The change in water availability as a result of invasion by Acacia Mearnsii in the Kouga Catchment, Eastern Cape, South Africa

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Abstract

The change in water availability due to Australian Blackwattle (*Acacia Mearnsii*) invasion in the Kouga Catchment, Eastern Cape, South Africa, was investigated and modelled. The Australian Blackwattle is a highly invasive plant species, which replaces the indigenous fynbos and grassland vegetation, and can consume significantly more water, leading to a potential decrease in water availability. The methods and materials that were used are (i) field research to determine the riparian zone in the Kouga Catchment, (ii) a literature review, summarizing the recent knowledge regarding the black wattle and the invaded vegetation (iii) a model was made in Excel to calculate the change in water availability for different black wattle management scenarios in the Kouga Catchment. Completely clearing the Kouga Catchment of black wattle would gain between 0.33 and 1.17 Mm^3 annually by 2050, respectively 0.26 to 0.87% of the current water flowing out of the Kouga. Neglecting the black wattle problem can lead to a loss in water availability of 9.4 to 26.2 Mm^3 per year in 2050, which is respectively 7.5 to 19.4% of the current outflow. Uncertainty exists about the accuracy of the evapotranspiration of the Australian Blackwattle, fynbos and grassland vegetation. The outcomes lead to the conclusion that the potential loss in water availability can be very high, which can affect downstream water users and threatens the water supply to reservoirs, most notably the Kouga Dam at the end of the catchment. Therefore it is recommended to maintain and preferably increase the clearing of Australian Blackwattle in the Kouga Catchment.

Keywords: *Acacia Mearnsii*, Kouga Catchment, Water availability, Evapotranspiration

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1 Introduction

South Africa is a water-scarce country and its water supply can be severely threatened invasive alien plants, as these can consume large amounts of water (Le Maitre, et al., 2000). The Kouga Catchment is an important watershed in the Eastern Cape, South Africa, and suffers from invasion by alien invasive plants.

Plant species are called invasive when they out-compete the indigenous vegetation and thus replace them. This can have great impacts on the services, such as a reliable water supply, that the ecosystem normally provides (Van Wilgen, et al., 1996).

The most common invasive plant species in the Kouga valley is the Australian Blackwattle (*Acacia mearnsii*), also called black wattle. This species accounts for about 35 per cent of the South African alien species clearing program (Marais, et al., 2004). The South African Department of Water Affairs and Forestry (DWAF) Working for Water program focuses on clearing these invasive species. Other species in the clearing program are the lantana (*Lantana camera*), gum trees (*Eucalyptus* spp.) and pine trees (*Pinus* spp.) (Marais, et al., 2004). In the Kouga valley the gum and pine trees can be found as well, though they are not as dominant as the Australian Blackwattle.

Many of these species unintentionally spread from plantations. The *A. Mearnsii* is widely used in South Africa for the production of fuel wood, timber and tannin (Midgley & Turnbull, 2003). Some aspects that are normally seen as positive, such as increasing the amount of nutrients in the soil, providing shade and fast growth, turn out to be destructive for the indigenous species of South Africa.

The South African fynbos vegetation, an open shrub vegetation, requires high amounts of sunlight and a nutrient poor soil, and is therefore not capable to compete with the Australian Blackwattle trees, leading to a loss of biodiversity (Van Wilgen, et al., 1996). Loss of biodiversity often produces an ecosystem that is more susceptible to soil erosion. Through soil erosion the soil structure declines even further and the run-off might damage downslope vegetation or structures, or enter water streams, polluting these with high concentrations of sediment.

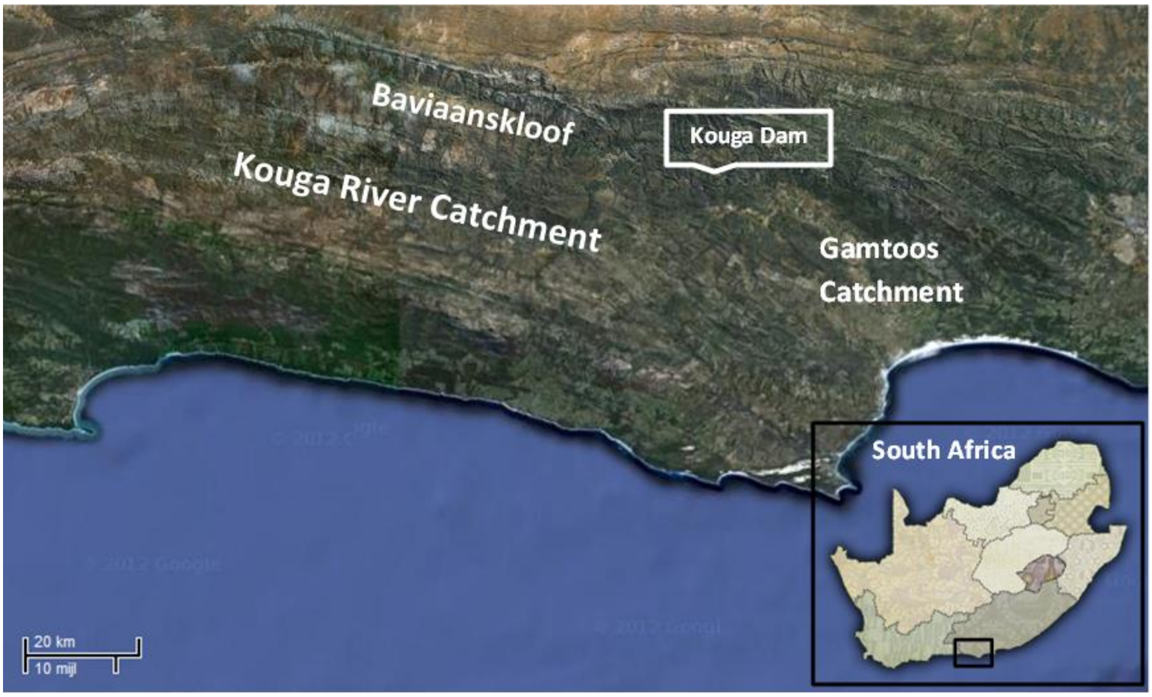

Figure 1 The Kouga river catchment in the East Cape of South Africa

The Acacia displaces other plants and consume more water (Dye, et al., 2001), while reducing the water holding capacity of the ecosystem (Van Wilgen, et al., 1996), resulting in a change in the eco-hydrology.

The hydrology of the Kouga valley also affects the socio-economical situation. Agriculture suffers through reduced water availability and the supply of water becomes less secure. Water flows from the Baviaanskloof in the Kouga River and is stored behind the Kouga dam from where it is used to irrigate the farms downstream in the Gamtoos river catchment (Figure 1).

All these aspects show that invasive species not only are a threat to the biodiversity and composition of the indigenous ecosystem, but also have a strong social aspect in the Kouga Catchment. The purpose of this research is to show the amount of water that is lost due to invasion of the Australian Blackwattle in the Kouga valley. Providing quantitative information on the change in water flow may lead to increase the involvement in black wattle clearing programs and contribute to stakeholder awareness.

1.1 Research questions

1.1.1 Research objective

The objective of this research is to investigate how the Australian Blackwattle, the most invasive tree species in the Kouga valley, affects the water balance and to model the impact of further spreading of this species on the water balance.

1.1.2 Research questions

Based on the information described in the introduction the following main research question has been formulated:

How would the water balance in the Kouga Valley be differently affected by various levels of invasiveness of the Australian Blackwattle?

In order to arrive at an answer to this question a set of sub questions is necessary:

- SRQ1: What are the growing conditions (climatic, physical and hydrological) of the Black wattle?
- SRQ2: What levels of invasiveness are possible in the Kouga valley based on the growing conditions of the Australian Blackwattle?
- SRQ3: What are the ecosystems that can be replaced by the invasive tree species in the valley, how much area do they cover and what are the main plant species in these vegetation types?
- SRQ4: What is the difference in water use between indigenous vegetation types and the vegetation type dominated by the Australian Blackwattle?
    - What are the characteristics in terms of water use by indigenous vegetation types?
    - What are the characteristics in terms of water use by invaded vegetation types?

1.2 Structure of this thesis

The setup of this thesis is as follows: (1) a conceptual framework, presenting the concepts necessary for answering the research question (2) methods and materials used, which consists of (i) a site description, (ii) field research to determine the riparian zone in the Kouga Catchment, (iii) a literature review, summarizing the recent knowledge regarding the black wattle and the invaded vegetation (iv) a model study to calculate the change in catchment water availability for different black wattle management scenarios. The results of the field research and modeling, the methodology, the assumptions and the resulting uncertainties will then be discussed. The interpretation of the results will be done in a separate discussion chapter, followed by a chapter with conclusions and recommendations.

2 Conceptual Framework

To answer the main research question, it is necessary to compare the current outflow with the outflow under different black wattle management approaches. To do this a simple water balance is required with a focus on the outflow of water.

A water balance consists of multiple components and can be viewed on various scales. The scales that are of importance in this research are the local and catchment scale. On local scale the interaction is vertical between the atmosphere and plant, atmosphere and soil, plant and soil, and between soil layers, and horizontal between inflow from upstream and outflow downstream. The equation to calculate the change in water storage in unit of height per time unit over time is (Hillel, 1971)

$$n * Z_r * \frac{ds(t)}{dt} = P(t) - I(t) - Q[s(t), t] - ET[s(t)] - L[s(t)]$$

Where n is the porosity of the soil, Z_r is the root depth, s is the saturation and t is the time. On the right hand of the equation are precipitation (P), interception (I), run off (Q), evapotranspiration (ET) and percolation (L). In this formula run off is shown as one term, while it can be split into an inflow of water into the system from upstream areas and outflow to downstream areas

$$Q_{out}[s(t), t] = P(t) + Q_{in}[s(t), t] - I(t) - ET[s(t)] - L[s(t)] - n * Z_r * \frac{ds(t)}{dt}$$

The water balance is very similar on catchment scale. The main difference between the two is that on catchment scale is subject to spatial variation in plant cover, rainfall, soil types and topography. Another difference is that the Kouga Catchment does not have any catchments upstream. The focus of this research is the replacement of indigenous vegetation by the Australian Blackwattle. Thus the variation in plant cover is not only spatially important but also in a temporal sense. The last difference is that the water storage may locally be depleted through run off and percolation, but on catchment scale this water is not lost and in general resurfaces in a lower point. Some variables that are commonly part of the water balance, but not part to this study, are water for irrigation, water used by industries and households, and water storage in reservoirs.

The Kouga Catchment consists of several vegetation types that can be invaded by the black wattle. A simplified form of the earlier formula for a vegetation type is

$$\mathrm{Q_{out}} = \mathrm{P} - \mathrm{ET}$$

Where the outflow is in unit of height per time unit. The potential evapotranspiration differs per vegetation type and the actual evapotranspiration depends on the type of water supply.

The evapotranspiration amount is divided in classes and each class pertains to a surface covered by a certain vegetation type. The water consumption (C) can easily be calculated by multiplying the surface (A) of a vegetation class with the evapotranspiration of that vegetation class.

$$C = ET * A$$

The sum of the water consumption of all the vegetation classes is the output to the atmosphere, while the rest can flow downstream. The only variation exists in plant cover of the black wattle and the vegetation types that it invades. The way these cause differences in the water balance is explained below.

The difference to the water balance by different plants is caused by plants preventing water from reaching the soil and the plants using water, in both cases delivering the water to the atmosphere. Plants preventing water from reaching the soil is called interception and the amount of water intercepted depends on the type of leaves and mostly on the leaf area index. Water use by plants is called transpiration and is depended on the plant natural water use and the water supplied by its surroundings. Water is supplied by the soil which receives water from the atmosphere in the form of precipitation or subsurface flow from upstream areas. Where water gathers are at the lowest points and often streams and rivers form here. The area around these points is called the riparian zone, and plants in this zone have an abundant water supply.

Thus plants are mostly relying on precipitation or water inflow from upstream areas to transpire optimally. The optimum amount of transpiration is higher in the case of many invasive alien plants, such as the Australian Blackwattle. The black wattle grows very fast, which makes the plant require more water than the slow-growing indigenous vegetation. How the black wattle replaces the indigenous vegetation is explained in the Australian Blackwattle chapter.

3 Methods and Materials

Each sub research question has to be answered. Fieldwork is a part of that and is used to determine the situation in the field and to investigate black wattle distribution. The relation between water bodies, such as streams and reservoirs, and the riparian zone will be investigated for use in the water model.

3.1 Site description

Black wattle distribution will be analysed in the Kouga Catchment, a large catchment mainly located in the Eastern Cape Province, South Africa. The upper reaches of the catchment, called the Bo Kouga are part of the Western Cape Province. The catchment covers 282,040 hectares (Mander, et al., 2010) and its coordinates run approximately from 23^{0}19'E to 24^{0}46'E and 33^{0}34'S to 33^{0}55'S.

The Kouga Catchment is bordered by several mountain ranges. The Tsitsikamma Mountains and Suuranys Mountains to the south and the Kouga Mountains to the north, the river runs from east to west. In the west, at Twee Rivieren, the Kouga River turns north where it is joined by the Baviaanskloof River before ending up at the Kouga Dam. The most western point is the Kouga Dam and the most eastern one is at Haarlem in the Bo Kouga. A few important places, with their location in the Kouga Catchment and their altitudes, can be found in Table 1.

Table 1 Altitudes (m.a.s.l.), and latitude and longitude in DD MM SS of important locations in the Kouga Catchment

Site	Location description	Altitude	Latitude	Longitude
Twee Rivieren	Kouga and Baviaanskloof Rivers meeting point (east)	160 m.a.s.l.	33 39 52 S	24 23 37 E
Joubertina	Centre of the Langkloof	533 m.a.s.l.	33 49 08 S	23 50 35 E
Haarlem	Westernmost town		33 43 56 S	23 18 28 E
Tsitsikamma Mountains	Mountains to the south	1675 m.a.s.l.	33 51 50 S	23 42 07 E
Kouga Mountains	Mountains to the north	1758 m.a.s.l.	33 38 18 S	23 48 07 E

Transects were done in several locations in the Kouga Catchment. Each location was at driving distance from Joubertina and location description assumes Joubertina as a center for these locations (Table 2).

Table 2 Altitudes (m.a.s.l.), latitude and longitude in DD MM SS, and number of transects of field work locations in the Kouga Catchment

Site	Location description	Altitude	Latitude	Longitude	Number of transects
Diepkloof	Tributary south of Joubertina	586 m.a.s.l.	33 51 56 S	23 50 08 E	2
Klein Rivier	Tributary near the Kouga River	392 m.a.s.l.	33 45 29 S	23 51 44 E	4
Kouga River	North east of Joubertina	224 m.a.s.l.	33 47 16 S	24 01 27 E	1
Kransfontein	Near the Kouga River, north west of Joubertina	623 m.a.s.l.	33 46 17 S	23 47 05 E	1

The land in the catchment consists of rugged parallel mountainous ridges and river valleys. The valleys are home to intensive agriculture and rivers, while surrounded by steep mountains. In general the soils are sandy, low in nutrients and well drained, with the only exception being the valley bottoms, which can be more fertile (Veerkamp, 2013). The Langkloof is the most important valley and can be found just north of the Tsitsikamma Mountains and is partially located in the Kromme Catchment.

3.2 Fieldwork

A subarea is studied to define the habitat of the black wattle. This study is used to determine the extent of the riparian zone and to confirm expectations, adjust them or formulate new ones when necessary. The calibration will be done by choosing a location and analysing several transects. Each transect is selected perpendicular to the valley bottom, normally an open water body.

The case study serves to

- Determine the area where black wattle does not suffer from water stress;
- Determine the area where black wattle does suffer water stress;

The materials used are a camera, GPS, compass, inclinometer and a checklist (Annex 1: Transect checklist**Error! Reference source not found.**). Prior to the field work an overview of the different vegetation types was made to recognize them. In the field the following steps are made per transect to achieve the wanted results:

1. A starting point is chosen. At this point the first part of the checklist is filled with the number of the transect, date, location in coordinates and words, altitude, and direction of the water stream and the transect in degrees. The GPS and compass are used here.
2. Start walking away from the water body and make a waypoint every time the slope, vegetation, black wattle density or other notable features change. Between each waypoint is a section, and of each section the following is determined
    a. The length of the section in meters
    b. The slope of the section in %
    c. The density of the black wattles, estimated by comparing tree numbers to tree sizes and looking up vertically at circa four places in each section, with the following distinctions
        i. None
        ii. Low: Lower than 40% canopy cover
        iii. Medium: Between 40 and 80% canopy cover
        iv. High: More than 80% canopy cover
    d. The state of the black wattles, with or without drought
    e. The dominant ground cover, such as bare ground or fynbos
    f. The species and density of other invasive species
3. Stop when either there are no more black wattle

3.3 Literature Review

This is an overview of the plants and vegetation types that are relevant to this study. Of the different biomes in the Kouga Catchment (Figure 2) the fynbos, renosterveld and grassland biomes are endangered by invasion from the Australian Blackwattle. The thicket biome is not invaded. The savannah and forest biome are also not known to be invaded and make up less than 1% of the catchment (Veerkamp, 2013).

First the characteristics and impacts of the *A. Mearnsii* and then the characteristics of the important indigenous vegetation types are described. Fynbos and renosterveld will be described in the same chapter.

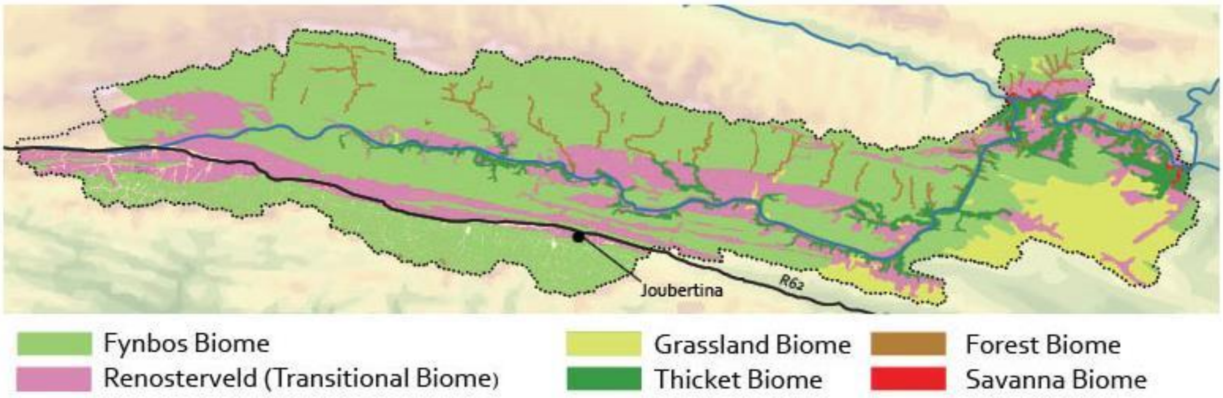

Figure 2 Overview of the different biomes in the Kouga Catchment (Veerkamp, 2013)

3.3.1 Australian Blackwattle (*A. Mearnsii*)

The Australian Blackwattle, or simply the black wattle, is a perennial tree in the *Dicot* group and in the family of the *Fabaceae*, subfamily *Mimosoideae*. The black wattle has a wide habitat and is mostly restricted by its water supply (ICRAF, sd). However in most parts of the Kouga catchment precipitation is sufficient to provide the black wattle with an opportunity to grow. The tree has yellow flowers which appear in winter. Older trees have a hard black and fissured bark (Figure 3), presumably giving the tree its common name. When growing in the wild, the stem can branch at the base of the tree and the crown has a rounded form (Midgley & Turnbull, 2003). This is different in close stands or plantations.

Figure 3 A single Australian Blackwattle that branches at the base and is flowering

The leaves have a feather form, with in the middle a rachis along which a series of leaflets (pinnae) are attached in pairs. This leads to a typical form for leaves of an Acacia species (Figure 4A & B). The rachises vary in length from 8 to 15 centimetres. Along the rachis there are 8 to 21 pairs of leaflets, which are only 2 to 5 cm long. Each of the leaflets has 20 to 70 tiny sub-leaflets. The seeds are similar to beans and are stored in pods (Figure 4C & D). The pods take about fourteen months to mature (ICRAF, sd).

In contrast to the South African acacia species, the invasive acacias do not have thorns. The *A. Mearnsii* can be distinguished from other invasive acacias by its leaves. The leaves are bipinnate, small (1.5 to 15 mm long), green and there are glands on the rachis at and between the junction of the leaflets (Coates Palgrave, 2005).

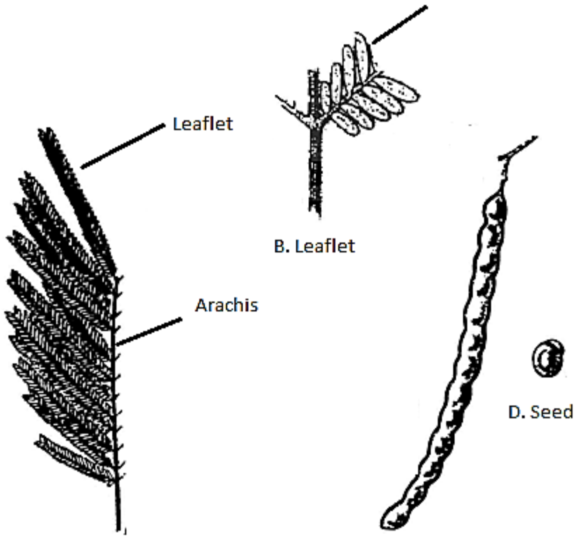

Figure 4 Sketch of the leaves and seeds of the *A. Mearnsii*

Temperatures limit the growth range as the plant cannot withstand very high temperatures that can occur in the summer period. In the first five years of growing the tree also is extremely vulnerable to frost, limiting its growth to zones free of frost. The tree has a shallow root system and transpires all year round. Therefore it cannot withstand severe droughts. Other information on the *A. Mearnsii* can be found in Table 3. The tree grows best in well-drained soils, such as sandy loam soils, where it can easily spread its roots (Prabhakaran Nair, 2010).

Table 3 Important data about the *A. Mearnsii* (ICRAF, sd)

Parameter	Values	Unit
Height range	6 to 25	metres
Maximum trunk diameter	50	centimetres
Optimum growing conditions		
Altitude	600 to 1200	metres above sea level
Rainfall	1000 to 1200	millimetres
Limits on growing conditions		
Altitude	300 to 2440	metres above sea level
Rainfall	500 to 2050	millimetres

Uses and services

The tree is widely used because of the commercial value of its services, although it is not used in the Kouga catchment. The tree can yield good fodder, fuel, fibre, timber and tannin (Midgley & Turnbull, 2003). The tree also serves well as a location for beehives, erosion control on poor and acid soils, and adding nitrogen to the soil. The *A. Mearnsii* is a plant from the *Fabaceae* family that can fix nitrogen which is then added to the soil in the form of green manure (ICRAF, sd). This is preferable in plantations and agroforestry systems, but can lead to a decrease of suitability for indigenous plants.

Impacts

The black wattle is known to displace to vegetation in the area that it invades. There are several mechanisms that give it a competitive advantage over the other plants. The most important ones are an increase in shade, decrease in water availability, allelopathy and acidification of the soil. While the usual vegetation does not reach great heights, the black wattle becomes much higher. The black wattle has a broad crown in open situations and dense foliage when they stand together. Their crown blocks out the sun to the light demanding species beneath it, outcompeting them. This results in little vegetation, reduced soil fauna and a thick layer of black wattle leaves on the ground.

The black wattle consumes more water than the normal vegetation (Dye, et al., 2001). The change in hydrology due to the high water consumption by the black wattle increases the impact on the indigenous vegetation. This in turn makes it easier for the black wattle to grow, leading to an increase in the area it occupies. This leads to even more water losses (Didham, et al., 2005).

Another impact of the black wattle, that inhibits the growth of other plants, is that the soils under black wattle trees are more acid. The soil under a black wattle plantation has a pH of 4.4 in comparison to pH 5.3 under grassland (Montgomery, 2001).

Although the allelopathic effects of *A. Mearnsii* have not been intensely investigated, Fatunbi, et al., (2009) have investigated the effect of the *A. Mearnsii* on germination of cabbage, grass (*Eragrostis curvula*) and maize. Their results showed that cabbage, a crop that is sensitive to allelopathy, was affected significantly and germination dropped between 6.7 and 46.7%, while the *Eragrostis curvula*, a grass native to South Africa, had germination reduced between 50 and 70%. The effect on maize was not found to be significant.

Figure 5 Ground covered with black wattle seeds that can quickly resprout after a fire or clearing

Other impacts are the changes in environment. The amount of the nutrients (especially nitrogen) increases, the occurrence and intensity of fires increases, and the trees destabilize river banks. An increase in nutrients decreases the suitability of the soil for indigenous vegetation (Van der Waal, 2009). Fires do already occur regularly in Mediterranean Fynbos and grassland vegetation types. However the intensity increases due to the high amount of biomass in black wattle stands. The black wattle tree also has strong seeds that sprout quickly after fires (Figure 5). The destabilization of river banks leads to soil and plant loss during floods, which can cause severe erosion at the location and sedimentation downstream.

Riparian and upland zones

The Australian Blackwattle has a wide range in rainfall requirements for its growth, from 500 to about 2000 millimetres annually (Table 3), to grow properly. This wide range in precipitation and therefore in transpiration can be compared to a range from semi-arid vegetation to tropical rainforest transpiration requirements. The rainfall between 1980 and 2009 is on average 500 mm/y at Joubertina and rises to about 700 mm/y in the upper Kouga (Veerkamp, 2013), which is at the lower border of its habitat in terms of rainfall. This means that, in terms of rainfall, the Australian Blackwattle can grow about everywhere in the catchment. However in riparian zones, the valley bottoms, the supply of water comes not only from rainfall, but also from run-off upslope. Black wattles in these places can transpire a lot more, depending on the vapour pressure deficit (VPD) and number of daylight hours (Dye, et al., 2001).

Kouga specifics

The black wattle trees in the Kouga do not differ from elsewhere. The amount of area, that they currently and potentially cover, is described in the chapter on input data for the model. There are no black wattle plantations in the Kouga Catchment. The topography and infrastructure in the Kouga can provide difficulty in clearing efforts. Large parts of the catchment are difficult to access. The rainfall varies greatly and thus the black wattle suffers regularly from drought stress outside the riparian zones. This variation in rainfall and the impact on the water use by black wattle will also be described in the modelling chapter.

3.3.2 Fynbos vegetation

Fynbos is vegetation type that consists of bushes, grasses and heathland. The name means slender forest, because the wood of the plants was too thin to be useful as building material. Fynbos can only be found in South Africa, in the south-western and southern parts of the land. The vegetation is located in areas at the coast and in mountains that have a Mediterranean climate. Fynbos is heavily dependent on fires for its high level of plant diversity (Higgins, et al., 1997).

Fynbos is part of the Cape Floral Kingdom, which is one of the six floral kingdoms in the world. It is one of the top locations in terms of biodiversity. There are around 9000 plant species in the Cape Flora area, and about 6000 of those are endemic to South Africa (Higgins, et al., 1997).

There are many large plant families in fynbos, but only the most important plant families will shortly be discussed. The *Proteaceae* family has a wide array of characteristics. In the fynbos vegetation it has 14 genera, of which the most important are the *Protea* (sugar bushes), the *Leucospermum* (pincushions) and *Leucadendron* (cone bushes) (Rourke, 2000). The family *Asteraceae* is characterized by composite flowers, which are flower heads consisting of pseudo flowers, and has around 200 genera that are endemic to southern Africa (Herman, et al., 2000). The *Restionaceae* family has 18 genera in South Africa and consists of herbaceous plants that look like grass (Archer, 2000). Other mayor families are the *Ericaceae* (heather), *Rutaceae* (citrus fruits) and *Iridaceae* (iris) families (Leistner, 2000).

Services and uses

Services of mountain fynbos can be divided into six categories (Higgins, et al., 1997). The most important service is hydrolgical, as fynbos uses relatively little of the available water, which is all the more important because of an increase in water demand in South Africa. Hydrological services also consist of supplying quality water and preventing soil erosion (Van Wilgen, et al., 1996). The impact of alien species on the hydrological services by replacing fynbos was already discussed in the introduction and the black wattle chapter.

Second, some flowers such as Rooibos and Honeybush can be used for tea production. Third and fourth are the possibilities to hike in the mountain fynbos and to attract ecotourists. Lastly endemic species are a source for the flower and herb industries, and its genetic material can be of future use. These six categories can add up to an estimated monetary value between R4.75 million and R75 million per square kilometer in the western part of the fynbos biome (Higgins, et al., 1997).

Fires and spatial variation in water use

The fynbos vegetation is often subject to fires leading to rejuvenation and causing the ecosystem to be spatially very heterogeneous (Hope, et al., 2009). Fires are expected to occur on average every 12 to 15 years between summer and autumn (Higgins, et al., 1997). The probability of fire will increase when enough biomass has accumulated meaning that young fynbos does not burn as readily as older fynbos. This also means that spatial variation in the age of the fynbos persists, leading to different percentages of ground cover, density of leaves, root depth and thus transpiration. Water usage by fynbos is therefore very variable (Hope, et al., 2009).

In areas with sufficient rainfall the fynbos vegetation can return in six months after a fire and reaches full cover in two years (van der Merwe, S. (pers. comm. 2013). Department of Agriculture. Joubertina, EC.). Fires occur more often on slopes that are facing north due to higher temperatures and less water, while the south-facing slopes are wetter and cooler. Once an area is burned most fynbos species appear again within 12 months. The diversity then decreases as almost no new species enter the area and some species die of age (Campbell & Van der Meulen, 1980).

Kouga specifics

The fynbos biome covers approximately 80% of the Kouga Catchment (Veerkamp, 2013). The exact surface cover data will be described in the chapter on land cover, as well as the rate of spread of black wattle in fynbos.

The high level of diversity in plant species and the specific climatic, geographical and hydrological properties of the Kouga valley cause that the fynbos vegetation in the Kouga valley differs from other places. Fires are just as likely to occur during the winter months as during summer months and there are no optimal times for fires in terms of fynbos rejuvenation, and lastly the fynbos recovers slightly faster in the eastern part of the fynbos biome (Powell, et al., 2009). The total area that is prone to fires is 259,606 hectares (Table 4Table 4) and can be divided into three classes (Table 4 & Table 5).

Table 4 Overview of vegetation surfaces with different fire frequencies (Powell, et al., 2009)

	Surface in hectares
Total fire prone area	259,606
Class 1	30,893
Class 2	153,687
Class 3	75,026

Table 5 Overview three fire regime classes and the time needed to become mature after a fire (Powell, et al., 2009)

	Normal fire-return intervals	Young veld	Mature veld	Old veld
Class 1	2-4	0-4	5-8	>9
Class 2	8-12	0-8	9-15	>15
Class 3	15-30	0-15	>15	-

The most general distinction in fynbos types are between lowland or coastal fynbos, mountain fynbos and renosterveld. All the fynbos in the Kouga valley can be classified as part of either mountain fynbos or renosterveld. Mountain fynbos can be distinguished from other fynbos types because of its shorter vegetation, its low shrubs and herbs, and a higher diversity in old fynbos (Campbell & Van der Meulen, 1980). Renosterbos (*Elytropappus rhinocerotis*) is the dominant plant species in renosterveld. Plants in renosterveld grow on soils that are richer in nutrients, such as valley bottoms. Renosterveld is often converted for agricultural purposes. It is possible to distinguish up to 18 different fynbos vegetation classes in the Kouga Catchment. They differ in the composition of species which mostly depends on the physical geography of the catchment (Annex 2: Vegetation information).

3.3.3 Grassland vegetation

The grassland biome mainly consists of grasses and little to no scrubs and trees. It is one of the biggest biomes in Africa and covers around 24% of South Africa (Palmer & Ainslie, 2005). Grassland is similar to fynbos in many aspects. Grassland grows on nutrient poor soils, burns regularly (Palmer & Ainslie, 2005) and is susceptible to invasion by black wattle (Dye, et al., 2001). The main differences between the two biomes are the absence of woody plants, lower biomass (Palmer & Ainslie, 2005) and lower evapotranspiration rate in grasslands (Dye, et al., 2001).

Grasslands are dominated by the *Poaceae*, also called *Gramineae*, family. Grasses occur in South Africa between sea level and 3300 m.a.s.l. and in areas with an annual rainfall from 400 to 1200 millimeters (Palmer & Ainslie, 2005).

Uses and services

The main use of grassland is for grazing (Altona, et al., 1955). Grazing is done by cattle and livestock on private land, and by wild animals on abandoned and fallow land or in the nature reserves. It is therefore not surprising that fynbos is often burned to allow grasses to sprout.

Just like fynbos the evaporation rate of grassland is normally lower than precipitation and adds to the water supply of catchment. Grasses also have potential to be cultivated and improved on, although this is not investigated in the Kouga Catchment. Grassland can also be used for tourism, such as hiking or safaris.

Kouga specifics

In the Kouga Catchment the grassland biome makes up around 8% of the surface and is found mostly in the north-eastern part of the catchment. More information is provided in the chapter on land cover. The area is very small in comparison to fynbos, but the difference in evapotranspiration between grassland and black wattle is higher. Grassland is found in the eastern part of the Kouga Catchment. Furthermore it is an important pioneer species after fires and can often be found in combination with fynbos. The two types of grassland that can be found are Suuranysberg Sour Grassland and Baviaanskloof Sweet Grassland and both can be invaded up to 80% in sixty years (Appendix: Vegetation types).

The main difference between sour and sweet grasslands is that sour grassland occurs on acid and nutrient poor soils at higher altitudes and with more rainfall (Palmer & Ainslie, 2005). The sweet grasses have a lower fibre content and can be used for grazing throughout the year. Sour grasses have a higher fibre content and are not eaten by livestock in winter (Bredenkamp, et al., 1996).

3.4 Modeling

3.4.1 Model outline

Calculations

This is a description of the concepts described earlier in the form of equations and Excel formulas.

The water consumption, as stated before, can be calculated

$$C = \frac{ET * A}{100000}$$

Where C is the water consumption in million cubic meters per year, ET in millimetres per year and A in hectares. In the model each year the surface covered by a vegetation type changes. The model is used to produce results for four different scenarios over the time period 2010 to 2050. Each scenario and their results will be described in their respective chapters.

The water consumption in year zero (2009) is used as a reference point and is calculated by the following formula

$$C_{total} = \sum_{i} \frac{ET_i * A_i}{100000}$$

Where i is a vegetation class. Each vegetation class will be described in the chapter on land cover. There are six fynbos classes, one grassland and two black wattle classes. The change in water consumption per year is calculated by

$$\Delta C_{yearly} = C_{year-1} - C_{year}$$

The difference between the reference year and a year during the time period

$$\Delta C_{cumulative} = C_{reference} - C_{year}$$

The cumulative difference is converted to a graph over the time period of 2010 to 2050. This is calculated for low, average and high rainfall years in each scenario. An overview of the input data for the model and their respective chapters are found in Table 6.

Table 6 Input data of the water model and their respective chapters

Data	Symbol	Unit	Chapter
Precipitation	P	mm	Climate
Evapotranspiration	ET	mm	Evapotranspiration
Land cover	A	ha	Land cover
Time step	Years	y	-

Excel

In this chapter the formulas as they are used in Excel are described (Table 7), as well as the variables, Excel functions and notations used (Table 8). Each formula is applied each year to present the annual change in area cover.

The first formula describes the area of a vegetation type that is invaded by the black wattle, which depends rate of spread of black wattle and on the area cleared of black wattle in that vegetation type. The second and third formulas describe the black wattle area in the landscape and the riparian zone. The next three formulas describe respectively the area of fynbos in the riparian zone, fynbos in the landscape zone and grassland, which is entirely in the landscape zone. These three areas are thus not invaded by black wattle. The three formulas after this are used to calculate the water consumption of black wattle, fynbos and grassland, which depends on the hectares and water use of each. The last formula calculates the difference between the water consumption of a year compared to the original water consumption. This will yield the amount of water lost or gained through a specific black wattle management.

Table 7 Description in words and equations of the formulas used in Excel

Description	Formula in Excel
Area invaded by black wattle vegetation class per year	$A_{veg\ class \to BW} = IF\left(A_{y-1} - \left(A_{cl} * \frac{\%_{cl}}{100}\right) + A_{gr} > \max\left(A_{veg\ class}\right); \max\left(A_{veg\ class}\right);\ A_{y-1} - \left(A_{cl} * \frac{\%_{cl}}{100}\right) + A_{gr}\right)$
Black wattle area in the riparian zone	$A_{BW\ rip} = IF(A_{FR10 \to BW} > 0;\ A_{FR10 \to BW}; 0)$
Black wattle area outside the riparian zone	$A_{BW\ landscape} = IF(A_{FL30 \to BW} + A_{FL60 \to BW} + A_{FL80 \to BW} + A_{FL120 \to BW} + A_{GL60 \to BW} > 0;\ A_{FL30 \to BW} + A_{FL60 \to BW} + A_{FL80 \to BW} + A_{FL120 \to BW} + A_{GL60 \to BW};\ 0)$
Fynbos area in the riparian zone (not invaded)	$A_{fynbos\ rip} = \max(A_{FR10}) - A_{FR10 \to BW}$
Fynbos area outside the riparian zone (not invaded)	$A_{fynbos\ landscape} = \max(A_{FL30} + A_{FL60} + A_{FL80} + A_{FL120} + A_{GL60}) - (A_{FL30 \to BW} + A_{FL60 \to BW} + A_{FL80 \to BW} + A_{FL120 \to BW} + A_{GL60 \to BW})$
Grassland area (not invaded)	$A_{grassland} = \max(A_{GL60}) - A_{GL60 \to BW}$
Water consumption by black wattle	$C_{BW} = ET_{BW} * A_{BW\ rip} + IF(\ ET_{BW} > P;\ P; ET_{BW}) * A_{BW\ landscape}$
Water consumption by fynbos	$C_{fynbos} = ET_{fynbos} * A_{fynbos\ rip} + IF\left(ET_{fynbos} > P; P;\ ET_{fynbos}\right) * A_{fynbos\ landscape}$
Water consumption by grassland	$C_{grassland} = IF\left(ET_{grassland} > P; P;\ ET_{grassland}\right) * A_{grassland}$
Change in water consumption per year	$C_{cumulative} = \left(C_{BW} + C_{fynbos} + C_{grassland}\right)_{2009} - \left(C_{BW} + C_{fynbos} + C_{grassland}\right)_{year}$

Table 8 Variables, functions in Excel and notations

	Description
Variables	
$A_{veg\ class}$	Area covered by a vegetation class in year *y*
$A_{veg\ class \rightarrow BW}$	Area of a vegetation type that is invaded by black wattle in year *y*
A_{y-1}	Area covered by black wattle the year before year *y*
A_{cl} and $\%_{cl}$	Area of black wattle cleared in that vegetation class in year *y* and percentage of black wattle clearing in that specific vegetation class
A_{gr}	Area invaded by black wattle in year *y*
$A_{FR10,\ FL30/60/80/120,\ GL60}$	Area covered by each individual vegetation classes as described in the land cover chapter
ET	Evapotranspiration
P	Precipitation
C	Water consumption
Functions	
IF()	Excel IF() function is used to ensure vegetation land cover does not drop below zero or above their maximum area (described by the Max() notation). Also used to ensure that evapotranspiration does not exceed precipitation in the landscape area
Solver	Excel Solver function is used to calculate the amount of clearing needed in scenario 1
Notation	
max()	Maximum area that can be covered by the vegetation class
$()_{year}$	Used to calculate the cumulative water consumption in a year compared to another year, normally the reference year 2009
BW	Black wattle
rip	Riparian zone
landscape	Landscape zone

3.4.1 Input data

This chapter contains and describes the data used in the water model. They concern land cover, climate, evapotranspiration and scenarios.

Land cover

The entire surface of the Kouga Catchment is 282040 hectares (Veerkamp, 2013). The area that feeds the Kouga dam also includes the Baviaanskloof which adds to a total of 388700 hectares. The surface of the Kouga can be divided into several types of land use (Table 9). The biggest area is occupied by vegetation, which can be divided into several vegetation types (Table 10).The data does not add up exactly to the 282040 hectares mentioned earlier, but old and degraded fields can be classified as vegetation as well. The difference is 5316 hectares and it is assumed that the 24550 hectares covered by vegetation is correct.

Table 9 Overview of the land use types and the area that they cover, adapted from (Mander, et al., 2010)

Land use	Hectares
Farmland	14022
Irrigated farmland	3524
Dryland and old cultivated fields	8804
Degraded fields	4146
Urban and peri-urban	693
Wetlands and water bodies	1620
Vegetation	254550
Total	**287356**

Table 10 Overview of the different vegetation types in the Kouga and the area they cover in 2010, adapted from (Veerkamp, 2013)

Vegetation	Hectares
Fynbos	155542
Transitional	51525
Grassland	23188
Thicket	22539
Savanna	498
Forest	1255
Total	**254550**

The total length of rivers and streams is 6836.2km and the perimeter of the water bodies in L82A and L82D is 104.09km (Bolhuis, 2013). In the same report these two subcatchments have 232.2 hectares of water bodies, compared to 1620 hectares of water bodies in the whole catchment (Veerkamp, 2013). It assumed that the ratio of the water surface to water perimeter in these two subcatchments applies to the whole Kouga Catchment, thus the perimeter of the water bodies is 726.2km. The total perimeter of streams, rivers and reservoirs is 14398.6km.

Australian black wattle

The Australian Blackwattle is an invasive alien plant (IAP) and is being cleared by the Working for Water program since 1994. The area cleared has steadily increased since the start of the program. Between 2002 and 2008 the program has cleared 6,455 hectares of IAP's, of which 32.8% (2,115 ha) was black wattle. In 2009 there was still 18437 hectares of condensed IAP's left to be cleared (Powell, et al., 2009). In subcatchments L82A and L82D of the Kouga Catchment 776.6 hectares of black wattle were mapped in 2010 at a density of 80% or higher (Bolhuis, 2013). These two subcatchments amount to 86001 hectares combined. Assuming that the black wattle density over the entire catchment is the same, means there are around 2547 hectares of black wattle (13.8% of all the IAP's) in the Kouga Catchment. This percentage is deemed too low and attributed to the fact that only dense stands were mapped. It is likely that the percentage of black wattle to total AIP cleared is similar to the percentage black wattle cover to total IAP cover in the Kouga in 2009. This means that 32.8% of 18437 hectares is 6047 hectares of condensed black wattle.

There are several types of fynbos and grassland types that can be invaded by black wattle and some types are more susceptible then others (Annex 2: Vegetation information). This means the time for black wattle to cover the area previously covered by that fynbos or grassland type differs. The invasion time to an 80% black wattle land cover in years was established during a workshop with various experts (Powell, M. (pers. comm. 2013). Rhodes University. Grahamstown, EC.). Combining the invasion times with the surface of each vegetation type leads to a rate of spread of the black wattle in hectares per years per vegetation type. These vegetation types can be separated into classes characterized by an invasion time to 80% and the rate at which the area of the vegetation type decreases per year (Table 11).

Table 11 Classes based on growth rates, includes the code of each class, surface that can be invaded in hectares, invasion time in years and black wattle spread rate in hectares per year

Class	Code	Surface (ha)	Years	Rate of spread (ha/y)
Fynbos - Riparian 10 yr	FR10	4025.0	10	402.5
Fynbos - Landscape 30 yr	FL30	41701.4	30	1390.0
Fynbos - Landscape 60 yr	FL60	3198.2	60	53.3
Fynbos - Landscape 80 yr	FL80	87714.0	80	1096.4
Fynbos - Landscape 120 yr	FL120	20917.8	120	174.3
Grassland -Landscape 60 yr	GL60	18550.9	60	309.2
Total		**176107.3**		

The area of the riparian zone is based on the perimeter of the water bodies and the average distance from water bodies to boundary of the riparian zone. The perimeter of the water bodies of the whole Kouga is adjusted to the size of the invaded riparian vegetation zone, and the horizontal distance covered by the riparian from a water body is a result of the fieldwork performed for this research. This means that the riparian zone in the fynbos area is 4024 hectares (Table 11).

Climate

Here the relevant weather data is described. Data of importance to this research are precipitation, relative humidity, temperature, day length and solar radiation.

Precipitation

Rainfall is the only source of water in the Kouga Catchment. In general it can be said that rainfall increase from the south to the north, and from the west to the east of the Kouga (Markham, 2011). Annual rainfall in the Tsitsikamma Mountains varies between 800 and 1000 mm. In the Langkloof the rainfall declines from 700 mm in the west to around 500 mm at Joubertina in the east. In the mountains to the north, rainfall can be between 800 mm at the peaks and 400 mm in the valleys.

Rainfall data from the weather station near Joubertina was used (Lynch, 2003) and (SAWS, 2012), as this was the station with the most recent and continuous data available. Just after 1980 the annual rainfall abruptly decreased (Annex 3: Rainfall data from Joubertina & Figure 6) and dropped to below an average rainfall of 500 mm for the last 30 years (Table 12 & Figure 7).

Table 12 Average, minimum and maximum precipitation in Joubertina in approximately the last 30 years, 1983-2009

Rainfall in Kouga Catchment	Precipitation (mm/y)
Average	474.0
Min	224.1
Max	785.7

It may seem like Joubertina is a location with lower rainfall then most other locations of the Kouga. However, the valleys with low rainfall cover the largest surface in the Kouga. Locations with higher rainfall, such as parts of the Langkloof, are used for orchards and intensive agriculture. Therefore this dataset appears to be a reasonable average of the area that is of interest for this research.

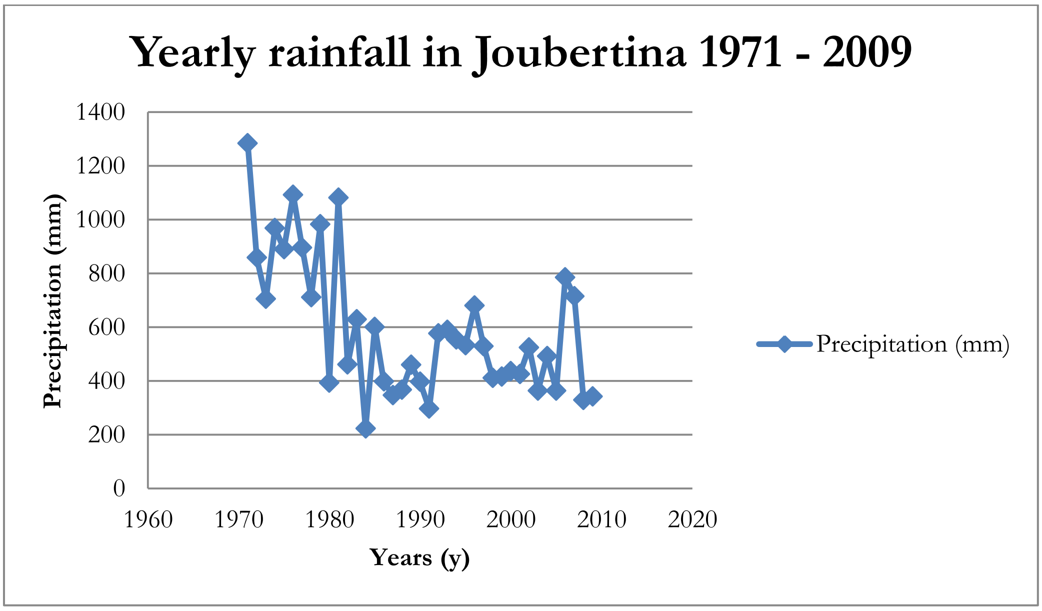

Figure 6 Yearly rainfall around Joubertina, Kouga Catchment, between 1971 and 2009

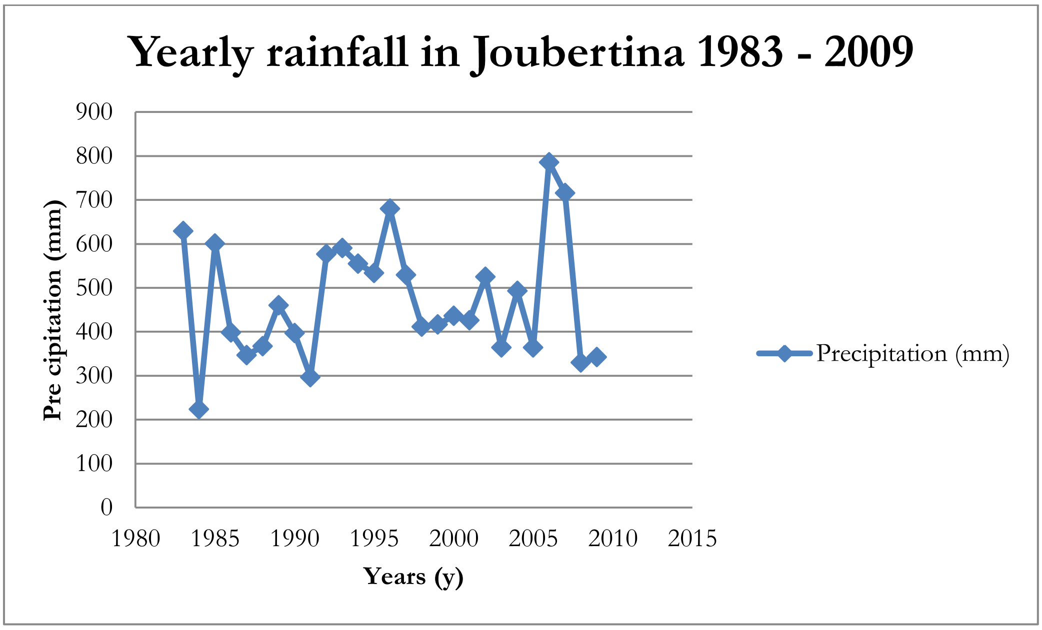

Figure 7 Annual precipitation in Joubertina between 1983 and 2009

Other data

This section shortly describes the average annual values of the relative humidity, temperature, day length, solar radiation and evapotranspiration in the Kouga Catchment (Table 13). The values of relative humidity and day length times were measured in the Dennehoek, just south of Joubertina, between 1979 and 1988 (Lynch, 2003). Temperature was measured over the period of 1971 to 2000 at Joubertina (Schulze & Maharaj, 2003). Lastly solar radiation averages annually around 2200 kWh m^{-2} y^{-1} (Huld, et al., 2005) and the evaporation measured in an A class pan between 1983 and 2002 in the Langkloof averages 1562.1 mm/y (DWAF, sd).

Table 13 Values of weather variables in the Kouga Catchment

Weather variable	Value	Unit
Temperature	19.0	C
Relative Humidity	63.6	%
Sunshine hours	6.7	h/d
Solar radiation	2200.0	kWh m^{-2} y^{-1}
Evaporation in an A class pan	1562.1	mm/y

Evapotranspiration

The evapotranspiration (ET) of the black wattle can be calculated specifically for the Kouga Catchment. The potential evapotranspiration depends on several factors and the actual evapotranspiration on the water available to the plants. It is assumed that plants in riparian zones have an unlimited water supply, while in landscape zones the evapotranspiration is limited to the water supplied by yearly rainfall. The implications of that last statement will be further discussed in the discussion chapter. The calculations for the ET of fynbos and grassland are discussed after the Australian Blackwattle.

Australian Blackwattle

The formula for the ET of black wattle is as follows (Dye, et al., 2001)

$$Total\ plot\ sap\ flow\ (mm * d^{-1}) = \frac{7.9738 * X}{11.4287 + X}$$

Where X is equal to $Mean\ daily\ VPD\ (kPa) * number\ of\ daylight\ hours$ and total plot sap flow is equal to the transpiration. The mean daily vapour pressure deficit (VPD) is calculated by the following formulas

$$VPD = \left(100 - \frac{RH}{100}\right) * SVP$$

$$SVP = 610.7 * 10^{7.5 * \frac{T}{237.3 + T}}$$

Where T is the temperature in Celsius degrees, RH is the relative humidity in % and SVP is the saturated vapour pressure in Pascals. The yearly average temperature, relative humidity and number of daylight hours are already discussed in the chapter on climate. The value of the VPD is adjusted from Pascals to kilo Pascals. Taking these values and inserting them in the formulas leads to an average transpiration of 926.4 mm/y. Adding the average interception by the black wattles of 185 mm/y leads to an average ET of 1111.4 mm/y by black wattles in the Kouga Catchment (Table 14). This is the evapotranspiration if there is enough water available.

Table 14 Evapotranspiration data for the Australian Blackwattle

Variable	Value	Unit
Temperature	19.0	^{0}C
Relative Humidity	63.6	%
Sunshine hours	6.7	h/d
Interception by black wattle	185	mm/y
Saturated Vapour Pressure	2196.9	Pa
Vapour Pressure Deficit	798.9	Pa
	0.799	kPa
X	5.337	kPa*h/d
Transpiration	2.538	mm/d
	926.4	mm/y
Evapotranspiration of Australian Blackwattle	1111.4	mm/y

Fynbos

The only formula for the evapotranspiration of fynbos has solar radiation as input (Dye, et al., 2001).

$$\text{ET} = 0.2501 * \text{Solar radiation } (\text{MJ} * \text{m}^{-2} * d^{-1}) + 0.2103$$

This formula however does not yield reliable results, as the average annual evapotranspiration would be 2057.6 mm per year. Therefore a relation is assumed between the potential evapotranspiration of black wattle and fynbos. The evapotranspiration of the black wattle has already been adjusted to the Kouga Catchment. The ratio, based on Dye et al. (2001), would be

$$\frac{ET\ of\ black\ wattle}{ET\ of\ fynbos} = 1.128$$

In this case the average annual evapotranspiration of fynbos is 985.0 mm/y. Another way to calculate the evapotranspiration is multiplying the vegetation factor of fynbos and the reference evapotranspiration (ET_0) of the Kouga Catchment. To calculate the ET_0 from an A class evaporation pan the following formula applies (Allen, et al., 1998)

$$ET_0 = K_p * E_{pan}$$

where K_p is the pan coefficient and E_{pan} the evaporation from pan. The pan coefficient is approximately 0.7 based on the surroundings of the pan at the experimental farm and the pan evaporation was presented in the climate chapter. The ET_0 would become 1093.5 mm/y. The vegetation factor of Atlantis Sand Plain Fynbos is 0.69 (Bugan, et al., 2011). Thus the potential evapotranspiration would be 754.5 mm/y for fynbos. Because the actual potential evapotranspiration is uncertain the average of 985.0 and 754.5 mm/y is used to obtain an evapotranspiration of 870 mm/y for the fynbos vegetation.

Grassland

A similar formula as the fynbos is provided for grassland (Dye, et al., 2001)

$$\text{ET} = 0.2302 * \text{Solar radiation } (\text{MJ} * \text{m}^{-2} * d^{-1}) - 0.7129$$

The relation between daily solar radiation and daily ET for differs per period of the year. During the period of October to May the evapotranspiration is at its maximum while during the rest of the year the evapotranspiration is around 10%. This means that combining the eight months with a high ET and four months with 10% of this ET the average potential annual ET is 1094.1 mm/y. This is a very high number for grassland compared to precipitation. A similar ratio, based on Dye et al. (2001), can be applied

$$\frac{ET\ of\ black\ wattle}{ET\ of\ grassland} = 1.507$$

This results in an average annual evapotranspiration of grassland of 737.4 mm/y. For comparison the method using reference ET and vegetation factors is used as described in earlier in the chapter on fynbos ET. There is an active season of eight months of which ten days are the initial stage and a dormant season of four months. The vegetation factor differs for each of these three stages, being 0.75, 0.3 and 0.1 respectively (Allen, et al., 1998). The average vegetation factor is 0.52 and the annual evapotranspiration is 572.9 mm/y. The average evapotranspiration is then 653.1 mm/y.

3.4.3 Scenarios

There are four different scenarios that will be discussed. The scenarios are 1) the Kouga Catchment is entirely cleared of black wattles by 2050, 2) there is no clearing done at all between 2010 and 2050, 3) a gradual increase in clearing activities over the years, and 4) only the riparian zones are cleared of black wattle each year. Each scenario is divided in the possibility of a high and low rainfall year, or average rainfall.

The first scenario yields the best result in 40 years. The Australian Blackwattle is completely eradicated by 2050. The yearly clearing activities in each vegetation class total 3589.3 hectares (Table 15). After 2050 the clearing activities should be focussed on suppressing new invasions and the total clearing activities will be equal or less than the rate of spread of black wattle, which can be found in Chapter Surfaces.

Table 15 Yearly clearing activities necessary to reach zero percent cover of black wattle by 2050

Class	Clearing done as % of total clearing	Clearing done in hectares
FR10	15.6	405.9
FL30	37.7	1425.0
FL60	1.5	56.0
FL80	31.4	1169.9
FL120	5.1	191.8
GL60	8.8	324.7
Total	100.0	**3573.3**

In the second scenario no black wattle is removed at all, zero hectares are cleared, and the black wattle thus spreads at its maximum rate.

The third scenario involves an increase in yearly clearing activities. At this moment the Working for Water programme is aiming to increase clearing yearly (Koyo, V. (pers. comm. 2013). Working for Water Manager in the Kouga, Joubertina, EC.). This scenario assumes that in 2001 zero hectares were cleared and since then hectares cleared each year have increased gradually. The increase is based on the 2114.5 hectares cleared in total between 2002 and 2008 as stated in the chapter on land cover. This means that 604 hectares were cleared in 2009 and each year 75.6 hectares extra are cleared, thus 680 hectares were cleared in 2010 and 3626 hectares in 2050. The percentages of clearing in each vegetation class are adjusted to avoid negative quantities of black wattle cover in a vegetation class.

The fourth scenario assumes that the same clearing is done as in 2009 and no further efforts are made. Thus throughout the period 2010-2050 the yearly clearing is 604 hectares.

4 Results

Fieldwork

The fieldwork resulted in 42 sections of which 31 were started at a water body (Annex 4: Fieldwork results). The black wattle density was correlated with both horizontal and vertical (height) distance from the water body, and with the slope to the nearest water body. The black wattle density was divided in low, medium and high density, as described in the fieldwork chapter. The standard deviation of the mean was calculated in Excel using the formula below and compared to the mean (Table 16).

$$STD_{mean} = \frac{1}{\sqrt{n}} * \sqrt{\frac{\sum(x-\bar{x})^2}{(n-1)}}$$

The average of both vertical and horizontal showed very high deviation (Table 16). However, the highest density was found close to the water in both the horizontal and vertical sense. On average the black wattle density decreased with increasing slope, but the standard deviation was very high as well (Table 17).

Table 16 Overview of density classes, average distance per density class in meters, as well as the standard deviation of the mean

Density class	Mean distance (m)	STD of the mean (m)
Horizontal distance		
None	54.3	14.9
Low	48.3	26.7
Medium	52.7	11.4
High	17.2	7.8
Vertical distance		
None	8.05	2.47
Low	4.65	1.83
Medium	7.38	2.08
High	1.93	1.07

Table 17 Overview of density classes, average slope per density class in % and radians, as well as the standard deviation of the mean

Density class	Mean slope (%)	Mean slope (radians)	STD of the mean (radians)
None	32.3	0.284	0.125
Low	26.7	0.247	0.063
Medium	18.0	0.171	0.053
High	10.6	0.104	0.036

During field work some indications of possible drought stress on the black wattle were observed and noted. There were three types of stress signs; the first was the change of colour on the leaves, the change in form of the leaves, and finally the absence of leaves or leaflets.

In some trees the leaflets were not green, but instead brown, white, yellow or grey. Also some leaves were found with red or brown glands, instead of light green ones. When black wattle experiences drought, then the leaves start to fold. Many black wattles also had some or many leaflets missing, which could also be due to mammals or insects. However, it was not possible to recognize whole patches with similar signs of stress. Each time one of these signs was found in a plant, the surrounding plants were also searched.

Modeling

As rainfall is less than potential crop evapotranspiration, and actual evapotranspiration is set to rainfall, the fynbos and black wattle both have the same actual ET in low, average and high rainfall years, while grassland has a lower actual ET than rainfall in high rainfall years (Table 18). This results in low and average rainfall years having the same reduction or increase in water availability. Also invasion of black wattle in grassland is the prime reason for reduction in water outflow in the landscape zone. The low and average rainfall years are visualized in the graphs by the same markers, because the impact on quantitative water consumption does not differ for years with minimum and average rainfall years.

Table 18 Precipitation and evapotranspiration of the vegetation types in and outside the riparian for minimum, average and maximum rainfall

	Precipitation	ET Blackwattle		ET Fynbos		ET Grassland
	mm/y	riparian	landscape	riparian	landscape	landscape
Minimum rainfall	224.1	1111.4	224.1	869.9	224.1	224.1
Average rainfall	474.0	1111.4	474.0	869.9	474.0	474.0
Maximum rainfall	785.7	1111.4	785.7	869.9	785.7	653.1

The addition of water flow from the Kouga saved by clearing the black wattle between 2010 and 2050 would be 332992 m^3/y in low and average rainfall years and up to 1177902 m^3/y in high rainfall years (Figure 8). The amount of yearly clearing needed is 3573 hectares per year in total divided over clearing in each vegetation class. The percentage of total yearly clearing done is 11.4% in FR10, 39.9% in FL30, 1.6% in FL60, 32.7% in FL80, 5.4% in FL120 and 9.1% in GL60.

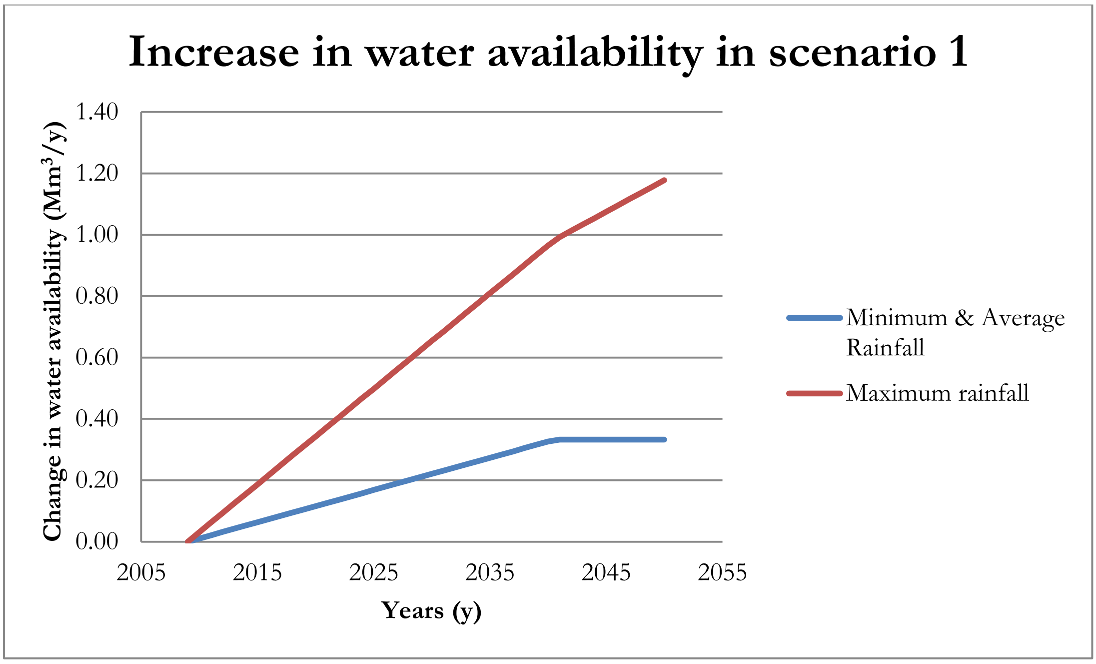

Figure 8 The change in water yield is positive in scenario 1

In scenario 2 water availability in 40 years decreases by a maximum of 26179117 m^3/y and a minimum of 9364754 m^3/y (Figure 9). In this scenario no clearing was assumed in the Kouga between 2010 and 2050. By 2019 the FR10 class is maximally invaded by black wattle and by 2038 the FL30 is also fully invaded. The other vegetation classes are not fully invaded yet by 2050.

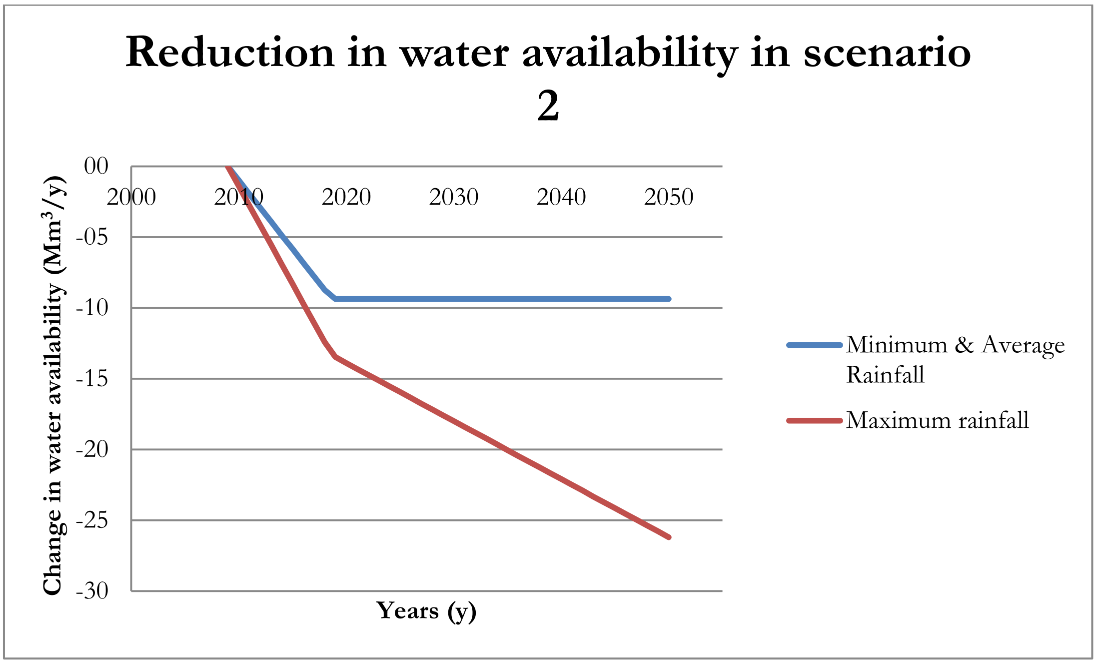

Figure 9 The yearly water availability by 2050 in the second scenario is highly decreased

Scenario 3 assumes a gradual increase in clearing activities which means that by 2050 outflow is still reduced with 1207796 m^3/y if it is a low or average rainfall year and 9107339 m^3/y in case of high rainfall (Figure 10). The greatest decrease in rainfall would occur between 2030 and 2035.

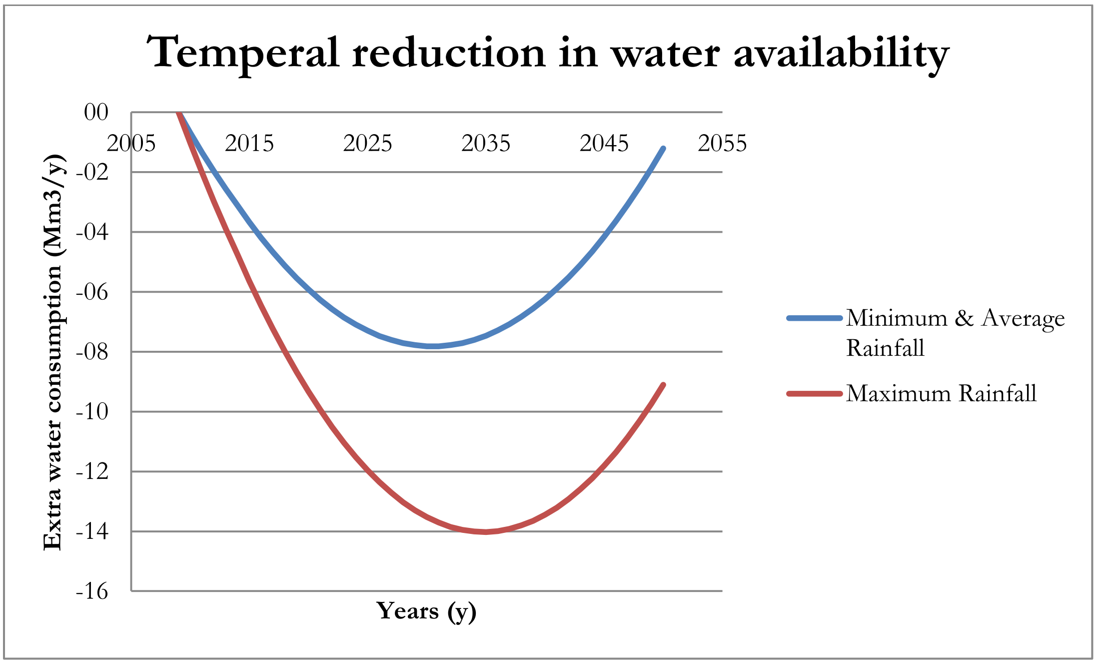

Figure 10 Change in yield over the years in scenario 3

The greatest yield loss of 14 Mm^3/y would be experienced in 2035 if it were a high rainfall year. The low and average rainfall years have a minimum yield around 7.8 Mm^3/y between 2029 and 2032. Clearing is done every year with the same percentage of the total. The percentages are 19% in FR10, 45% in FL30, 2% in FL60, 21% in FL80, 5% in FL120 and 8% in GL60. By 2050 the black wattle in FR10 is almost entirely cleared with 638 hectares remaining. The classes FL30 and FL80 are still the most heavily invaded, with 20632 and 30323 hectares in 2050 respectively.

Of the 604 hectares that are cleared yearly in the fourth scenario 67% is done in FR10 and the other 33% in GL60. In 2050 the entire riparian zone is cleared and the spread of black wattle in GL60 is only 39% of the normal spread rate. The yearly water yield increases by 332992 Mm^3/y in 2050 if it were a low or average rainfall year, and decreases by 5634473 Mm^3/y in a high rainfall year (Figure 11).

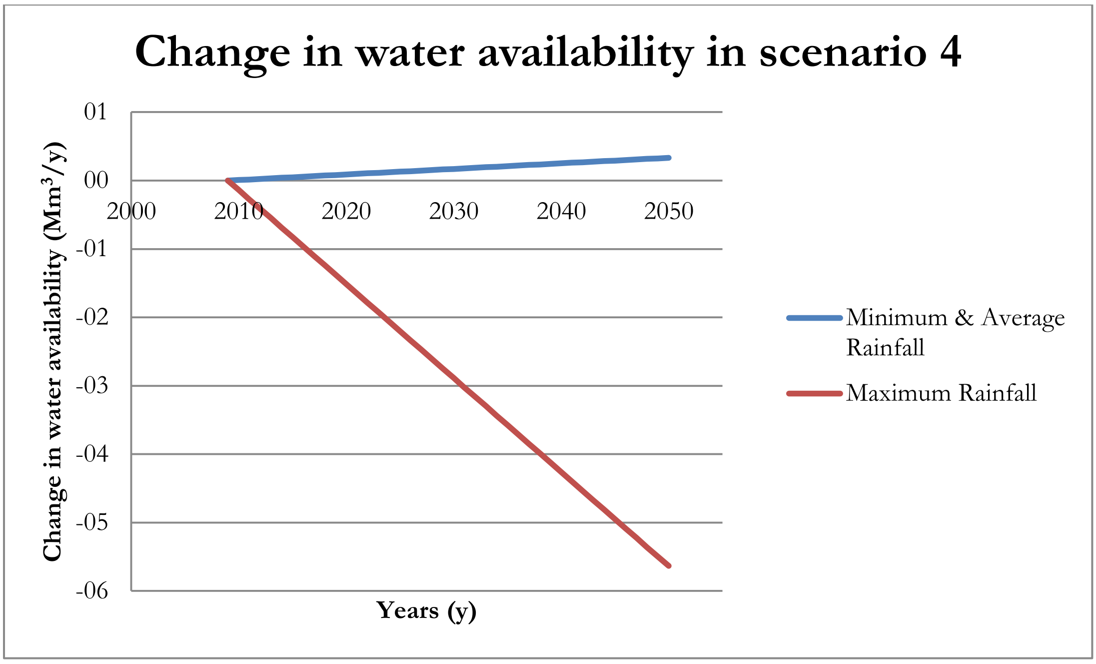

Figure 11 Clearing done in the right locations in scenario 4 decreases the impact of black wattle on the water availability

The Kouga River provides between 125 and 135 Mm^3/y to the Kouga Dam Reservoir (Jansen, 2008). The variation in water supply is assumed to depend on variation in precipitation. The gains and losses in water availability as shown in scenario 1 and 2 can be viewed as a percentage of the water supplied by the Kouga to the Kouga Dam (Table 19).

Table 19 Percentage of change to the Kouga River outflow depending on black wattle management

	Kouga River outflow	Change in outflow	
	Mm^3/y	Mm^3/y	%
Scenario 1			
Minimum rainfall	125	0.33	0.26
Maximum rainfall	135	1.17	0.87
Scenario 2			
Minimum rainfall	125	-9.36	-7.5
Maximum rainfall	135	-26.18	-19.4

5 Discussion

Fieldwork

The relation between distance from a water body and the tree density is not linear like the relation between the slope and tree density. The density classes of no black wattle, and low and medium density occur over an average horizontal distance from the water body of around 50 meters and average vertical distance of 5 to 8 meters. The average distance in both the horizontal and vertical direction of the high density class is a lot lower. The variation is very high in all density classes. Since no literature could be found on the extent of the riparian zone in the Kouga Catchment, a horizontal distance of 17.2 meters will be used as the average distance from a water body to the average boundary of the riparian zone. This is based on the assumption that the density of black wattles is the highest in riparian zones. This number could be improved by doing more transects in other different parts of the Kouga Catchment.

This assumption also provides an alternative to an idea that was proposed earlier. Part of the field work was aimed at recognizing water stress. This was expected to yield an average distance from a water body at which point the black wattle trees start experiencing drought signs. As mentioned in the results, this proved to be more complex than anticipated. Performing a similar study in a dry year or using soil moisture measurements, would yield more reliable results. Due to the size and variation with the Kouga, such research would need to be extensive.

Horizontal distance is preferred over vertical distance as it is easier in the model calculations and the horizontal distance in the high density class has a lower deviation. Lastly, the relation between the mean slope per density class and the density class is not used in the model, but will be shortly discussed below.

This relation is linear and one can expect a higher black wattle density in flatter areas. Therefore it can be interesting for further research. However, the variation in slopes is enormous, around the same as the average slope. This means that no final conclusions can be made regarding this relation. Also, while the slope measurements are fairly accurate, the density measurements were less so. Also the density classes are very wide, which could not be prevented easily. To take smaller ranges for density classes would require better canopy cover measurement equipment. Finally the calculations for average slope also take into account small sections (21sections are 10 meters long or less, of which 6 sections are 5 meters long or less). Ignoring these in the calculations does not change the relation by much; it only makes the deviation slightly larger. This could be remedied by doing more transects, with longer continuous sections.

Field research provided this thesis with results on the relation between black wattle density and slope, and horizontal and vertical distances to a water body. The horizontal distance was used in the model, since it is the best applicable in Excel. However, with water availability changing between dry and wet years, as well as overall in the long term, the extent of the riparian zone will change as well. The great variability means that the 17.2 meters cannot be applied in the field and it should only be used as an average.

Modeling

Firstly, as has already been stated this model is quite a simple one and not all subtleties, such as variation in rainfall and soil types, are captured. Secondly the input data, as it is used, are very rough. This mostly reflected in the fact that the time step is a year, therefore rainfall and evapotranspiration are generalized, and the rate of spread of black wattle in vegetation classes is linear in time with no consideration for location. There is no interaction between vegetation classes or between upstream and downstream locations.

There is also uncertainty about the evapotranspiration of fynbos and grassland, and about the drought stress after which plants have to recover. The evapotranspiration in this model does not differentiate between total available water and readily available water, and thus no water stress coefficient and water storage is used. It is not realistic that all rain is captured and used by the plants and not every surface is always covered. The evapotranspiration of both grassland and fynbos in other research is around the level of average rainfall. The calculations in this research, however, provide evapotranspiration rates that are significantly higher than the average rainfall. The ET in the landscape zone is in reality lower than the rainfall, but it is uncertain by how much. The difference in actual evapotranspiration between black wattle and the indigenous vegetation will thus be dependent on other factors, such as root depth, ground cover and interception.

The high evapotranspiration of both black wattle, and fynbos and grassland has led to little variability in the landscape zone. Only the grassland landscape zone uses less water in high rainfall years then the other two. Therefore the determining factors are the cover of black wattle in the riparian zone and in the grassland vegetation.

When comparing scenario 1 and 2 it becomes clear that some water can be saved by clearing the black wattle. The real difference however can be made by preventing the spread of black wattle into the rest of the vegetation. In scenario 2 it becomes clear that a significant decrease of water yield will happen when the black wattle is not cleared. The current increase that can be gotten in yield is only 3.56% to 4.50% of the decrease in yield that would yearly occur by 2050 through the invasion of black wattle. Thus to most important reason to continue clearing is to prevent great future losses of water.

In scenario 3 and 4 the hectares cleared in the first year are the same. In scenario 3 the amount of clearing increases each year, but by 2050 the water availability is less than in scenario 4. This shows that water can efficiently be saved by clearing in the right places. However, increasing clearing beyond what is necessary to maximize the water availability will increase the stability of the whole ecosystem and prevent great conversions of indigenous vegetation to an invasive one.

The results of the model show that currently water can be saved by clearing Australian Blackwattle trees from the riparian zones and grassland zones. This amount however is low in comparison to the potential losses if black wattle spreading is not controlled. The change in water consumption that the black wattle can cause in the fynbos landscape zones is unclear. This is because the potential evapotranspiration of both the fynbos and the black wattle is above the maximum rainfall in the region. The variation of fynbos density and type, rainfall and soil type would provide more variation in the results and increase the accuracy of the generated numbers.

There are a few other factors that have not been described or discussed before, but are relevant to the water availability. The climate change that is happening all over the world will also affect the Kouga Catchment. There is a risk that rain events will become more erratic and intense, which will decrease the base flow. Another point of interest is that areas cleared of black wattle are often used by farmers for agriculture. Especially in riparian zones this can negate the water saving attribute of clearing black wattle. The water is used economically, but downstream water users would not profit.

6 Conclusions and Recommendations

The main question will be answered first, which is

How would the water balance in the Kouga Valley be differently affected by various levels of invasiveness of the Australian Blackwattle?

It can be concluded that the water balance in the Kouga Catchment is negatively affected by an increase of Australian Blackwattle in the catchment. The areas most strongly affected by invasion of black wattle are the fynbos riparian and grassland zones. The literature review strongly suggests that the black wattle affects the water balance in the fynbos landscape zones too, as well as having indirect effects on the eco-hydrology of the catchment. However, due to the limitations of the model it was not possible to accurately represent these differences.

Not only does a change in water flow affect the water reserves in the Kouga Dam, but also the local reservoirs that can be found throughout the Kouga. Reservoirs often rely on years with high rainfall to refill to provide an adequate water supply during dry years. Black wattle upstream of reservoirs can severely decrease the water supply and thus threaten farming practices.

The effect of the black wattle, as an invasive alien species, on the change in water flow has already been researched in South Africa. Thus this thesis does not present an original discovery. It does however (1) create more awareness among water users in and downstream of the Kouga about the impact of the black wattle, (2) contribute to the knowing what the extent of water lost through alien invasive species is and (3) instigate new research on the black wattle in the Kouga Catchment.

Awareness is created by a news article that is distributed to farmers in the Kouga and to those downstream of the Kouga Dam, and a policy factsheet that is handed to policy makers and land and water managers in the Kouga and the organization of the Working for Water program. Both the article and the policy factsheet contain the results and recommendations of this research.

The results of this thesis support the earlier claims that downstream water users can benefit from properly applied alien invasive species management upstream. This can encourage a system where land owners are rewarded for providing water from their land. To implement such a system, the outflow from plots has to be measured in a reliable and simple way.

To aide future modeling actions in the Kouga Catchment research on the evapotranspiration rates of the most important vegetation types should be performed. The most notable vegetation types would be Mesic, Arid and grassy fynbos and renosterveld. Not only would the results from such research add subtlety to modeling, but it would also add to the knowledge body of fynbos evapotranspiration, which has been focused on the Western Cape. Future modeling should combine the prediction of land cover change in time, a geo-information program and accurate water use data. To aid defining the potential spread of black wattle it is interesting to investigate is the relation between the slope and the black wattle density.

Other potential research can be done on quantifying the spread of black wattle in vectors. This should combine variables such as black wattle age, seedbank size, location, water streams, et cetera. This will aid the allocation of clearing activities, since the Kouga Catchment has a rugged terrain and areas that are difficult to reach.

The situation of water supply and demand is dependent on a range of factors. There are many factors such as the price of water, the efficiency of water transport and water use, the valuation of ecosystems among others. One of the important factors is the water consumption of black wattle and the effort put into restoring the landscape to its former health. By doing this the services provided by the Kouga ecosystem will certainly improve.

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7.1 Personal communication

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8 Annexes

Annex 1: Transect checklist

General information

Transect number		
Date (ddmmyyyy)		
Location in coordinates	Latitude	
	Longitude	
Location in words		
Altitude		
Direction of the water flow in degrees		
Direction of the transect in degrees		

Section list

Section	Distance	Slope	Black wattles		Dominant ground cover	Other invasive species	
	meters	%	Density	State	Type	Type	Nr.
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							

Annex 2: Vegetation information

Table 20 Vegetation types, their surface in hectares and percentage of the whole Kouga Catchment and the time necessary for the black wattle to reach 80% canopy cover in each vegetation type, based on (Veerkamp, 2013) & (Powell, et al., 2009)

Vegetation type	Hectares	Percentage of the Kouga Catchment	Invasion time by Australian Blackwattle
Kouga Mesic Fynbos	55636.4	19.7	30 years (riparian zone 10 years)
Kouga Subalpine Fynbos	2542.7	0.9	
Kouga Arid Fynbos	26147.2	9.3	120 years
Kouga Restioid Fynbos	937	0.3	
Tsitsikamma Subalpine Fynbos	43.5	0.0	
Tsitiskamma Ericaceous Fynbos	3934.8	1.4	
Kouga Mesic Proteoid Fynbos	1521.6	0.5	30 years (riparian zone 10 years)
Kouga Grassy fynbos	48284.1	17.1	80 years
Elandsberg Grassy fynbos	117.6	0.0	60 years
Langkloof Grassy fynbos	9221.3	3.3	80 years
Langkloof Waboombeld	7156.2	2.5	80 years
Fynbos total	**207067.4**	**55.1**	
Baviaanskloof Sandolienveld	16216.8	5.7	80 years
Gamtoos Fynbos woodland	1427.9	0.5	60 years
Langkloof Renosterveld	11939.3	4.2	80 years
Langkloof Bontveld	2452.3	0.9	60 years
Baviaanskloof Renoster Sandolienveld	11464.6	4.1	80 years
Kouga Renoster Sandolienvend	5360.2	1.9	80 years
Haarlem Fynbos renosterveld	2663.9	0.9	
Transitional total	**51525**	**18.3**	
Suuranysberg Sour Grassland	21474.8	7.6	60 years
Baviaanskloof Sweet Grassland	1713.8	0.6	60 years
Grassland total	**23188.6**	8.2	

Annex 3: Rainfall data from Joubertina

Table 21 Rainfall data from Joubertina between 1971 and 2009

Years	Precipitation (mm)
1971	1284.4
1972	859.2
1973	705.5
1974	968.4
1975	890.8
1976	1092.6
1977	896.3
1978	712.3
1979	982.6
1980	394
1981	1081.8
1982	461.3
1983	629.1
1984	224.1
1985	601.1
1986	398.5
1987	347
1988	367.2
1989	460.7
1990	397.1
1991	297
1992	576.8
1993	590.4
1994	554.8
1995	533.6
1996	680.3
1997	529.6
1998	411.7
1999	416.5
2000	436.2
2001	426.2
2002	525.2
2003	364.1
2004	493
2005	364.6
2006	785.7
2007	715.8
2008	330
2009	342.4

Annex 4: Fieldwork results

Table 22 Results of the transects made during field work, the sections marked with an asterisk (*) were in a transect that not started at a water body

Transect section	Section length (m)	Slope (%)	Slope (radians)	Density class
1	8	5	0.05	low
2	7.7	33	0.32	low
3	13.8	1	0.01	medium
4	8	48	0.45	medium
5	21	5	0.05	medium
6	9	36	0.35	medium
7	13	1	0.01	medium
8	13	1	0.01	none
9	13	1	0.01	none
10	30	1	0.01	medium
11	69	1	0.01	low
12*	5	3	0.03	high
13*	6.5	2	0.02	high
14*	6.5	2	0.02	high
15*	9.5	2	0.02	high
16*	28	3	0.03	low
17	5	1.5	0.01	low
18	4.5	16	0.16	high
19	6	16	0.16	medium
20	4.7	12	0.12	high
21	5.6	32	0.31	medium
22	7.5	0	0.00	low
23	3.7	30	0.29	high
24	9.2	2	0.02	high
25	9.3	5	0.05	medium
26	17	65	0.58	low
27*	22	9	0.09	medium
28*	23	15	0.15	low
29*	27	34	0.33	low
30*	30	45	0.42	low
31*	36	64	0.57	low
32*	37	63	0.56	low
33	15	8	0.08	high
34	6	50	0.46	none
35	20	90	0.73	none
36	12	3	0.03	high
37	8	4	0.04	none
38	18.5	5	0.05	medium
39	14.3	18	0.18	low
40	1.6	48	0.45	none
41	10	37	0.35	high
42	33	57	0.52	medium