone management legislation and policies in South Africa.

The time period was selected with the intention of showing the changes in the condition of the riparian zone which will be assessed largely on the availability of aerial photographs that cover the selected sites along the Berg River. The available aerial photographs had widely different scales and they were taken at irregular intervals with the older photographs having low spatial resolutions while the spatial resolutions for the more recent images were higher. Nevertheless, all the images had few surface details thereby posing difficulties in the visual gathering of the different vegetation types.

1.9 Structure of the thesis

This thesis comprises five chapters. The first chapter provides an introduction to the research. The literature review for the study is given in Chapter 2. Chapter 3 provides a detailed description of the research method, while Chapter 4 gives a presentation of the study results, analysis and discussion. Lastly, Chapter 5 concludes on all the topics discussed in the project. This chapter is followed by the references and appendices.

CHAPTER 2: Literature Review

Introduction

Riparian zones form the interface that connects terrestrial and aquatic environments comprising of soils, fauna and flora assemblages (Corenblit & Steiger, 2009; Seavy *et al*., 2009; Naiman *et al*., 2005). There is an intricate linkage between these two ecosystems and the resultant material and energy flow (*ibid)*. As a result of the materials and energy flow in the riparian zones, the zone is rich in biodiversity in its natural state (Seavy *et al*., 2009; Perkins & Hunter, Jr., 2006; Broadmeadow & Nisbert, 2004).

The riparian zone offers a number of important functions. These include filtering of pollutants from adjacent terrestrial environments, offering aesthetic value, providing a habitat and an ecological corridor for wildlife, and stabilising river banks to prevent channel erosion and siltation of rivers (Richardson *et al*., 2012; Seavy *et al*., 2009; Broadmeadow & Nisbert, 2004). In addition, the riparian zone provides goods such as wood, fibre, fruits and medicine (Vidon *et al*., 2010). However, worldwide there is plenty of evidence of the degradation of riparian zones (Corell, 2005; Holmes *et al*., 2005) caused by urbanisation, clearing of land for agricultural expansion and the proliferation of human settlements that extends through to the river's edge, along with the damming of rivers as well as trampling and grazing of the riparian zone by livestock (Vidon *et al*., 2010; Holmes *et al*., 2005).

2.1 Riparian zones: provision of ecological services

The variety of ecological services provided by the riparian zone in its pristine state is well understood. These include services such as the provision of organic and inorganic food sources for aquatic ecosystems; corridors for dispersal of plants and animal movement; stabilization of river banks to reduce erosion; timber and food sources; habitat for plant and animal species; a buffer to maintain water quality of adjacent stream; and the provision of areas where some fish species can spawn (Kanasashi & Hattori, 2011; Virbickas *et al*., 2011; Naiman *et al*., 2005; Perkins and Hunter, Jr., 2006; Sharitz *et al*., 1992; Gregory *et al*., 1991). Riparian vegetation forms the most important component of the riparian zone in the provision of ecological services (Gregory *et al*., 1991). The riparian plant communities contribute to the successful provision of ecological services in a number of ways (*ibid*).

Firstly, the riparian zone vegetation controls solar inputs into the stream thereby moderating the stream temperature (Gregory *et al*., 1991). According to the authors, solar radiation passing through the riparian canopy is selectively reflected and absorbed. This alters the quality of light available for primary producers in adjacent streams (*ibid*). The composition of riparian vegetation determines the extent of shading of the stream (Gregory *et al*., 1991). As such the canopies that are relatively open allow light to reach the stream's surface (*ibid*). While low overhanging and dense canopies greatly reduce the amount of light reaching the stream (*ibid*).

In the absence of shading, light reaches the stream surface (Nordin *et al*., 2008) and this increases the water temperature of the stream which in turn can impact the biological functioning of sensitive species in the aquatic ecosystem (Arnaiz *et al*., 2011; Nordin *et al*., 2008). Consequently the primary productivity of the stream will be compromised. In addition, Hancock *et al*. (1996) state that the shading and cooling of a river in eutrophic waters curbs algal blooms ultimately improving the quality of the water.

Secondly, the riparian zone plant community increases the ability of the zone to recycle nutrients and absorb heavy metals and other toxic chemicals (Sharitz *et al*., 1992). Riparian vegetation slows down surface runoff and in the process encourages infiltration and deposition of suspended materials (Broadmeadow & Nisbert, 2004). The roots of riparian trees improve the soil structure ultimately stabilising the river banks, a move that reduces siltation of the river and maintains a deep channel that is necessary for fish to thrive (*ibid*). Naiman and Decamps (1997) note that erosion of major banks is 30 times higher in non-vegetated banks compared to vegetated ones.

In addition, Gregory *et al*. (1991) point out that the vegetative demand of riparian plants for dissolved nutrients has potential to reduce the nutrient influx from upland areas runoff into streams. A study in the United States revealed that riparian zone vegetation was able to remove more than 75% of dissolved nitrate in cropland runoff before it entered Maryland River (Gregory *et al*., 1991). At the same time, a study done in the coastal plains of Georgia indicated that riparian forest retained 30% of phosphorous and more than 65% of nitrogen released from agricultural lands (*ibid).* Such processes provide a buffer zone that protects the water quality of the adjacent stream (Sharitz *et al*., 1992).

Thirdly, riparian vegetation provides abundant food sources for aquatic food chains (Sharitz *et al*., 1992; Gregory *et al*., 1991). The food sources are in the form of decomposed leaf litter, dissolved organic carbon inputs and woody debris that drains into streams (*ibid*). In addition, woody debris, organic material and inorganic sediment from riparian zone vegetation provide habitat for important aquatic invertebrate assemblages (Arnaiz *et al*., 2011; Gregory *et al*., 1991).

In order for organic material and inorganic sediment to be available to serve as either food sources or habitats for aquatic organisms, there has to be a mechanism to retain them in streams (Gregory *et al*., 1991). The riparian vegetation helps to increase the relative stream bed roughness and in the process improve the retentive characteristics of river channels (*ibid*). The structure of riparian plant communities is directly linked to the retentive capacity of the river channel (*ibid*). Consequently the distribution and abundance of aquatic invertebrates in a given stream has a strong relationship with the riparian vegetation structure (Sweeney *et al*., 2004).

Moreover, riparian zones are characterised by relatively high rates of primary and secondary productivity (Broadmeadow & Nisbert, 2004; Sharitz *et al*., 1992). This characteristic makes them suitable habitats for many plant and animal species (Sharitz *et al*., 1992). Some species use the riparian corridors as a link to different habitat patches while others use them as spawning areas (*ibid)*. In terrestrial ecosystems, ecological goods such as wood, fibre fruits, other edible parts, and medicine and fence posts are derived from riparian plants (Vidon *et al*., 2010). In addition, riparian zones play a role in the preservation of plant propagules which protect plant biodiversity (Jansen & Robertson, 2001). Other studies indicate that the riparian zone is useful in improving the outlook of the landscape (Broadmeadow & Nisbert, 2004).

According to Naiman and Decamps (1997), the riparian zone contributes to social functions such as aesthetics, recreation and cultural significance. Thus the improved quality of the landscape as a result of improved riparian vegetation will increase the chances of this goal being realised.

Furthermore, the riparian zone also plays a variety of hydrological roles (Naiman *et al*., 2005; Sharitz *et al*). According to Broadmeadow and Nisbert (2004), the roots of riparian vegetation stabilises river banks to prevent channel erosion. In addition the riparian zone helps to control downstream flooding by providing storage for flood waters (Naiman *et al*., 2005). The flood water storage occurs when the zones act as areas for aquifer discharge and recharge thus providing continuous water supply (Sharitz *et al*., 1992).

2.2 Riparian zones as complex systems

Riparian zones are increasingly being described as complex integrated terrestrial and aquatic systems (Corenblit & Steiger, 2009; Naiman *et al*., 2005; Nilsson & Svedmark, 2002). Such systems in some cases are known as complex systems. Although complex systems are difficult to define, the characteristics exhibited by these systems can be described (Chu *et al*., 2003; Cilliers, 1998). The defining properties of socio-ecological systems are described in the paragraphs that follow.

Firstly, complex systems are open systems that interact freely with their environment (Cilliers, 1998). This makes it difficult to define their boundaries (Cilliers, 2001; Cilliers, 1998). However, the extent of the system is usually defined by the reason for its description rather than the system's characteristics (Heylighen *et al*., 2007; Cilliers, 1998). In addition, the position of the observer can be used to define the boundaries of such systems through a process called framing (Heylighen *et al*., 2007).

Secondly, complex systems are made up of many components (Cilliers, 2008; Berkes, 2004; Cilliers, 2000). The components themselves are usually simple (Cilliers, 2000; Cilliers, 2008). They interact with each other in a non-linear and dynamic manner (Folke, 2006). The output of the components is a function of the inputs (*ibid)*. The state of the system is a result of the amount of the inputs and the outputs (Cilliers, 2008). The interactions are defined by the relationships between the actual inputs and outputs from the components (Cilliers, 2008). Such relationships are dynamic while the strength of the interactions varies over time (Cilliers, 2008). In addition, the interactions are not only physical because they also include information transfer (Cilliers, 2000).

Thirdly, each component in the system should be ignorant to the behaviour of the system as a whole where it only reacts to information that is available to it locally (Cilliers, 2008; Cilliers, 1998). The rich interactions of simple components that only react to the information received by each one of them gives rise to the complexity (Cilliers, 2008). The emergent behaviour displayed by complex systems is a result of the interactions between the components rather than the inherent characteristics of an individual component (Mazzocchi, 2008). In addition, complex systems are always evolving and are culminating in an unpredictable nature that is characterised by change (Mazzocchi, 2008; Cilliers, 2000).

Fourthly, the systems function at conditions far from equilibrium (Cilliers, 2008; Folke, 2006). As such a constant flow of energy into the system is required (Cilliers, 2008). This helps to ensure the system's existence and the maintenance of its organisation (*ibid*). In addition, there are multiple possible routes of interaction between the components of complex systems (Cilliers, 2008; Chu *et al*., 2003). The routes are mediated in various ways (Cilliers, 2008). Most of the sequences of interaction give rise to either long or short feedback loops (Cilliers, 2008; Cilliers 1998). The effect of any interaction can feed back on itself (*ibid*). Moreover, the feedback can be either positive or negative (Folke, 2006). A positive feedback is indicated by the production of an enhancing and stimulating effect (Cilliers, 2008; Mazzocchi, 2008). While a negative feedback is shown by the production of a detracting and inhibitory effect (*ibid*).

The fifth feature that characterises complex systems is that they have a memory (Cilliers, 2008). Owing to this quality, systems are able to behave in a certain manner over a range of varying time scales (Cilliers, 2008; Cilliers, 2001). Such a quality enables them to cope with their surroundings (Anderies *et al*., 2004). Complex systems can only be able to sustain themselves when part of the system changes at a rate that is slower than the rate at which the environment is changing (Cilliers, 2008). This is the part of the system known as the memory of the system (*ibid*).

Sixthly, these systems have a history (Cilliers, 1998). The system's past greatly influence their current conditions (*ibid*). This is because the systems continue to change over time (Mazzocchi, 2008; Cilliers, 2008). As such any meaningful and complete analysis of complex systems should factor in the time dimension (Cilliers, 1998).

The seventh defining property of complex systems is that they are able to self organise (Cilliers, 2008; Berkes *et al*., 2001; Cilliers, 2000; Cilliers, 1998). Self organisation occurs when the components of the system interact (*ibid)*. As the components interact, the properties of the system evolve (Mazzocchi, 2008; Folke, 2006). Owing to these interactions the system produces new structure internally (Cilliers, 2008). Again in reaction to the conditions in the environment there is also need for the system to adjust its internal structure (Mazzocchi, 2008).

Riparian zones exhibit the characteristics of complex system in a number of ways (Nilsson & Svedmark, 2002). These include the fact that the riparian zone, when in its pristine state, is made up of a number of components namely the soils, riparian fauna and flora, the floodplains and these interact in a non-linear and dynamic manner and that the systems are open to flooding and fires (*ibid*). They comprise interlinked physical and biological components (Corenblit & Steiger, 2009). The physical components are namely the water, soil and sediments while the biological components include the fauna and flora assemblages (Corenblit & Steiger, 2009; Naiman *et al*., 2005). These components interact in a non-linear manner through a number of processes (*ibid*). The processes include decomposition, carbon storage, nutrient cycling (Semlitsh & Bodie, 2003) and nutrient filtration (Naiman *et al.,* 2005).

Riparian systems are open systems that interact freely with their environment. The systems are very dynamic in nature owing to their exposure to flooding (Naiman *et al*., 2005) as well as to transformation by humans for agricultural, grazing and urbanisation purposes (Burger *et al*., 2010; Semlitsh & Bodie, 2003; Bodie, 2001). In addition, the open nature of riparian areas results in the elusiveness of their boundaries (Burcher, 2009; Naiman *et al*., 2005; Naiman & Decamps, 1997; Gregory *et al*., 1991).

According to Corenblit & Steiger (2009) the riparian zone is considered as an evolving and self organising system. The inter-linkages and interactions between the components over changing time scales cause the system to adjust its internal structure (*ibid).* In the riparian zone the components that will be interacting include landforms, water, sediment particles, genes, flora communities and fauna populations (Corenblit & Steiger, 2009). The adjustments in the riparian zone's internal structure give rise to the typical evolving riparian community assemblages (*ibid).*

Owing to the unpredictable nature of complex systems little is known about them (Cilliers, 1998). In order to improve our understanding of these systems there is need for the development of models (ibid). In line with this thinking, Gregory *et al*. (1991) suggested a riparian zone conceptual model that combines the ecological processes that produce food for aquatic systems, geomorphic valley flow landscapes and the processes that shape them, the succession patterns of terrestrial vegetation on the valley flow landscapes and the formation of riparian habitats.

2.3 Governance of the Riparian zone

In order to effectively govern these complex systems, an increased understanding of such systems should be sought (du Plessis *et al*., 2008). To this end, du Plessis *et al*. (2008) developed a conceptual framework that helps to improve an understanding of complex systems. This framework does not only focus on the ecological aspects of complex systems (*ibid*). It also takes into account the interconnected physical and mental phenomena embedded in these systems (du Plessis *et al*., 2008*)*. The physical phenomena encompass the tangible, visible and external experiences while the mental phenomenon encompasses the intangible, internal and invisible experiences (*ibid*). In addition, the phenomena occur both at individual and joint levels across temporal and spatial scales as well as at hierarchies of rising complexity and supremacy (*ibid*).

According to du Plessis *et al*. (2008) such an understanding draws heavily from the synthesis of three frameworks that were developed earlier. The synthesis describes complex systems as comprising an integrated system of matter, life and mind (*ibid*). In the synthesis, biogeochemical processes from human activity and behaviour are responsible for the disproportionate part thereby creating the combination of the exterior, while the process of thought and the human psyche created and brought experiences for the interior (du Plessis *et al*., 2008*)*. For this reason, it is necessary to consider a framework that takes into account the exterior and interior elements as well as the flows between them as the most likely means of improving the understanding of complex systems and thus improving the chances for effective management of these systems (*ibid*). The flows between the interior elements include structures of legitimisation like regulations, norms, value systems, interior changes indicated by a shift in favour of specific value systems, while the flows between the exterior elements include a shift in the value system that promotes the use of technology that increases pollution levels (*ibid*).

The systems approach to understanding the riparian zone requires the consideration of all the components of the zone (Berkes, 2004). The components are namely: the ecosystem components and their physical and biological interactions, the human system which is mainly the resource users and the governance system which entails the policies, plans, institutions, rules, regulations, management systems and procedures for user rights allocation. This should take into account the ecological, physical, social, economic, cultural and political aspects in time and space (*ibid*). The structures of legitimisation, the values and norms that are recognised in a given society influence the successful management of a given resource (Sweeney *et al*., 2004). For example, in most riparian zones deforestation occurs at unprecedented rates mainly because the value assigned to agriculture and wood products by humans is higher than the value assigned to riparian forest ecosystem services (*ibid*). In addition governance systems are complex in themselves (Pahl-Wostl & Toonen, 2009). This is because they entail a range of interacting regulatory processes (*ibid*).

Complex systems have a history and as such the system's past greatly influences its present state (Cilliers, 1998). In the case of riparian zones, the history of riparian zone management is responsible for shaping the current state of these zones. For example, in South Africa the history of riparian zone management was closely linked to riparian land ownership where management structures for these systems did not exist (Conca, 1994). In other words, landowners were responsible for managing that portion of the riparian zone within their property yet they were no platforms for proper interactions and engagements between state actors and land owners with regards to proper management of riparian zones to protect water quality (*ibid*).

In addition, the mismatch between the water flows in the country and the location of major industries and the populations led to the proliferation of inter-basin transfer technology (Conca, 1994). This entailed damming of most rivers (*ibid*). Damming of rivers has an indirect effect on the hydrologic flows in the riparian zones, a fact that needs to be considered as well (Holmes *et al*., 2005).

Complex systems are characterised by change where components are constantly adjusting to each other, and evolving strategies for their management ought to focus on properties related to change (du Plessis *et al*., 2008). The properties include resilience, adaptability, transformability, connectivity and diversity (*ibid*). This gives an indication of the system's ability to deal with change (du Plessis *et al*., 2008). As such governance regimes that are characterised by a high adaptive capacity and the importance for learning as opposed to final solutions are required to sustainably manage complex systems (Pahl-Wostl & Toonen, 2009; Ostrom, 2007).

Such adaptive governance systems have the capability for self organisation, often have diverse leadership and they exhibit emergent properties (Pahl-Wostl & Toonen, 2009; Folke *et al.*, 2005). In addition, adaptive governance regimes usually self organise into social networks (*ibid*). The social networks are often made up of teams and actor groups hailing from a range of experiences and knowledge systems (Folke *et al.,* 2005). This serves to ensure the development of policies and regulations where all the actors have a common understanding (*ibid*). Moreover, adaptive governance systems are able to deal with the unpredictable interactions within complex systems because they evolve together with them (Berkes *et al*., 1998). Such governance systems treat resource management policies as experiments from which organisations, institutions and managers can learn (*ibid*).

In addition, adaptive governance is operationalised through adaptive co-management (Folke *et al*., 2005). An adaptive co-management approach involves a joint management of resources by stakeholders, government and other external agents that include NGOs, universities and scientists during the design and implementation of management strategy (Alpizar, 2006; Folke *et al*., 2005).

It benefits from collaboration of stakeholders from diverse fields and with various knowledge systems operating through social networks (*ibid*). An important aspect of these social networks is the presence of social sources of resilience (Folke *et al.,* 2005). These can be through social capital in the form of trust or social memory (*ibid*). According to Pahl-Wostl and Toonen (2000), a typical adaptive governance system is exemplified by institutional settings where a balance between processes of central coordination and decentralization is allowed.

The riparian zone management approaches should take into account the fact that these zones are social ecological systems (Corenblit & Steiger, 2009; Naiman *et al*., 2005). As such they are characterised by many components interacting with each other in a non-linear manner (Corenblit & Steiger, 2009). In addition, riparian zones are open systems that interact freely with the environment ultimately rendering them unpredictable in nature (*ibid*). The unpredictable nature of riparian zones requires their governance regimes to be adaptive (Pahl-Wostl & Toonen, 2009; Folke *et al.,* 2005).

According to Folke *et al.* (2005) adaptive governance is accomplished through adaptive co-management, a term used to describe the various arrangements put in place to facilitate joint power sharing and decision making between several community and state actors (Hill, 2011). The actors include natural resources stakeholders, governments and other external agents like non-governmental organisations, universities and research institutions (Alpizar, 2006; Berkes *et al*., 2001). The various arrangements between the actors in the co-management partnership can be described as a continuum that ranges from an entirely government based management to an entirely community based management (Berkes *et al*., 2001).

In addition, co-management encompasses a process where management power is shared across organisation levels (Folke *et al*., 2005). Simply put, co-management is a governance form that involves resource users and the resource governing entities in the sharing of management rights and responsibilities (Robards & Lovecraft, 2010). It is a flexible participatory resource governance strategy that provides a conducive environment for resources users, state actors and stakeholders to resolve conflicts, share power, make rules, dialogue, make decisions, negotiate, generate and share knowledge (Robards & Lovecraft, 2010; Hill, 2011; Berkes *et al*., 2001). Moreover, the co-management procedure is driven by consensus (Berkes *et al*., 2001). As such it takes into consideration the capacity of the community, its needs, concerns, values and interests inherent in resources management and matches them with the state's ability to govern resources (Alpizar, 2006; Berkes *et al*., 2001).

The specific roles, responsibilities and rights of the partners are developed through consultation (Berkes *et al*., 2001). However, it should be noted that not all authority and responsibility should be given to local communities as their competency for decision making is questionable (*ibid*). In addition, the extent of community member participation in governance is greatly influenced by the cultural politics in the co-management set up (Robards & Lovecraft, 2010). As a result government co-management partners usually hold the power balance in the co-management partnership (Robards & Lovecraft, 2010; Berkes *et al*., 2001).

Furthermore, the sharing of responsibility and management power in a co-management arrangement often requires institutional arrangements (Hill, 2011; Folke *et al*., 2005). Such institutions may involve multiple linkages between the different user groups that include non-governmental organisations, communities and government agencies (Folke *et al*., 2005).

These institutions should provide mechanisms that allow for the actors to work together effectively namely legal support, conflict resolution mechanisms and advocacy and networking (Hill, 2011; Berkes *et al*., 2001).

Co-management is a resource governance approach that is adaptive to changing conditions in space and in time (Folke *et al*., 2005; Berkes et al., 2001). The adaptive nature of co-management is brought about by the flexible structure of the partnership that provides for learning and ways for shaping and responding to change (Folke *et al*., 2005). Learning occurs when stakeholders and co-workers share information among each other in an effort to support continuous improvement and modifications in the management of resources (Berkes *et al*., 2001). According to Folke *et al*. (2005) adaptive co-management entails the testing and revision of ecological knowledge and institutional arrangements in a continuous, dynamic and self organising manner where one will be learning by doing. In addition, the adaptive management's dynamic learning features and collaborative management are merged in adaptive co-management (*ibid*).

The benefits of co-management in natural resources governance are well understood (Robards & Lovecraft, 2010; Berkes *et al*., 2001). These include among others the fact that a participatory and deliberative process that takes place in co-management is more appropriate than approaches that depend solely on enforcement (Robards & Lovecraft, 2010); the active participation of local people in resources management decisions gives the local people a sense of ownership ultimately acting as an incentive to conserve natural resources; the cost of resources management in co-management is relatively low as less money and effort is spent on administration and enforcement; the involvement of local people ensures that regulation instruments that suit local conditions are put in place as indigenous people identify with their challenges and opportunities; the scientific information for management is complemented by indigenous knowledge and expertise on the state of the resource base; the co-management approach encourages social cohesion and can reduce conflict; a high level of compliance with the regulations is likely as community members will be actively participating in the enforcement of the management measures and lastly the adaptive nature of co-management provides for the incorporation of the lessons learned through adjusting the activities accordingly (Berkes *et al*., 2001).

The major constraints of co-management include the fact that the ability to provide consistent guidance and efficient decision making in the co-management process is compromised by pluralism where the community of resource users and those governing the resource is heterogeneous with different interests and needs and values (Hill, 2011; Alpizar, 2006);

considerable initial investment in terms of time, human and economic resources is demanded in the establishment of a functional co-management (Alpizar, 2006; Berkes *et al*., 2001); some local people may refuse to take up responsibilities in the co-management (Berkes *et al*., 2001); the process can also be hampered by lack of political will, leadership and appropriate institutions that support the roles of the actors (Berkes *et al*., 2001) and the process of changing the state's institutional organisation to accommodate a co-management approach to resources management is a difficult task (Alpizar, 2006; Berkes *et al*., 2001). Nevertheless, the success of co-management largely depends on transparency during data collection, decision making and the implementation of the program (Robards & Lovecraft, 2010).

2.4 Riparian zone governance in South Africa

Governance entails a range of regulatory and management activities that interact in different ways where individuals, public and private institutions address societal problems and create opportunities at different society levels (Pahl-Wostl & Toonen, 2009; Bavinck, 2005). The activities include the political, social, economic and administrative systems, and the application and formulation of policies and principles that guide and restrain the interaction between the activities (Bavinck *et al*., 2005). In addition, policies and values need to be supported by institutional arrangements and normative principles that enable and guide decisions and practices (*ibid*). Moreover, the involvement of different actors and networks in the formulation and implementation of policy instruments is central to effective governance (Pahl-Wostl & Toonen, 2009).

The South African National Water Act No. 36 of 1998 defined the riparian habitat as "the physical structure and associated vegetation of the areas associated with a watercourse which are commonly characterised by alluvial soils, and which are inundated or flooded to an extent and with a frequency sufficient to support vegetation of species with a composition and physical structure distinct from those of adjacent land areas" (Republic of South Africa, 1998: 9). As is the situation in rivers over most parts of the world, the riparian area in South African rivers has been negatively impacted by farming activities, human settlements, as well as invasion by alien invasive plants (Holmes *et al.*, 2005). The situation in South Africa is not helped by the increasing need for productive agricultural expansion that results in the clearing of riparian vegetation along with livestock grazing and trampling along water courses *(ibid)*. A study conducted in the midlands region of KwaZulu-Natal indicates that riparian zones were susceptible to exploitation by commercial forestry companies (Everson, 2007).

In another instance, the national spatial biodiversity assessment of rivers and riparian zones in South Africa showed that most rivers and riparian areas in the Western Cape Province were no longer intact and this was attributed to impoundment along the rivers (*ibid)*. Clark and Ratcliffe (2007) highlight the fact that the Berg River has not been spared from substantial modification of the river banks through agricultural activities, near total invasion by alien invasive plants, as well as sewage treatment plants responsible for eutrophic conditions.

The control of the proliferation of alien invasive plants in mountain catchments and riparian zones in South Africa is being lead by the Working for Water (WfW) programme (Turpie, *et al.*, 2008). This is a government funded programme that began in 1995 and is administered through the Department of Water Affairs (*ibid*). The programme entails the removal of the alien invasive plants through mechanical, biological and chemical control techniques and the planting of indigenous vegetation in the cleared areas (Hosking & du Preez, 2004). This is monitored by repeated follow up procedures involving further removal of re-growth in areas previously cleared (*ibid).* In addition to controlling and managing invasive alien plants, the WfW programme creates jobs and economically empowers the unemployed people from historically underprivileged societies (Marais & Wannenburgh, 2008).

The rationale for the WfW programme is premised on the fact that alien trees have a high water consumptive capacity (Holmes *et al*., 2008; Everson, 2007; Holmes *et al*., 2005) and their effects on water resources increase with proximity to water courses (Holmes *et al*., 2005).
In the Western Cape Province the removal of invasive alien species increased river flow by 9, 10, 12 m^3/ha/day in the Du Toits Kloof, Oaklands and Somerset West areas respectively (Marais & Wannenburgh, 2008).

The control of alien invasive plants by the WfW programme involves the distribution of inadequate resources (Forsyth *et al*., 2009). As such there is need for prioritisation of the areas to be cleared of alien invasions based on facts and opinions interpreted both subjectively and objectively (*ibid*). The Berg and Breede catchments were found to be the highest priority for invasive alien plant control operations (van Wilgen *et al*., 2008) because both catchments have a high water yield, high conservation value, high value for harvested alien trees products, high invasion levels by priority alien species and the high potential for employees to find alternative employment (*ibid*).

The Western Cape Provincial Department of Agriculture's Landcare programme is embarking on a project to clear the alien invasive plants in the riparian zones of the Berg River from Paarl to

Veldrif and intends finding measures and means to plant the riparian zone with indigenous vegetation (Department of Agriculture, 2012). The project started in November 2011 and it is expected to end in March 2014 (*ibid*). According to the Department of Agriculture (2012) there are multiple objectives in this initiative. These include the restoration of the Berg River system which will in turn ensure the successful irrigation of high value crops to sustain food security, provision of jobs in the surrounding farming communities, reducing the risk of natural resource losses due to flooding as a result of alien invasive plants clogging river flow (*ibid*).

Steyn (personal communication) explained that they are working closely with the farmers in the Berg River project to ensure that these farmers will take over managing the river when the project life cycle ends. In addition, the Western Cape Department of Agriculture makes use of the WfW expertise as and when they need during the course of their project (Steyn, personal communication).

The Department of Environmental Affairs and Development Planning is also involved in clearing the alien invasive plants and re-vegetation of the cleared areas with indigenous plants in the Berg River's Hermon area (*ibid*). This project is receiving some financial support from the South African National Biodiversity Institute (SANBI)'s Early Detection and Rapid Response Programme for Invasive Alien Plants through its Natural Resources Management Programme (SANBI, 2013). The programme entails the surveillance of emerging alien invasive plants both at a national and regional level, and the coordination of rapid response initiatives (*ibid*). However it should be noted that the involvement in the governance of the Berg River riparian zones by these departments is mainly dependant on the availability of funds for the specific projects.

According to Steyn (personal communication), the most ideal governance framework for the Berg River riparian zone is one that has been adopted by the Breede Overberg Catchment Management Agency (BOCMA). BOCMA is one of the Catchment Management Agencies (CMAs) established in the 19 Catchment Management Areas across South Africa in compliance with the South African National Water Act of 1998 (van Koppen, Jha & Merrey, 2002).

It is a CMA for the Breede Water Management Area located in South Africa's south-west corner falling in the Western Cape Province (BOCMA, n.d.). In addition, the Department of Water Affairs and Forestry has since 1998 delegated most of its water resources management roles to the CMAs (Bourblanc, 2012).

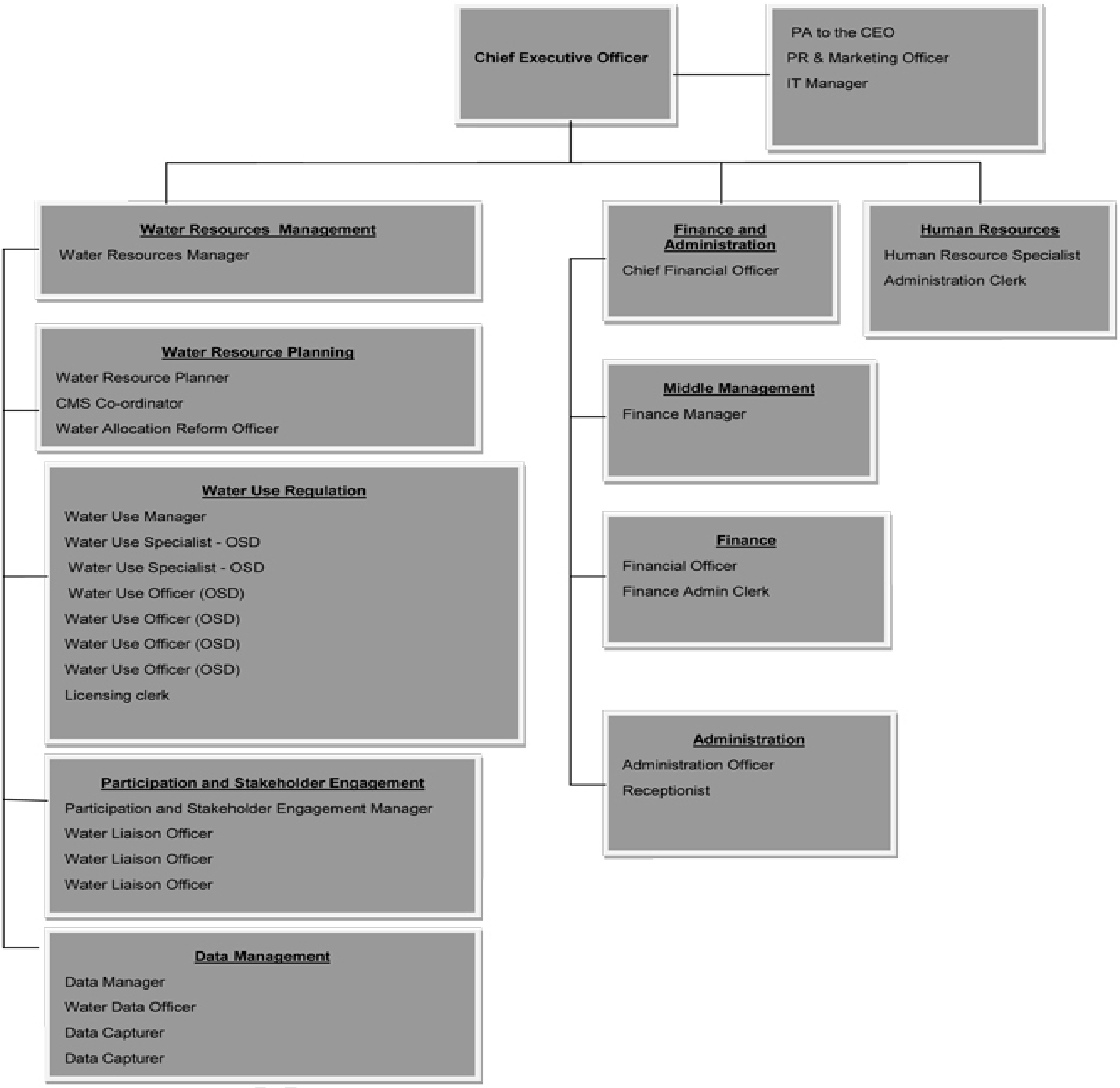


Figure 2: The Breede-Overberg Catchment Management Agency (BOCMA) Organogram (Adapted from BOCMA, n.d.)

The CMAs' governing bodies are made up of different water user representatives implying that a balance is achieved among the interests of the different water users in a fully functional CMA (*ibid*). For example the governing body for BOCMA has secured four seats from the commercial farming sector (Bourblanc, 2012). The evidence of the engagement of different actors (state and non state actors) and networks within the governing body for BOCMA suggests an enhanced effectiveness in the governance system (Pahl-Wostl & Toonen, 2009). Nevertheless, only two of the 8 CMAs that were gazetted since 1999 are functional (National Water Resources Strategy, 2012), namely Inkomati in Mpumalanga and the Breede Overberg in the Western Cape Province (*ibid*). Subsequently, the newly revised National Water Resources Strategy 2 has proposed that the 19 Water Management Areas be merged into 9 CMAs namely the Limpopo; Olifants; Inkomati-Usuthu; Pongola-Mzimkulu; Vaal; Orange; Mzimvubu-Tsitsikamma; Breede-Gouritz and Berg-Olifants (*ibid*). This move is an attempt to help operationalise the CMAs by improving the regional cooperation and the efficient distribution of scarce financial resources and technical skills across a smaller number of institutions (National Water Resources Strategy, 2012).

Another important riparian zone management initiative in South Africa seeks to minimise disturbances to the riparian zone. Activities in riparian areas fall under the National Environmental Management Act (NEMA) (de Villiers, 2010). These activities include the construction of structures such as canals, channels, bridges, dams and weirs in the one in 10 years floodline of a river or within 32 metres from the bank of a river in cases where the flood line is not known *(ibid)*. However, activities that include construction of structures that are related to existing residential uses are excluded *(ibid)*.

Listed activities that require licenses include dredging, excavation, infilling, removal of soil, rock or sand of a volume exceeding 5 m^3 from a river, tidal lagoon, tidal river, lake, dam, floodplain or wetland (Republic of South Africa, 2010). Nevertheless, Everson (2007) points out that policy and legislation regulating riparian zones in South Africa is disjointed and poorly coordinated as it involves multiple departments such as the Department of Water Affairs and Forestry and the Department of Environmental Affairs and Development Planning.

CHAPTER 3: Methodology

Introduction

The general methodological framework for this study is modelled around the use of sequential aerial photography captured at various stages covering the period from 1955 to 2012. This is the primary source used to assess the spatial and temporal changes in the riparian zone of the Berg River. The central aim of this study is to understand the geographical changes to the riparian zone along the Berg River over an extended period of time in order to improve the governance of the river system. As such the analysis of changes in the extent of different landuses and vegetation cover in the riparian zone of the study area is examined using Geographical Information Systems (GIS) mapping tools.

3.1 Site description

The Berg River is approximately 300km in length (de Villiers, 2007). The river has a catchment area of 9000km^2 *(ibid*). However, the study only covered a small section of the river in the Hermon area as indicated in Figure 1. The site was chosen because of an initiative taking place in that section of the river to remove Blue Gum trees (*Eucalyptus globules*) in the riparian zone.

In addition, the soils found in the vicinity of the study site are of the Malmesbury Group that comprise soft erodible rocks that results in the formation of low lying areas and flat plains with a few gullies discharging into the river as non-perennial streams (Clark, 2007). As such much of the Berg River Catchment is generally flat (Figure 3) (*ibid)*. Its average topographic gradient is 0.001 between Paarl and Laaiplek (*ibid*). Moreover, the soils produced by the Malmesbury Group sequency of rocks have high to moderate agricultural potential resulting in agriculture being the dominant landuse in the area (*ibid*).

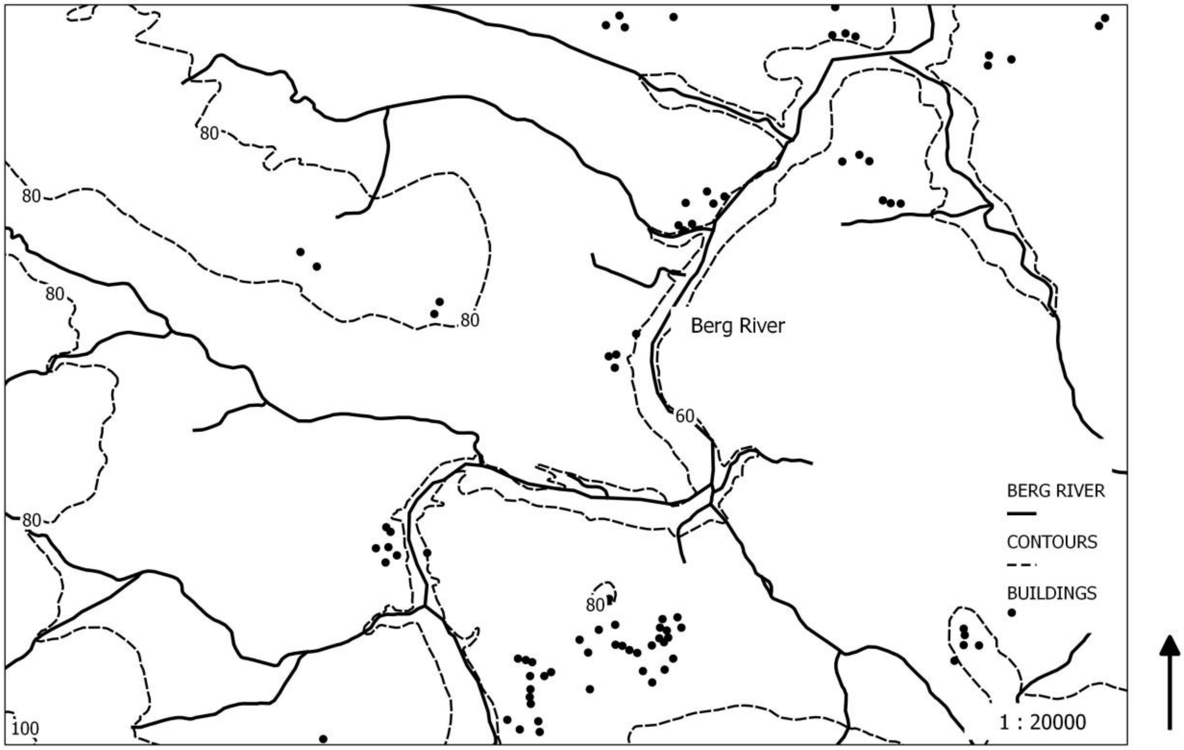


Figure 3: Topographical map of study site

3.2 Aerial photographs

Aerial photographs used in the study were obtained from the Department of Land Affairs's Chief Directorate: Surveys and Mapping. These digital aerial photographs were the only source available that recorded physical and vegetation changes along this stretch of the Berg River. The details of the digital copies of the aerial photos are outlined in Table 1. The photographs spanned a period between 1955 and 2000 and were available only at irregular time intervals. In addition, the latest Google Earth image of the study area was included. The date of the captured image is not supplied. An approximate date is inferred from the knowledge of developments and changes in the region, e.g. knowledge and evidence of recent road works and building developments in the region.

All the aerial photographs were rescanned at 2400 dpi to create a digital image and then georeferenced manually using points such as crossroads and houses to identify the co-ordinates to a vector map. Both the images and maps were converted to the Universal Transverse Mercator (South) projection using WGS 1984 as the datum.

3.3 GIS mapping

GIS maps of the Hermon area were used to illustrate and describe the changes in the vegetation and the physical extent of the riparian zone. In this study the assumption is shrubs represent natural uninvaded vegetation while trees represent the alien invasive Blue Gums. The riparian zone is defined as the area between the farm edge and the low water mark in this study. The scanned aerial photographs covering the Hermon area were attached to a GIS software application and used to analyse the changes in the riparian zone.

Table 1: Details of the digital copies of the aerial photographs used in this study

Year	**Job Number**	**Strip Number**	**Photo Number**	**Scale**
1955	371	12	05243	1: 36 000
1968	619	8	00428	1: 36 000
1972	699	7	00731	1: 20 000
2000	1033	13	07413	1: 50 000

3.4 Discussion of the methodology

Although integrating aerial photographs into GIS mapping tools is useful in assessing the dynamics of a phenomenon over space and time, there are a number of inherent inaccuracies that need to be taken into account. Aerial photographs have an inherent distortion known as the parallax error (Arnold, 1997). This distortion arises because satellite and aircraft data images are representations of the irregular surface of the earth (*ibid*). As such any vertical aerial photograph of land features lying above or below the average surface elevation is displaced on the aerial photograph resulting in the production of distorted image (Arnold, 1997). In addition, the curvature of the earth and the sensors being used distorts even images that are flat (Guide, 1999).

Moreover, the small spatial extent covered by each of the images meant that there were few positions for the placement of ground control points (Ben-Dor, 2002). Consequently the accuracy of the georeferencing process was compromised *(ibid*). This is because a reasonable number of ground control points that are evenly distributed are required to ensure successful georeferencing (Ben-Dor, 2002*)*. Furthermore, the visual gathering of the different vegetation types in the riparian zone of the study area using remote sensing and GIS tools was difficult because it was not easy to distinguish between the trees and the shrubs from the aerial photographs. As such these limitation needs to be taken into consideration when analysing the results of this study.

3.5 Methodology testing

The accuracy and replicability of the methodology used in this study was tested through an exercise that involved six purposively selected people. These were people known to the researcher. The researcher showed the people how the visual gathering of the different vegetation types using remote sensing and GIS tools was done.

The darker and denser vegetation on the aerial photographs was considered to be trees while the light coloured vegetation was considered to be shrubs in this study. The percentage error was calculated by dividing the difference between the average area in hectares obtained by the six people and the area obtained by the researcher by the area obtained by the researcher and then multiplying the value by 100 as follows;

% Error Trees Area = 0.273533333/2.9659* 100

% Error Trees Area = 9.22ha.

A small stretch of the Berg River riparian zone on the year 2000 image was chosen for this exercise. The selected people were then left to do the exercise on their own over a selected portion of the study area for the year 2000 image. Appendix A provides the polygons captured by each person during this exercise. The resultant area of the different vegetation types calculated from the 6 exercises was averaged and the figure was compared to the figure that the researcher got for the same stretch of the Berg River riparian zone to get the margin of error for this study (Table 2). As such when analysing the results of this study an error of 9.2% and 2.7% should be factored in for the spatial extent of the trees and shrubs respectively.

Table 2: Trees and shrubs area in hectares for individuals selected to participate in the methodology testing exercise

Test		**Trees** (Area in ha)	**Shrubs** (Area in ha)
1		2.9	0.77
2		3.38	0.65
3		2.36	0.38
4		3.01	0.62
5		2.06	1.61
6		2.44	1.39
	MEAN	2.69	0.90
RESEARCHERS SCORE		2.97	0.93
	DIFFERENCE	0.27	0.03
	% ACTUAL DIFFERENCE	9.22	2.73

CHAPTER 4: Results and Discussion

This chapter describes the spatial and temporal changes in the riparian zone along a selected stretch of the Berg River in the Hermon area. The study covered the period from 1955 to approximately 2012. The latter is an approximation because in this case a Google image was used but the date of the captured image is not supplied. An approximate date is inferred from the knowledge of developments and changes in the region, e.g. knowledge and evidence of recent road works and building developments in the region.

4.1 Spatial and temporal changes in the riparian zone

A summary of changes to the spatial extent of the riparian zone is displayed in various graphs that follow. The spatial and temporal changes in the riparian zone represent changes in vegetation and the spatial extent of the riparian zone. Appendix B shows the output from the visual gathering exercise that focused on identifying distinctive vegetation types (shrubs vs trees) and the spatial changes in the riparian zone area for each of the available aerial photographs.

Figure 4 and Appendix B show that from 1955 to 2012 there was a reduction in the area covered with shrubs (low bush and thicket) in the riparian zone of the study area. By 2012 shrubs were no longer visible on the aerial photograph. Shrubs may be present but the canopy of tree cover obscures any detection.

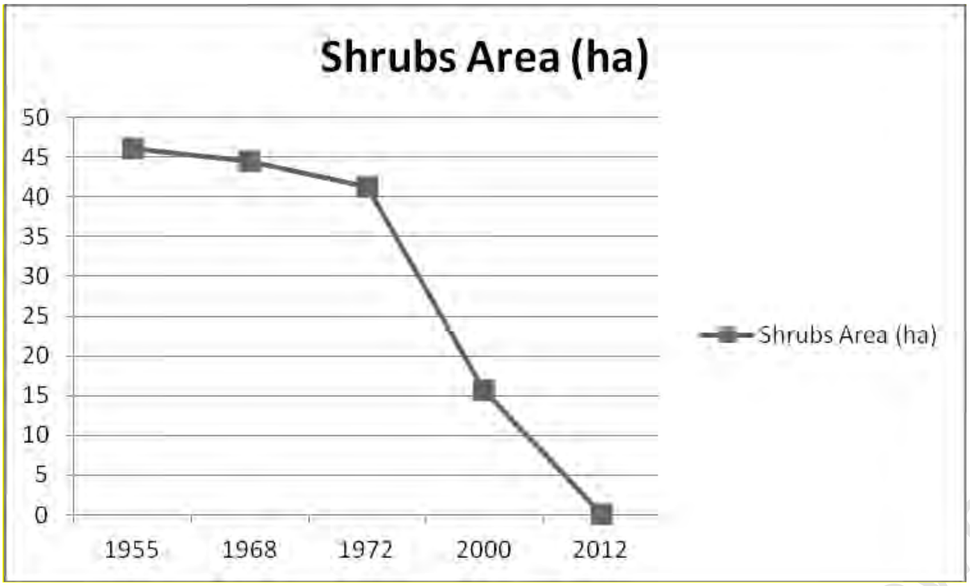


Figure 4: Change in the extent of shrubs in the riparian zone from 1955 to 2012

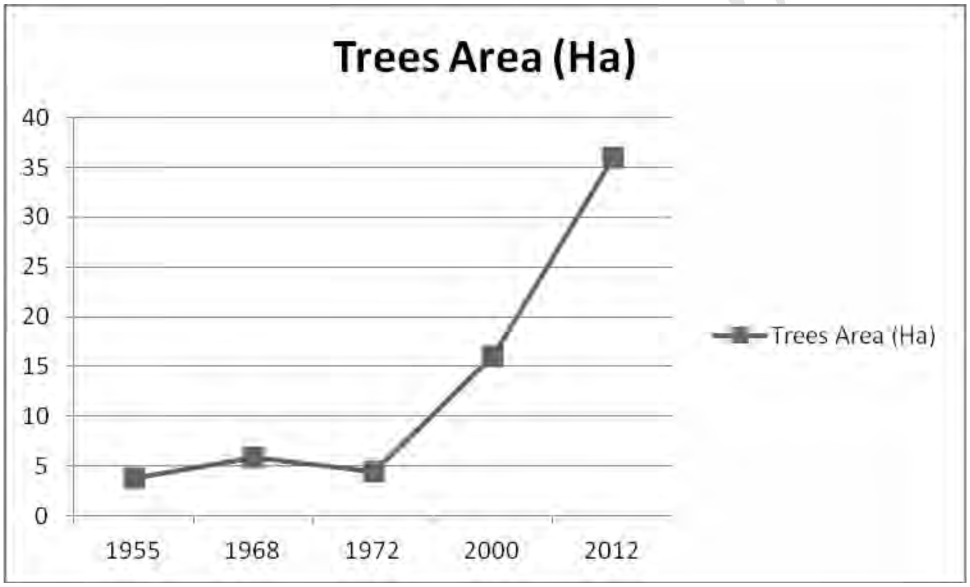


Figure 5 : Change in the extent of trees in the riparian zone from 1955 to 2012

In Figure 5 and Appendix B, there is shown an increase in the spatial extent of trees in the riparian zone of the study area for the years 1955 to 2012. By approximately 2012, the tree canopy covers the entire riparian zone (Figure 5 and Appendix B).

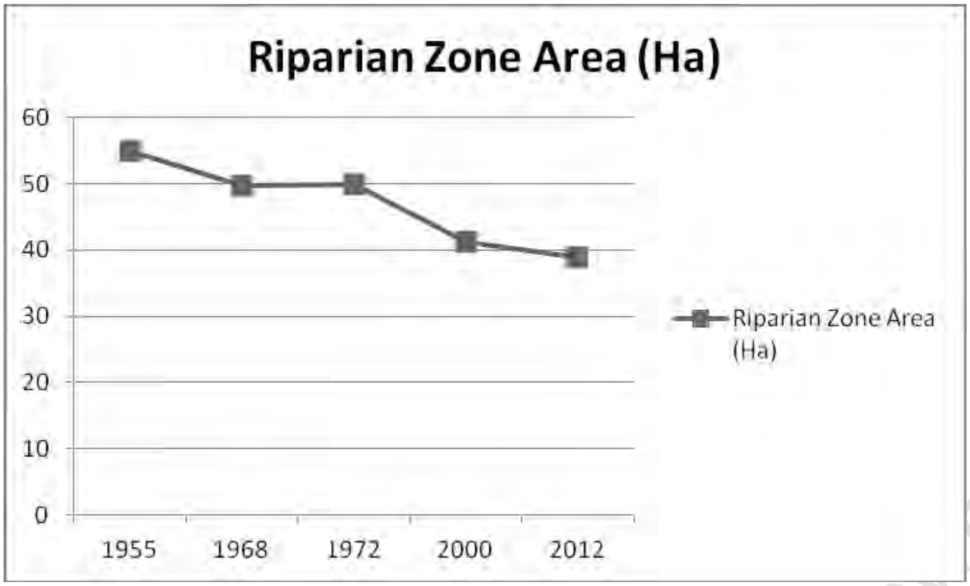


Figure 6: Change in the spatial extent of the riparian zone from 1955 to 2012

The study of aerial photographs also showed a steady decrease in the extent of the riparian zone in the study area from 1955 to 2012 (Figure 6 and Appendix B).

4. 2 Percentage change in the vegetation composition and spatial extent of the riparian zone

The vegetation distribution for 1955 and the spatial extent of the riparian zone for 1955 represents the base year for comparison with the subsequent years in the period of the study. Figure 7 shows the spatial coverage of shrubs in the riparian zone for the time period starting in 1955 to 2012. The coverage of shrubs measured as changes from the original baseline in 1955 decreased by 3.47% from 46.10 ha to 44.50 ha between 1955 and 1968. The spatial extent of the shrubs further decreased by 7.3% from 44.50 ha to 41.25ha between 1968 and 1972 (Figure 7). In addition, the extent of the riparian zone shrubs continued to shrink a further 62.1% from 41.25 ha to 15.65 ha between 1972 and 2000. This was followed by a further reduction in the area covered by shrubs decreasing from 33.95% of the cover first measured in the 1955 photos to not observable in 2012. (Figure 7).

In total, the area covered by shrubs in the riparian zone of the study area as per the analysis of the aerial photographs decreased by 100% from 46.10 ha in 1955 to 0 ha in 2012. This does not imply that there were no shrubs present, only that shrubs could not be visually detected on the aerial photographs because of a canopy of dense trees that dominated the riparian zone.

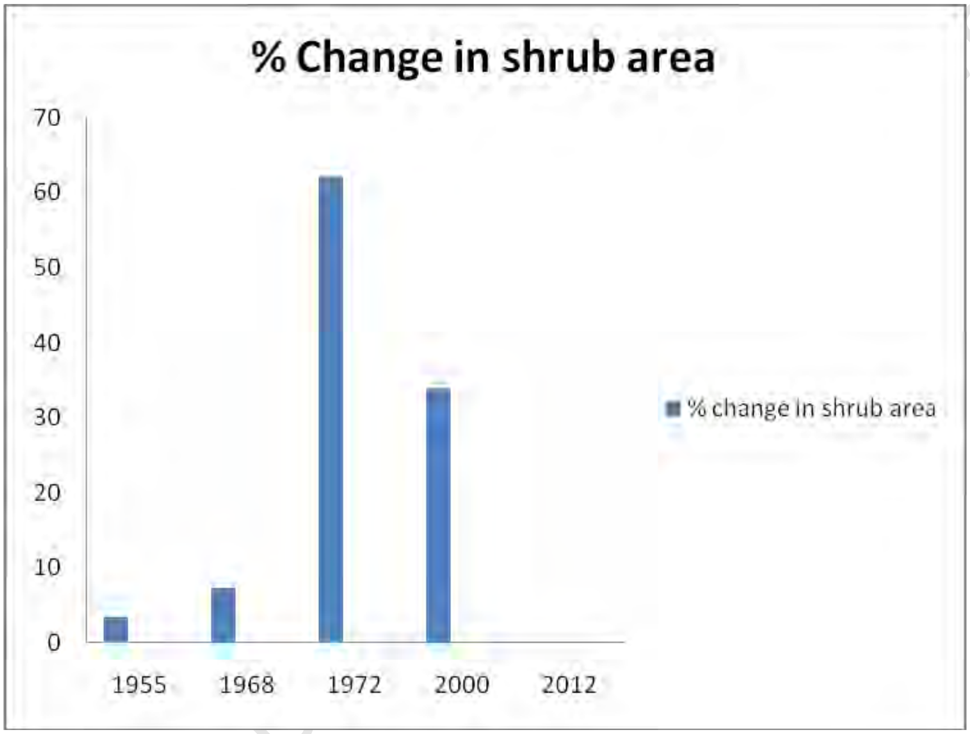


Figure 7: Percentage change in the extent of shrubs in the riparian zone

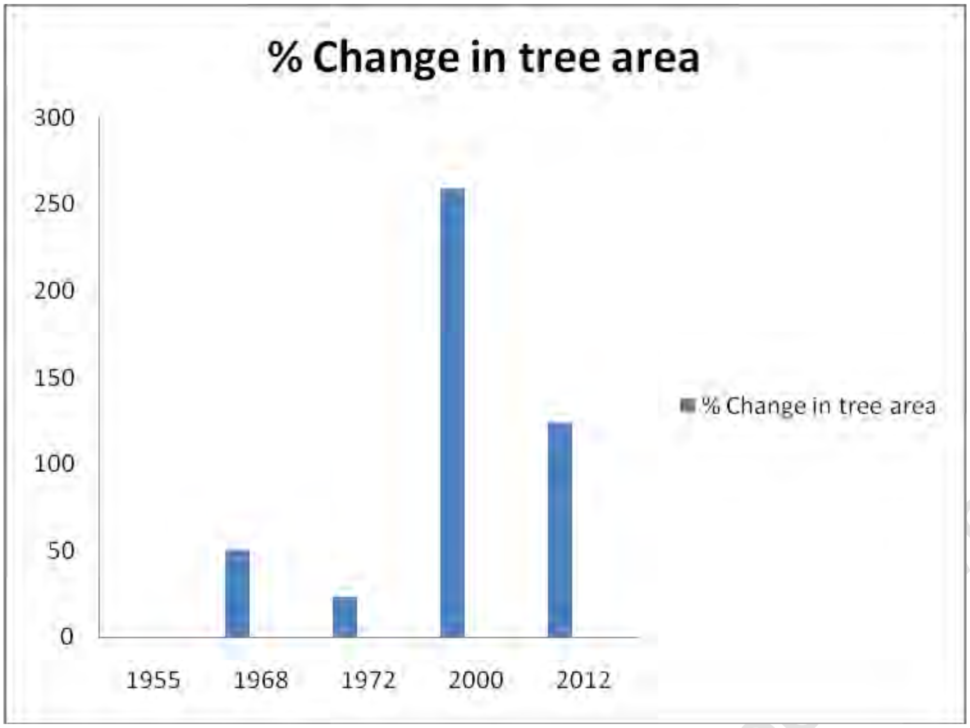


Figure 8: Percentage change in the extent of trees in the riparian zone

In Figure 8 the extent of trees covering the riparian zone increased by 50.1% from 3.84 ha in 1955 to 5.80 ha in 1968. This was followed by a 23% decrease in the area covered by trees from 5.80 ha in 1968 to 4.46 ha in 1972 (Figure 8). In addition there was a marked increase in the area covered by trees in the riparian zone of the study area of 259% from 4.46 ha in 1972 to 16.04 ha in 2000 (Figure 8). This was followed by an increase in the coverage of trees in the riparian zone of the study area by 124% from 16.04 ha in 2000 to 35.94 ha by 2012 (Figure 8).

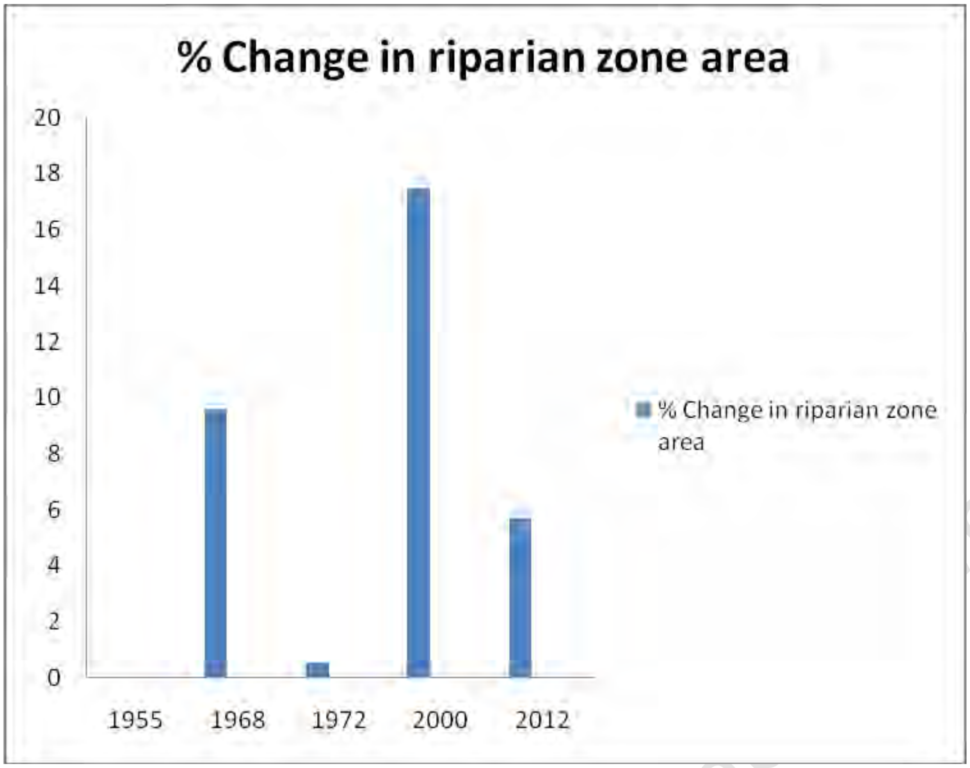


Figure 9: Percentage change in the extent of the entire riparian zone

The riparian zone decreased by 9.61% from 54.92 ha in 1955 to 49.64 ha in 1968. This was followed by a 0.56% increase in the spatial extent of the entire riparian zone from 49.64 ha in 1968 to 49.92 ha in 1972 (Figure 9). In addition, the extent of the entire riparian zone of the area under study continued to decrease by 17.5% over the 1955 figure from 49.92 ha in 1972 to 41.20 ha in 2000 (Figure 9). Moreover, the riparian zone further decreased by 5.7% from 41.20 ha in 2000 to 38.84 ha in 2012 (Figure 9). Possible explanations for these changes will be discussed in the next section.

4.3 Changes to the spatial extent of the entire riparian zone

Riparian zones are the interface between the terrestrial and aquatic environments (Richardson *et al.*, 2007; Holmes *et al.*, 2005). These zones are often the wettest and most fertile zones within a catchment because fluvial processes such as flooding results in deposits of alluvial soils in the riparian zone (Everson, 2007; Richardson *et al.*, 2007). As such the riparian zone supports a distinctive vegetation community type whose structure and function is different from the vegetation in adjacent upland areas *(ibid*). The riparian vegetation has a number of ecological functions that are linked to aquatic habitats. These include the provision of food for aquatic macro-invertebrates in the form of decomposed leaf litter, the regulation of water temperature through shading and evapotranspiration, the provision of a buffer zone that purifies nutrients and sediments, stabilization of river banks to prevent erosion, provision of habitat for wildlife and the provision of conduits for movement of biota, material and energy fluxes from adjacent upland ecosystems (Richardson *et al*., 2007).

The results of this study show that the riparian zone has decreased steadily over the years. This is in part due to the expansion of agricultural activities to the river's edge (Rheinhardt *et al*., 2006; Holmes *et al*., 2005; Phillips *et al*., 2000). In addition, the structures of legitimisation, values and norms in a given society control the extent to which the riparian zones can be successfully managed (Sweeney *et al*., 2004). For example there is a high rate of deforestation in riparian areas because people assign a higher value to agriculture and wood products than the value assigned to riparian forest ecosystem services (*ibid*).

These findings concur with results for similar studies done in Australia where extensive riparian vegetation on the banks of the river were cleared for sugarcane production in north eastern Australia, while 80% of the south west region of south western Australia were cleared through for broad scale agriculture (Hancock *et al*., 1996; Barling & Moore, 1994).

4.4 Changes in shrub and thicket cover

The results show that shrub and thicket cover decreased substantially. This is attributed to a number of factors. Firstly, indigenous shrubs were displaced by alien invasive trees that colonized the area (Lawes & Grice, 2010; Loo *et al*., 2009; Samways & Sharratt, 2009; Turpie, Marais & Blignant, 2008; Gerber *et al*., 2008; Holmes *et al*., 2005; Le Maitre *et al*., 2002). The displacement occurs when alien invasive plants suppress the growth of indigenous plants by reducing the amount of available space, light, moisture and nutrients (Magoba & Samways, 2010; Lawes & Grice, 2010; Dark, 2004).

Secondly, human disturbances in riparian zones can create transformed habitats that no longer support conditions conducive for indigenous plant species (Holmes *et al*., 2005). The disturbances include logging, grazing and trampling by livestock as well as water abstraction (Richardson *et al*., 2007; Dark, 2004). These disturbances also change the hydrological patterns, natural fire regimes, soil chemistry and structure such that the thriving of indigenous species is compromised (Dark, 2004). Moreover, alien invasive trees in riparian zones change the morphology of the river thereby preventing the recruitment of indigenous plant species in the riparian areas (Meek *et al*., 2010).

The results of this study support the findings of a study done in Japanese riparian zones that showed that indigenous plants were encroached upon by alien invasive species (Miyawaki & Washitani, 2004). Similarly, in another study carried out in North America, the riparian zones throughout the south eastern United States were invaded by Chinese privet ultimately displacing the indigenous plant species (Hanula *et al*., 2009).

4.5 Changes in trees species and tree cover

The increase in the area covered by trees (*Eucalyptus globules*) is attributed to a number of reasons. These include the fact that streams have a dynamic hydrology that increases the chances of recruitment for alien plants propagules after floods (Malikova & Prach, 2010; Hanula *et al*., 2009; Richardson *et al*., 2007; Holmes *et al*., 2005; Le Maitre *et al*., 2002). In addition, floods create sites in riparian zones where alien invasive trees can establish themselves whilst rivers act as conduits for the efficient disposal of alien propagules (Malikova & Prach, 2010; Richardson *et al*., 2007). Moreover, alien plant species disperse efficiently in water because they thrive in areas where there is a continuous water access (Holmes *et al*., 2005; Le Maitre *et al*., 2002).

The vulnerability of riparian systems to invasion by alien plant species is increased by anthropogenic disturbance (Holmes *et al*., 2005). Disturbances change habitats which can encourage the proliferation of alien plants (Richardson *et al*., 2007; Holmes *et al*., 2005; Dark, 2004; Hood & Naiman, 1999; Dye & Poulter, 1995). In addition, when riparian areas are disturbed, they can become unstable and more vulnerable to invasion (Dark, 2004).

The disturbance in riparian zones typically occurs because alien propagules are released into rivers; when grazing and trampling by livestock is unchecked; when deforestation causes soil erosion in, or in the vicinity of the riparian zone; and when the natural fire regimes are changed (Richardson *et al*., 2007; Dark, 2004). The success of alien plant invasion is also determined by other physical factors and climate (Dark, 2004). In addition, disturbance coupled with alien invasive plant propagule pressure increases chances of invasion (Meyerson & Mooney, 2007).

Moreover, the recruitment of alien plant propagules may occur after a fire and through dispersal by animals and wind (Holmes *et al*., 2005). Once the tree species are established in an area they outgrow the indigenous vegetation by reducing space, water and light available to native plants since most of the plants are woody, tall canopy trees (Hanula *et al*., 2009; Miyawaki & Washitani, 2004). The results of this study concur with the findings from a study carried out in the degraded riparian zones of New Zealand where alien invasive plants called gorse and broom proliferate in the disturbed alluvial riparian zones (Drake, 2011). Similarly, in a study of the riparian zone of the Eerste River in the Western Cape, South Africa, the findings indicate that the riparian zones in agricultural landscape were degraded by alien plant invasions and that the rate of the invasion was higher than in urban areas (Meek *et al*., 2010). The authors attributed this trend to nutrient inputs from agricultural landscape.

4.6 Challenges in governance of riparian zones

Obstacles to the successful governance of riparian zones were identified in literature as being that of a lack of financial and human resources, outdated policies, the lack of coordination among different disciplines, along with conflicting policies and knowledge gaps (Richardson, Naiman & Bisson, 2012; Lees & Peres, 2008; Everson, 2007; Holmes *et al*., 2005).

Riparian zones require an approach to governance that is adaptive and able to deal with change and surprise that is encountered in the system (du Plessis *et al*., 2008). Governance should be able to facilitate collaborations and partnerships that are necessary to bring together all the interested and affected members (Richardson *et al*., 2012; Holmes *et al*., 2005).

Most obvious is the extent to which the riparian zone can be successfully governed is greatly influenced by socio-economic factors (Holmes *et al*., 2005). For instance, land owners and farmers compromise the buffer width to create farming space at the expense of protecting aquatic and integrity of riparian system as a whole (Phillips *et al*., 2000). While there is active encroachment on these riparian zones, these areas are also some of the most neglected. Clearing riparian weeds are costly to land owners in countries where the responsibility for such actions rests solely on the affected farmers (Everson, 2007; Schulze *et al.,* 2004). In addition, a substantial amount of money is required to support the long term field experiments to fill the knowledge gaps on the current state of riparian zones, monitoring, planning and implementation that is important to ensure the ecological performance of the riparian systems (Richardson *et al*., 2012; Holmes *et al*., 2005).

The further governance challenge lies in the difficulties that are experienced in coordinating required interdisciplinary partnerships (Holmes *et al*., 2005). These partnerships are important because factors that control the state of the riparian zone in a given location occur at temporal and spatial scales that are outside the influence of the managers in that particular area (Arnaiz *et al.,* 2011; Holmes *et al*., 2005). For example, the loss of indigenous riparian and terrestrial vegetation upstream affects the riparian hydrology downstream (Holmes *et al*., 2005).

The coordination of riparian zone policies remains a challenge (Everson, 2007) and in some cases the policies are outdated (Lees & Peres, 2008). The South African legislation requires that all activities that entail dredging, excavation, infilling, removal of soil, rock or sand of a volume exceeding $5m^3$ from a river, tidal lagoon, tidal river, lake, dam, floodplain or wetland need approval under the provisions of NEMA (de Villiers, 2010). As such the large scale removal of riparian weeds will trigger the NEMA EIA regulations as more than $5m^3$ of sediments are likely to be bound to the operation required to remove riparian weeds. In such a case, policies for riparian zone management are in conflict with each other and new thinking and sensible approach to coordinated management is required (Everson, 2007).

According to the Agriculture Research Council (2013), the responsibility for managing riparian zones in South Africa lies with the national Department of Agriculture. The legislative mandate for the conservation of land resources in general, which includes the riparian zone, lies within the Conservation of Agricultural Resources Act (CARA) of 1983 (Department of Agriculture, 2011). The aim of CARA is to promote the conservation of water sources, soil and indigenous vegetation by controlling the use of South Africa's natural agricultural resources (Agriculture Research Council, 2013). The Department of Agriculture administers CARA through its Land Use and Soil Management directorate (*ibid*).

The Department of Agriculture aims to achieve the sustainable management of land resources through its Sustainable Resource Management Programme (Department of Agriculture, 2011). This programme is divided into 3 sub-programmes namely Engineering Services, Landcare Services and Land Use Management Services (Department of Agriculture, 2012).

The Engineering Services sub-programme provides services that include specialist planning on the design and implementation of structures that protect river bank erosion, while the Landcare Services sub-programme includes awareness raising and execution of projects that promote the conservation and continual enhancement of environmental assets and agricultural natural resources (*ibid*). Finally, the Land Use Management Services sub-programme entails the prevention of agricultural land fragmentation taking into consideration natural resources conservation imperatives through the controlling of agricultural land rezoning applications (Department of Agriculture, 2012).

The natural resources conservation programmes administered by Department of Agriculture help indirectly to protect the water quality of river systems through initiatives to control river bank erosion. These activities are allied to initiatives by the Department of Water Affairs to protect the water quality of river systems (*ibid*). A close partnership between these two departments is likely to improve the effectiveness of riparian zone governance. Moreover these are the lead agencies that should be responsible for initiating and sustaining viable platforms for effective engagement with different actors that include officials from the Department of Water Affairs, the CMAs, officials from the Department of Agriculture and farmers, bringing together a range of participants in governance as advocated by Folke *et al*. (2005).

CHAPTER 5: Conclusion

This final chapter reviews the aims and objectives of the study; discusses the degree to which the methodological limitations impact on the reliability of the findings; and concludes on the major challenges in governance of the riparian zone based on the study findings.

5.1 Review of aim and objectives

The central aim of this study was to describe the spatial changes to the riparian zone at a selected site along the Berg River over a reasonable period of time in order to understand the complex challenges confronting the governance of these areas. The results presented in Chapter 4 identified the spatial and temporal changes in the Berg River riparian zone. The nature and reasons for the change were discussed in Chapter 4 based on literature and from discussions with an official from the Department of Agriculture responsible for land care in the affected area. The objectives are presented again, in turn, and then discussed below to assess the study's achievements.

- Describe the riparian zone using aerial surveys, and map the changing state of the riparian zone along the Berg River over time

Digital aerial photographs were obtained from the Chief Directorate: Surveys and Mapping, and these were integrated into Quantum GIS software. This technique generated quantitative information on the changes to the spatial extent of the riparian zone for each year under study. The details of the aerial photographs were given in Table 1. However the photogrammetric inconsistencies found in the aerial photographs was a major source of error identified in this study.

The low temporal resolution of the aerial photographic record made it difficult to track the spatial and temporal changes in the riparian zone, for example, the latest aerial photographs covering the study area were last captured in 2000 which meant for the purposes of this study that a more recent image of the study area was obtained from Google Earth. As such the findings of this study need to be assessed against these limitations. Nevertheless, the overall pattern of remarkable and relatively rapid change in the riparian zone remains a resolute finding.

- Identify and describe the changes in the spatial extent of a selected stretch of the riparian zone along the Berg River

The change in the spatial extent of the riparian zone of the study area over time was measured by estimating the area between the river's edge and the cultivated lands through mapping the detail offered by the various aerial photographs and quantifying the area in hectares using the GIS quantifying tools. A steady decrease in the extent of the riparian zone was determined for the study area.

- Identify and describe the changes broadly in vegetation along the selected stretch of the Berg River riparian zone over time

The change in vegetation cover was assessed by determining the actual area covered by shrubs and large trees. Shrubs and large trees were distinguished by differences in the tone, hue and canopy structure observed on the aerial photographs. The findings show that the area covered by shrubs decreased significantly over time while the area covered by the trees increased. This is interpreted as a decrease in natural vegetation and an increase in invasive alien Blue Gum trees.

- Understand the current and future governance arrangements for the riparian zone

This objective was met by carrying out a literature search on riparian zone governance in South Africa. The information gathered from this exercise suggests that the responsibility to manage riparian zones lies largely within the national Department of Agriculture (Department of Agriculture, 2012; Department of Agriculture, 2011; Agricultural Research Council, 2013). The national Department of Agriculture, through its Sustainable Resources Programme, ensures that environmental and natural agricultural resources are conserved and continue to be enhanced (Department of Agriculture, 2012). This is achieved through engaging in activities that include controlling applications for rezoning of agricultural lands, execution of projects that promote sustainable use and management of natural agricultural resources, and the designing and implementation of structures that prevent river bank erosion (*ibid*). Such activities help to protect the water quality of river systems albeit indirectly.

In addition, the Departments of Water Affairs and Environmental Affairs sometimes take part in projects that are designed to manage the riparian zones depending on the availability of funding. According to Steyn (personal communication), an ideal governance arrangement for the Berg River riparian zone would be the model adopted by the Breede-Overberg CMA. Currently the Berg CMA is not operational. A close partnership between the Department of Agriculture and the Department of Water Affairs is likely to improve the governance of these resources since the Department of Water Affairs is responsible for protecting the water quality of the national river systems, and the Department of Agriculture is involved indirectly in protecting the water quality of river systems.

Collaborations and implementation initiatives between the CMAs and the Department of Agriculture will bring together many actors representing resource users, resource managers and state actors that are most likely to ensure effective governance of these resources.

The future governance arrangements for the Berg River riparian zone lie in the stated intentions and policy statements found in the soon to be published National Water Resources Strategy 2 which sets out to solve the water resource governance failures in the country. As such the proposed Berg CMA will hopefully be initiated once merged with the Olifants CMA. Once this becomes operational then the governing body for this CMA will be made up of different user representatives, i.e. the resource managers and the resource users. Such arrangements will likely lead to an improvement in the governance of the water resources.

5.2 Concluding discussion

Riparian zones represent enormously valuable natural ecological systems on a global, regional and national scale (Kanasashi & Hattori, 2011; Virbickas *et al*., 2011; Naiman *et al*., 2005). These zones provide services that include the filtration of pollutants from the discharge flowing from upland areas; provision of an ecological corridor for wildlife movement and habitat for wildlife; stabilisation of river banks; provision of food for aquatic macro invertebrates in the form of leaf litter; and control of stream temperature (Richardson *et al*., 2012). Effective governance arrangements are required to rehabilitate and sustain ecological goods and services of these fragile areas.

This study has shown that the riparian zone has decreased steadily over the past five decades partly due to the expansion of agricultural activities in the area, and has shown the increase in extent of the invasion of alien vegetation. The neglect of the riparian zone is evident.

Consequently, this study is an alert: there is an urgent need to improve the governance of riparian zones so as to ensure the sustainability of these systems to achieve the necessary ecological functions. Although the Department of Agriculture through its Sustainable Resource Management programme is involved in activities that conserve the riparian zones, further collaboration and co-operation with other departments, including the Department of Environmental Affairs and Development Planning, Department of Water Affairs and other stakeholders, is an urgent requirement that is necessary to deal with the governance of these resources. The lack of coordination among the different departments involved in the conservation of natural resources in South Africa has been identified as a contributing factor to the poor management of the national's natural resources (Everson, 2007).

Furthermore some legislation on the conservation of natural resources conflicts, for example the NEMA and CARA (de Villiers, 2010). The removal of more than 5 m^3 of soil from riparian zones, which is necessary for the rehabilitation initiatives, triggers EIA authorisations since the removal of alien invasive trees from these zones is likely to contain more than 5 m^3 of soil that will be bound to the roots of trees (*ibid*). EIAs are costly and will delay project initiatives and in cases may be the death knell for projects that are funded within an annual budget cycle. Alternatively a close partnership between the Department of Agriculture and the Department of Water Affairs together with the involvement of other stakeholders in the design and implementation of strategies to govern riparian zones is likely to improve the effectiveness of the governance of these resources as advocated by Berkes (2004). Both national departments are involved in the protection of the water quality and quantity of the nation's river systems either directly or indirectly.

Improved collaboration between these departments appears to be a fundamental prerequisite for the coordination of conservation activities and ultimately improving the governance of the riparian zone as an essential resource.

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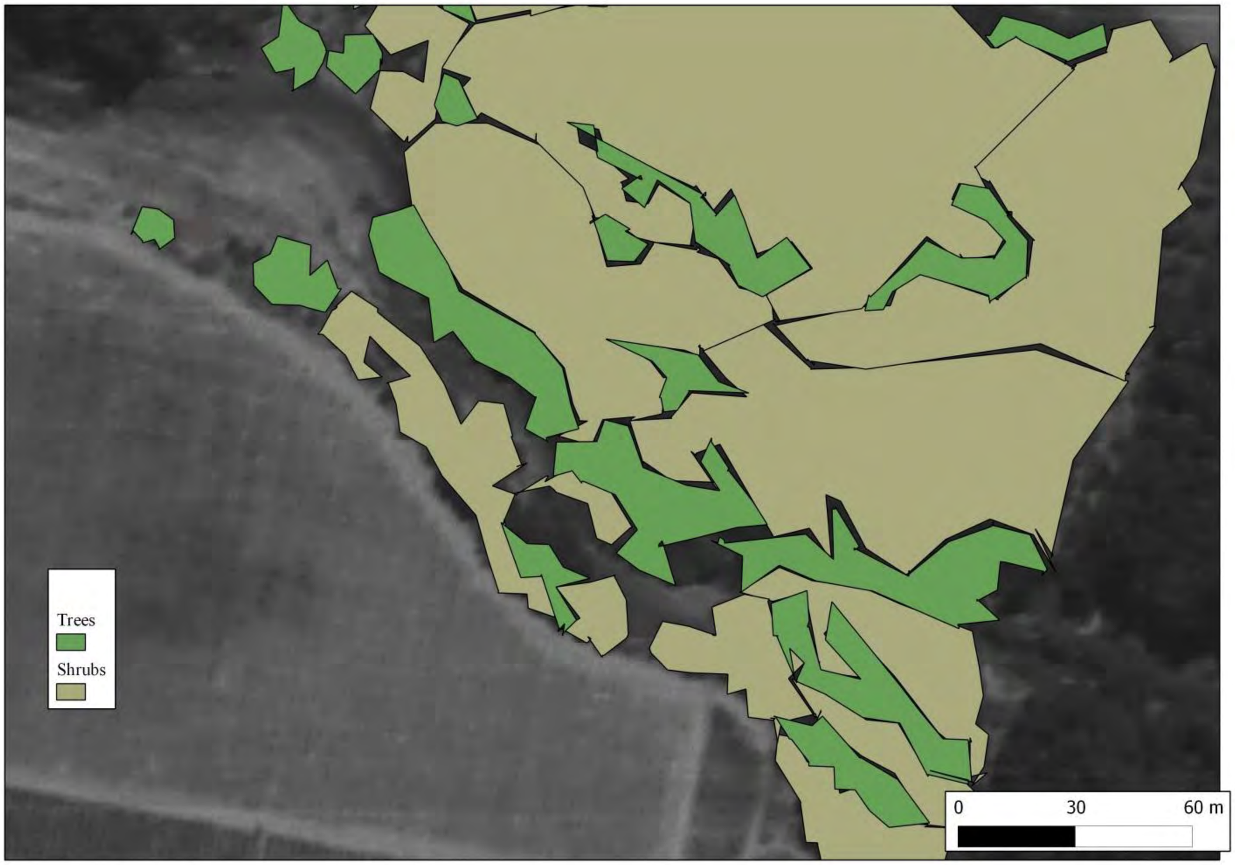
Personal Communication

Steyn, Francis – LandCare Programme Manager, Western Cape Department of Agriculture. 22 August 2012.

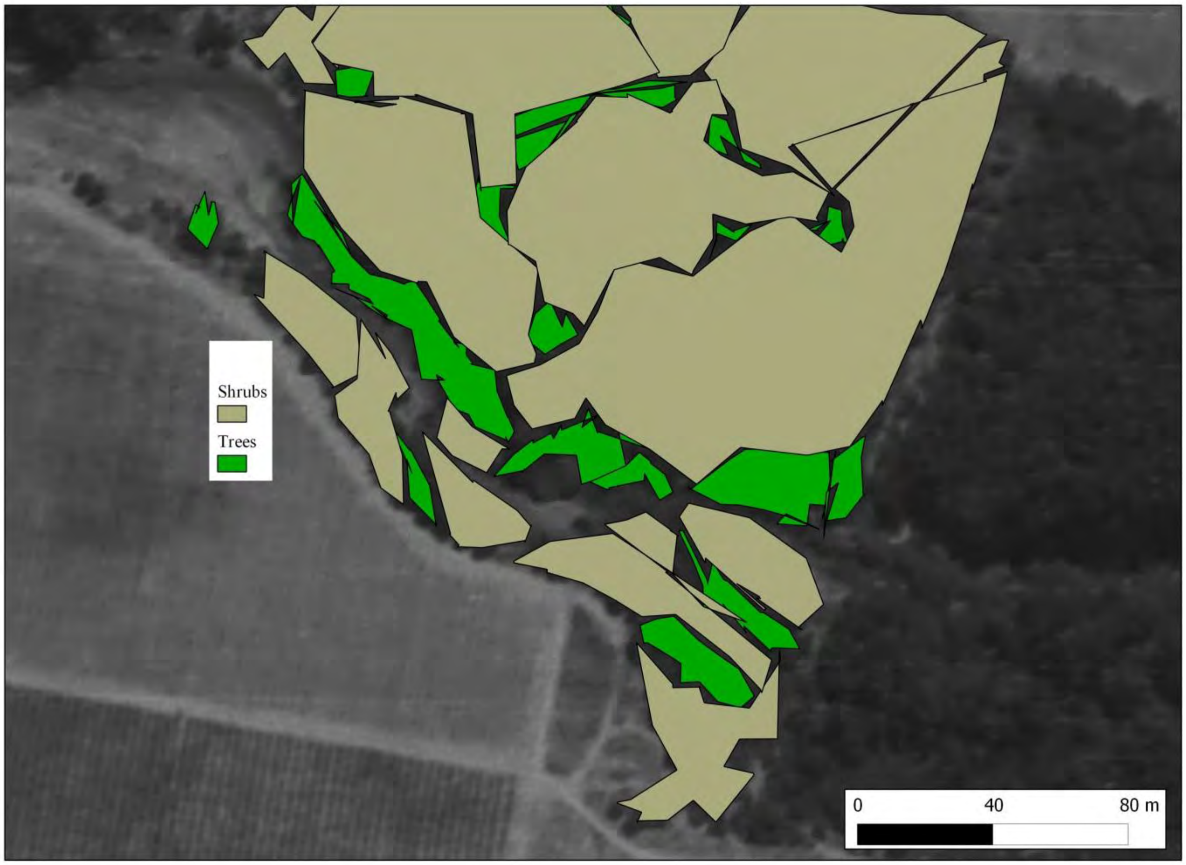
Appendices

Appendix A: Results of the methodology testing exercise

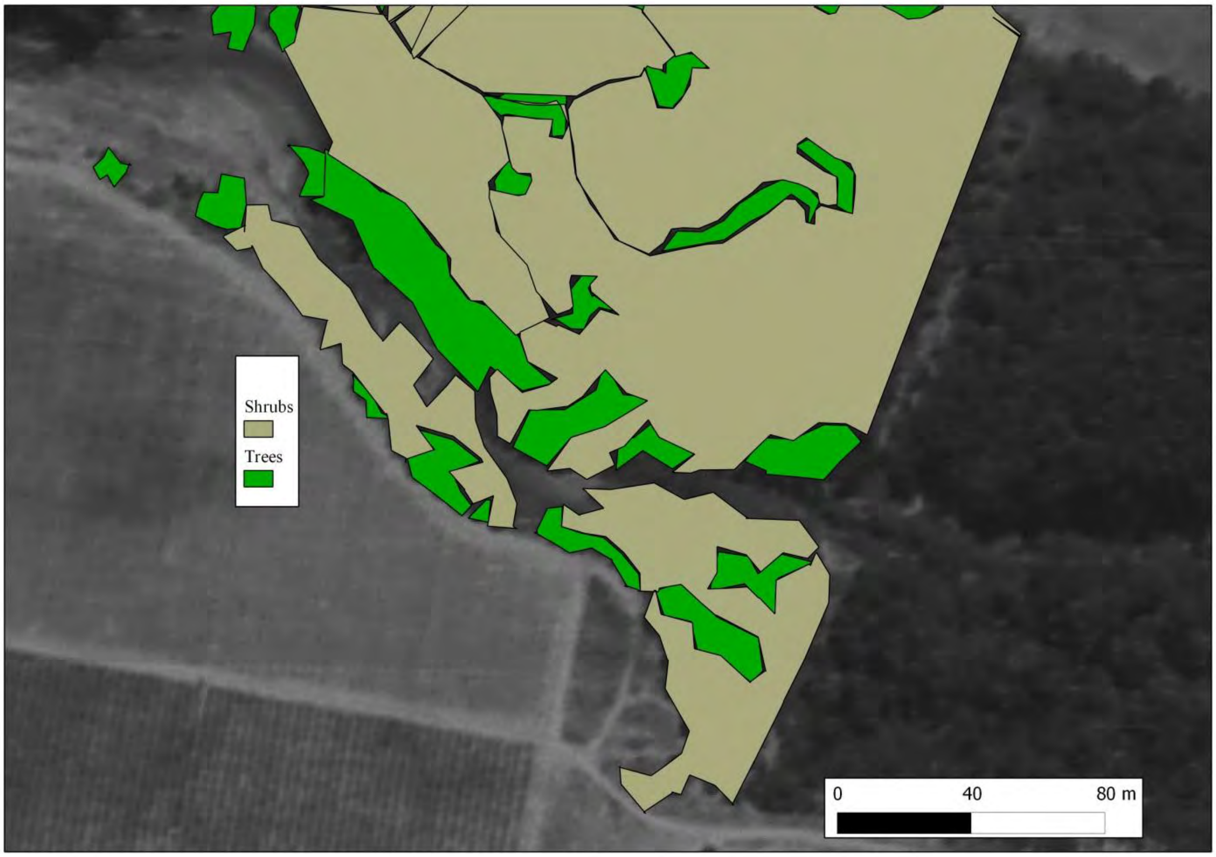


Test 1: Riparian zone vegetation

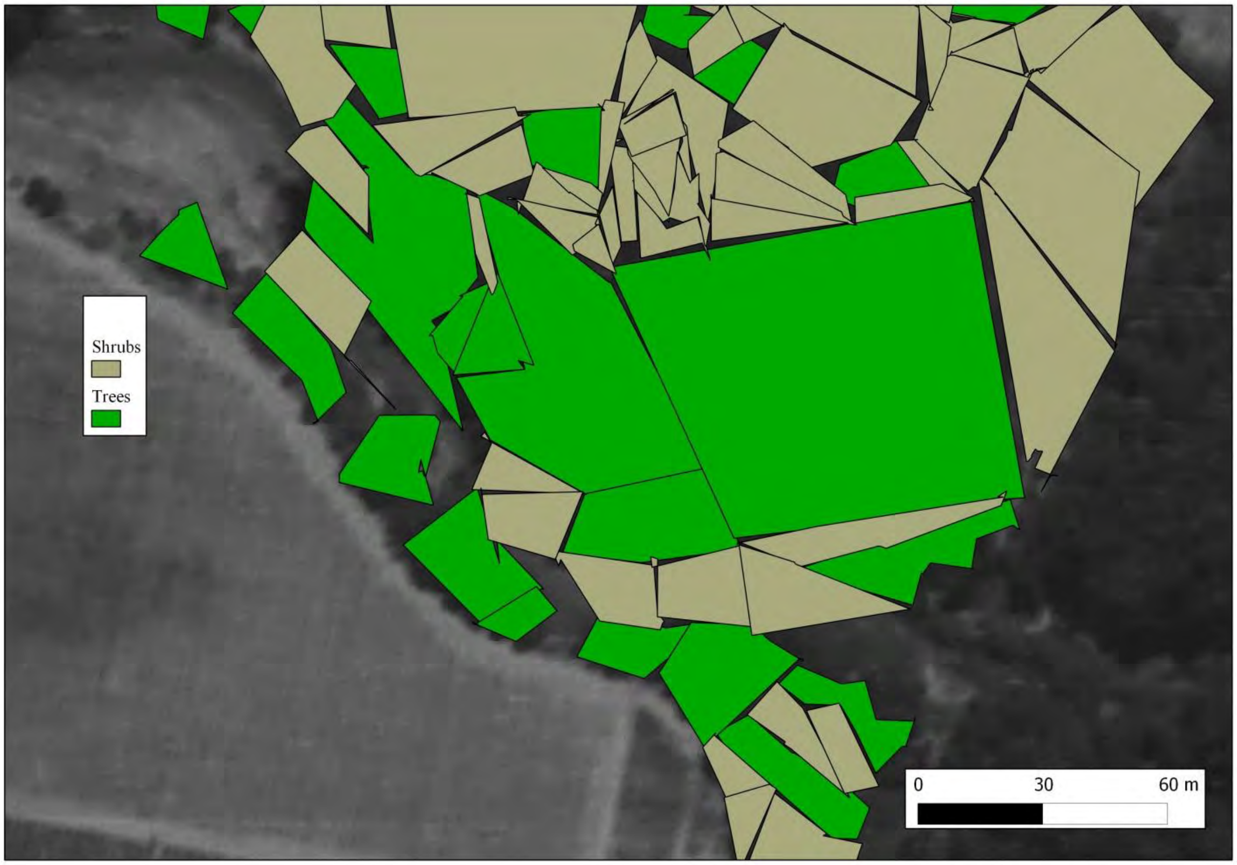
Test 2: Riparian zone vegetation



Test 3: Riparian zone vegetation



Test 4: Riparian zone vegetation



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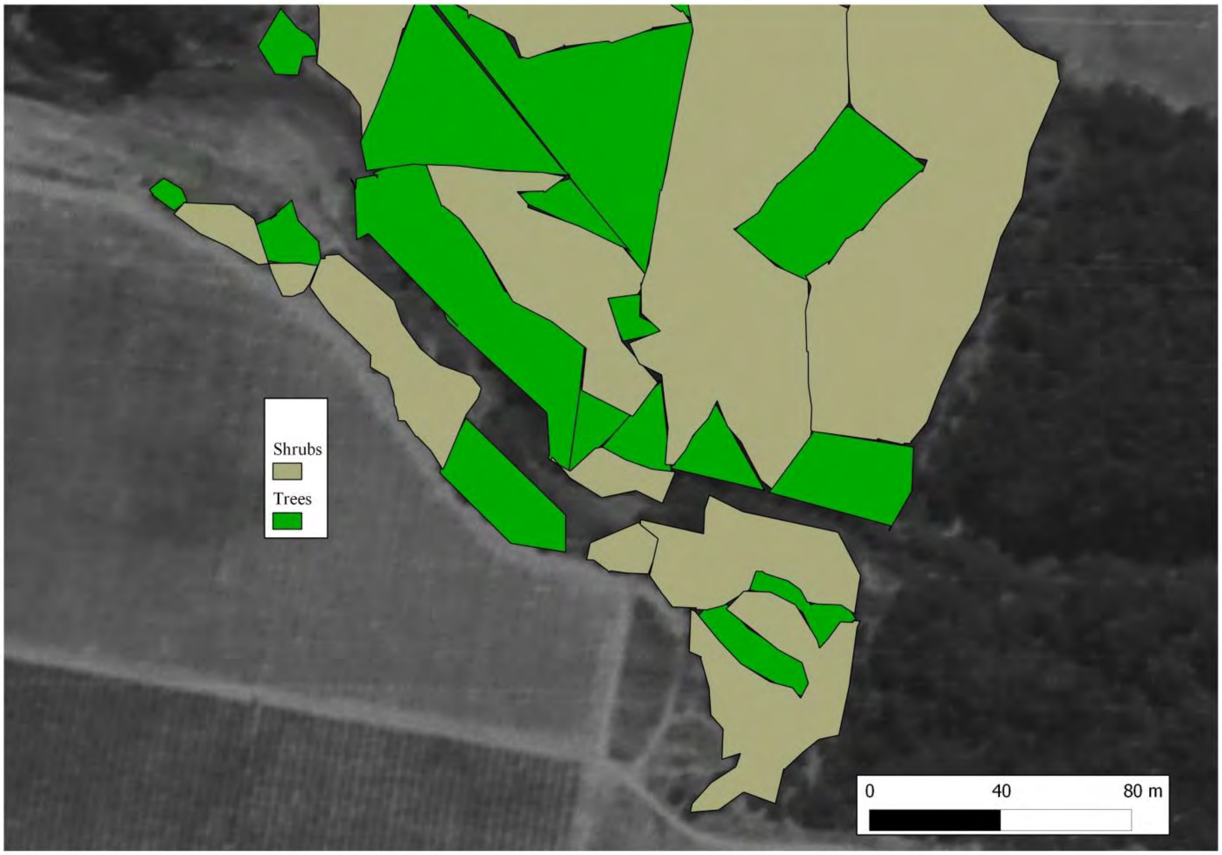
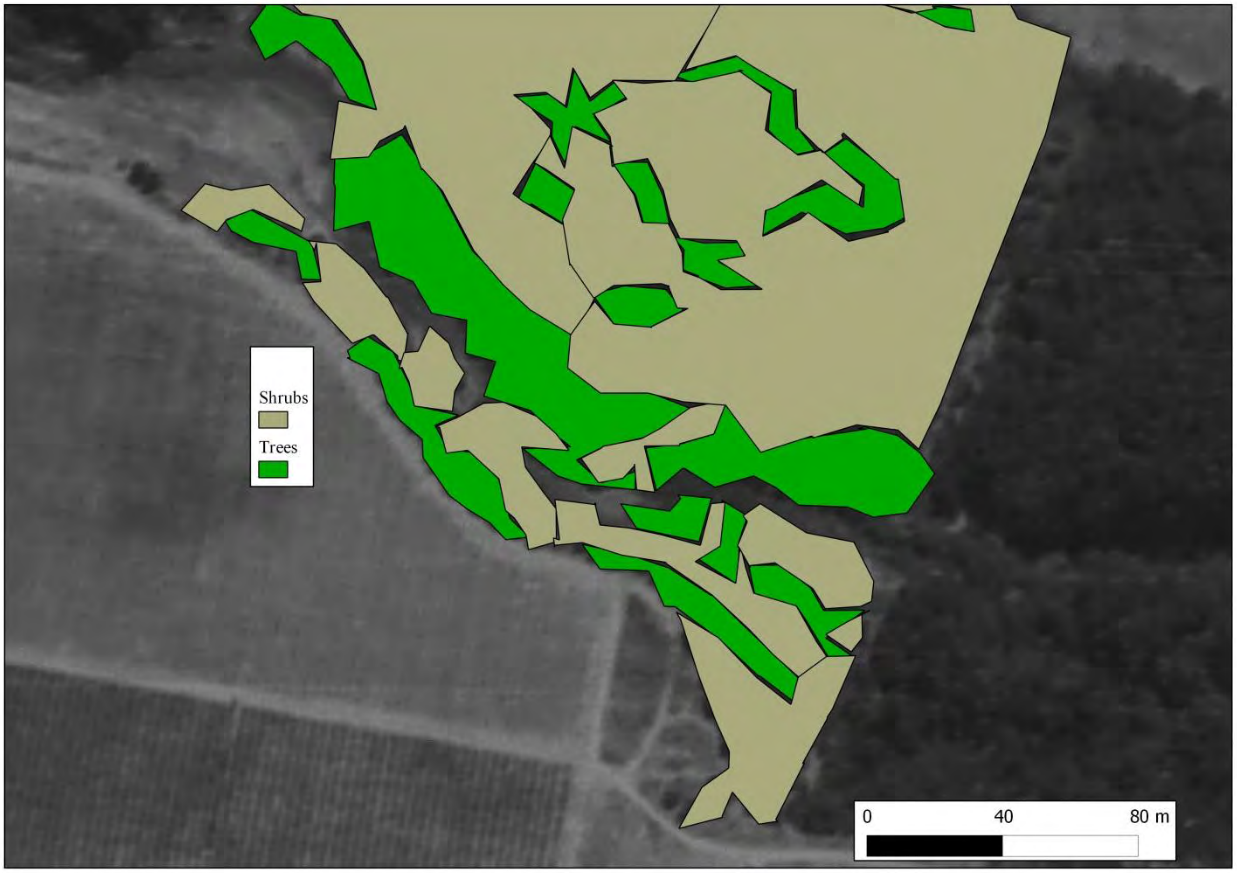
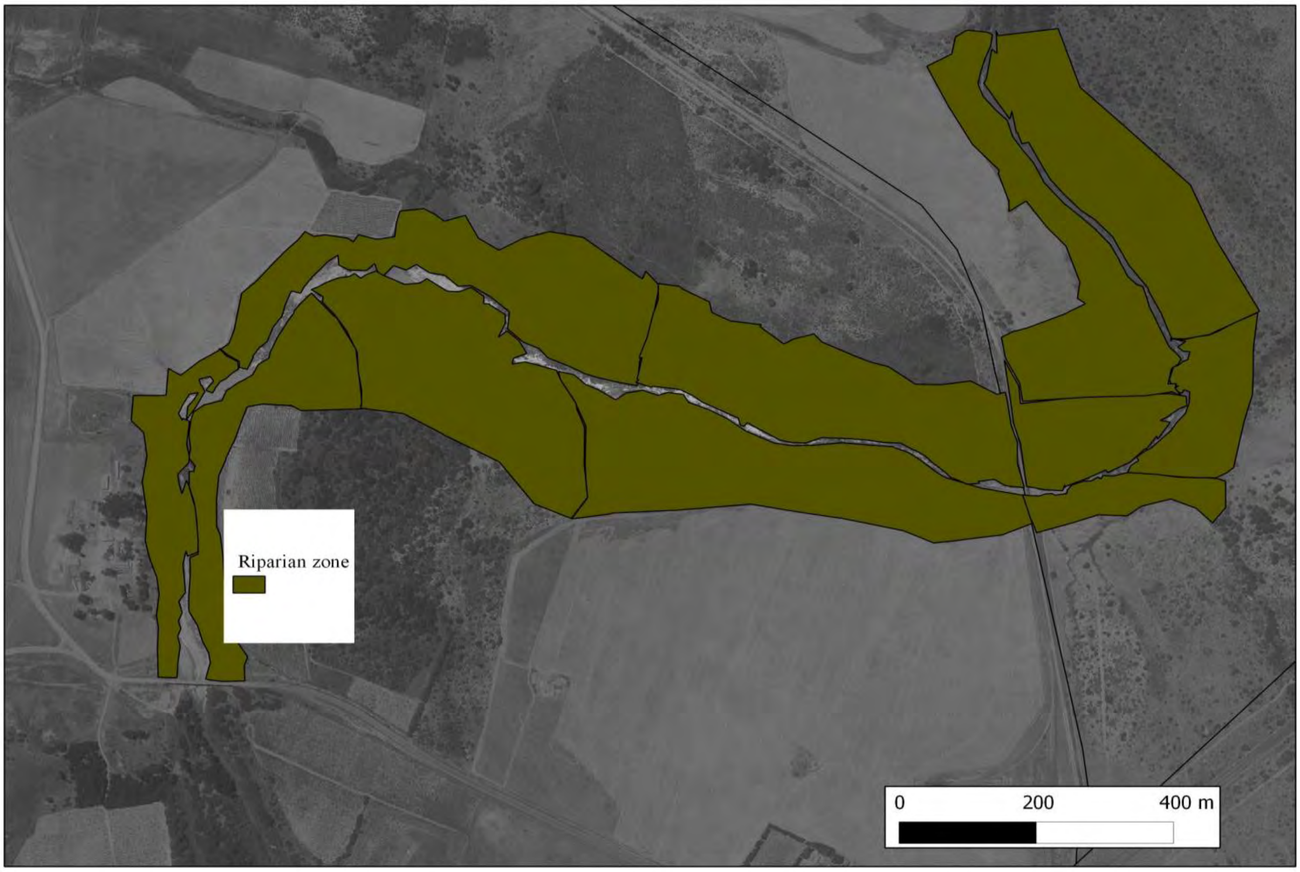


Test 6: Riparian zone vegetation

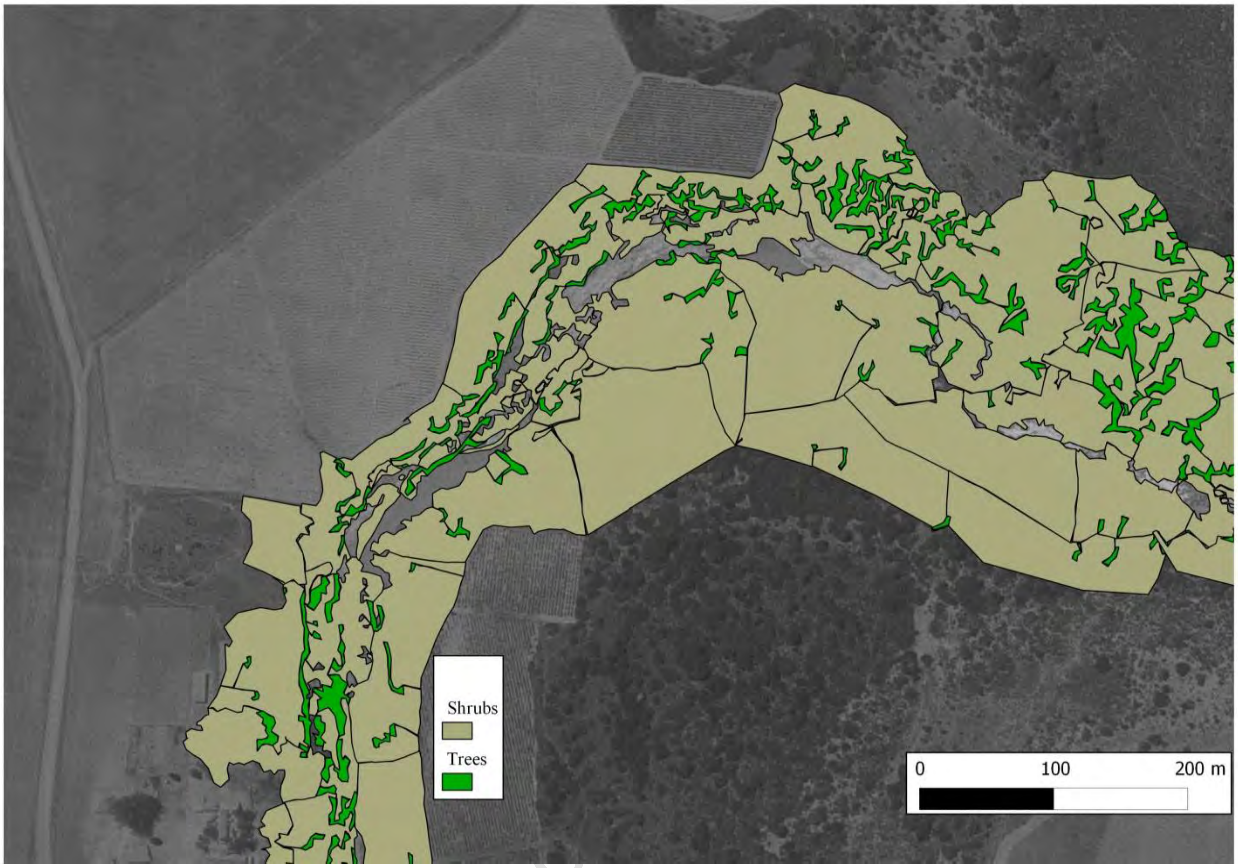


Test 7: Researcher's observation

Appendix B: The extent of the entire riparian zone and the changes in the vegetation types



Map B.1a: Riparian zone 1955

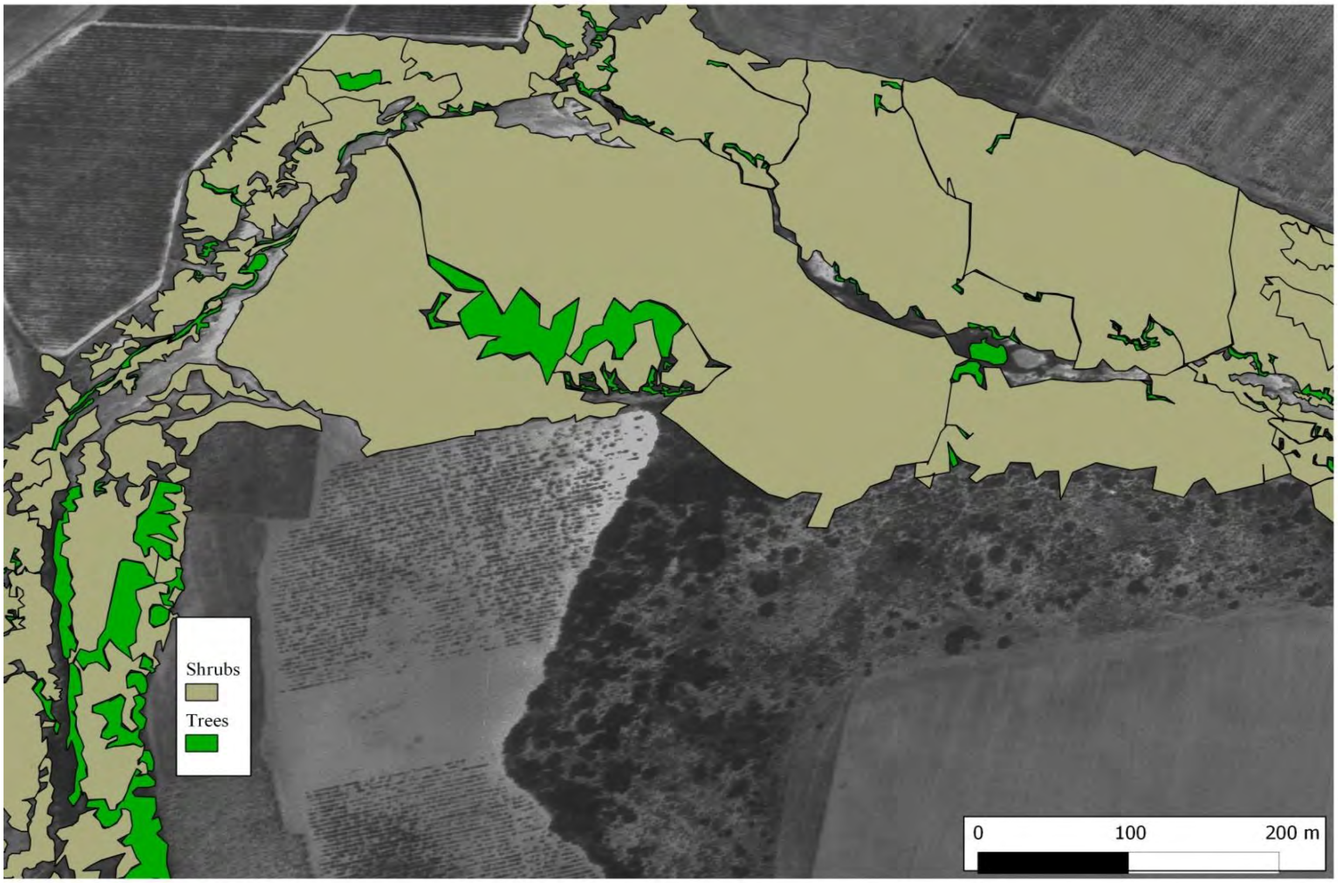


Map B. 1.b: Riparian zone vegetation 1955

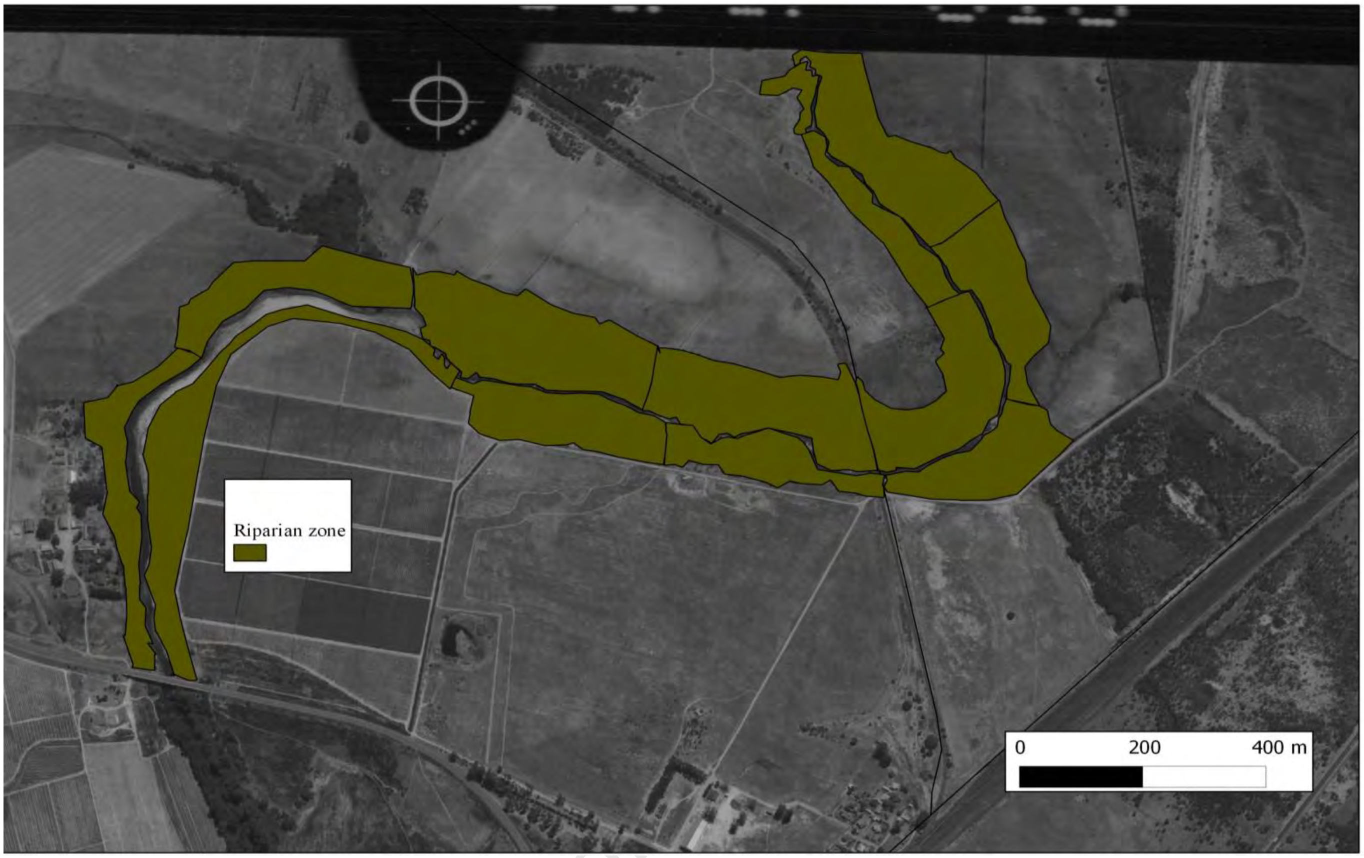
Map B. 2a: Riparian zone 1968

Map B. 2b: Riparian zone vegetation 1968

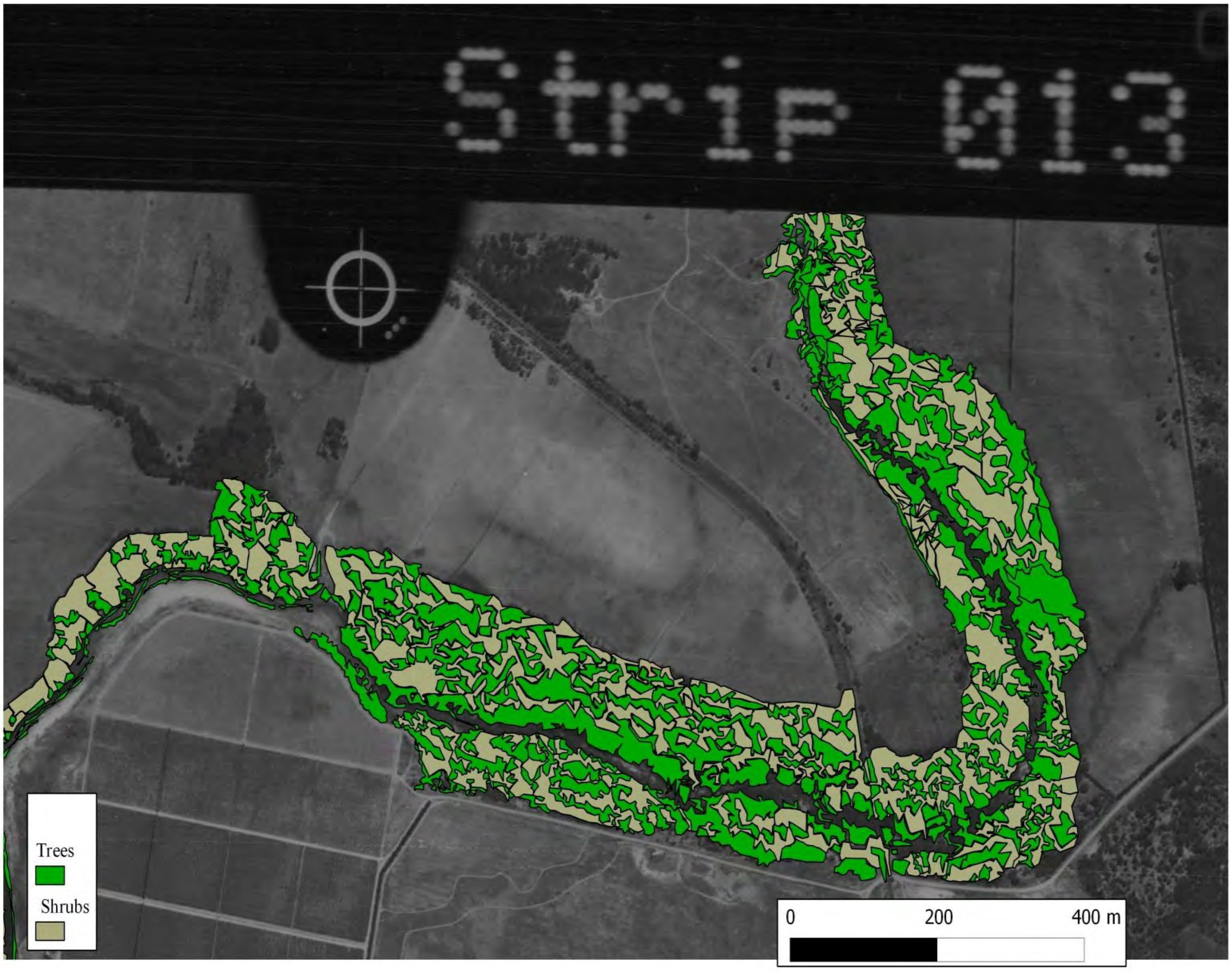
Map B. 3.a : Riparian zone 1972



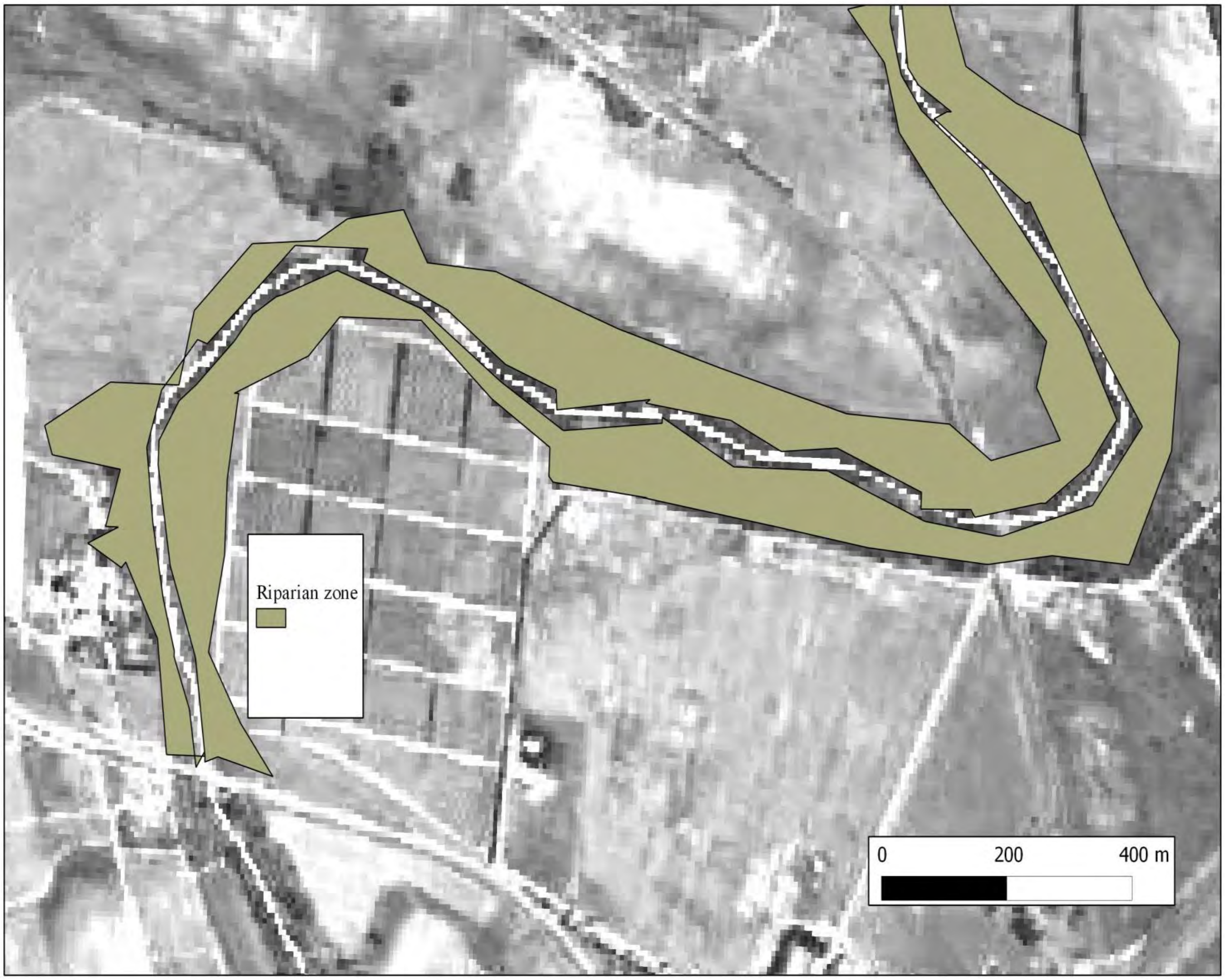
Map B. 3.b: Riparian zone vegetation 1972



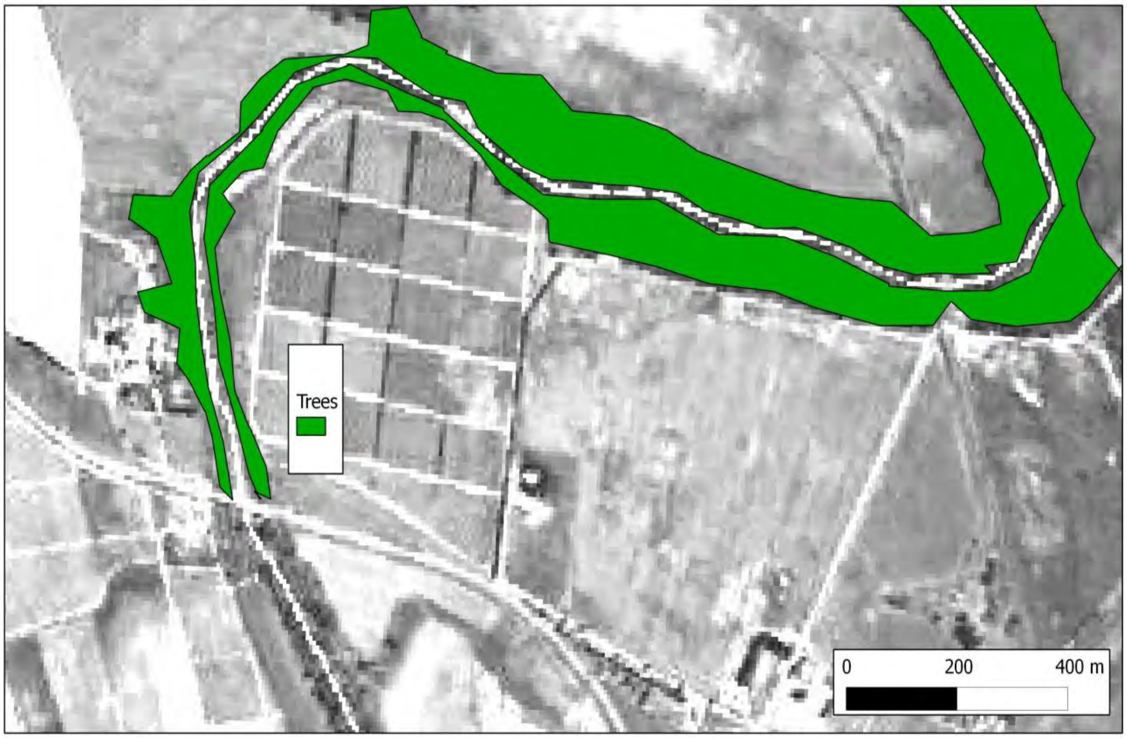
Map B.4.a: Riparian zone 2000



Map B. 4b: Riparian zone vegetation 2000



Map B. 5. a: Riparian zone 2012



Map B. 5. b: Riparian zone vegetation 2012