Estimating the threat of water scarcity in the Breede River Valley: a forecast-based analysis

Final Year Project Report

A final year project report submitted in partial fulfilment of the degree of BEng Industrial Engineering
with the supervision of Tanya Visser.

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I would like to thank Tanya for her guidance, insights and patience. Thank you for understanding that I needed to ask a lot of questions. Without you this project would not have been possible.

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I would like to thank my mother for her belief in me, her encouragement and unconditional love. You give me tremendous strength.

Declaration

I, the undersigned, hereby declare that the work contained in this final year project is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Ek, die ondergetekende verklaar hiermee dat die werk wat in hierdie finalejaar projek vervat word, my eie oorspronklike werk is en dat ek dit nog nie vantevore in die geheel of gedeeltelik by enige universiteit ter verkryging van ‘n graad voorgelê het nie.

Signature

Date

ECSA Exit Level Outcomes Reference

	Outcomes	Proof of compliance
1.	Problem Solving	• The research problem was identified (Chapter 1) and further explored in Chapter 3 by means of a literature study. • Data was collected and analysed to confirm the problem hypothesis and to satisfy the research objective (Chapter 4). Further insight into the problem is demonstrated in Chapter 5 where potential solutions to the problem are proposed and discussed.
5.	Engineering methods, skills and tools, including Information Technology	• Engineering methods, like multiple regression analysis, and information technology tools, like Minitab and Microsoft Excel, were in used Chapter 4 to do the multiple regression analysis and forecasting. • The ability to use engineering methods, tools and skills was demonstrated throughout the whole report.
6.	Professional and technical communication	• The student demonstrates this throughout the whole report.
9.	Independent learning ability	• The majority of the statistics that was used in this project was previously unknown to the student. Statistical analysis tools and various statistical tests were studied independently by the student in order to be able to complete this project. • The statistical software (Minitab & Excel's data analysis tool) that was used was also unknown to the student prior to this study.
10.	Engineering professionalism	• Engineering professionalism was demonstrated by the student throughout completion of the entire project. • It was demonstrated especially in Chapter 5.3 and 5.4 when the student realised that the analysis required (to prove that the proposed solution is feasible) lies beyond the scope of the project and the student's knowledge. The student undertook further studies. • The findings of this project (especially that of Chapter 4) were presented at the ORRSA conference. The conference was attended by a broad spectrum of people and the presentation and paper were both accepted well.

Summary

Water is a scarce resource in South Africa and especially in the Western Cape. It is, therefore, vital to manage it properly. There are a number of factors that make the task of managing water difficult. Climate change is one of these factors. It cannot be controlled and holds much uncertainty. In order to provide information for managers to plan water supply and demand in the in the Breede Water Management Area (WMA) effectively, the objective of this study is to forecast possible high, normal and low water demand and supply scenarios (Chapter 4). Furthermore this study will inform managers on the extent of the threat of the expected water scarcity occurring in the Breede River Valley through the scenarios.

It was seen that all scenarios indicate shortfalls within the forecasting period of 20 years. In the best case scenario, which is already severe, water shortages will occur 12 years from now. In the worst case scenario water shortages will occur within 6 years from now. These results show that planners and developers are afforded a lead time of approximately 6 years to affect the required interventions.

One possible solution involves building dams in the mountain ranges to exploit the catchment areas. The idea is that gravity fed water will be supplied to farmers from these dams – nullifying the necessity to draw irrigation water from the Breede River. It is recommended that further studies must be done to determine the feasibility and the environmental impact of interventions to reduce the expected water scarcity in the Breede River Valley.

Opsomming

Water is 'n skaars hulpbron in Suid-Afrika en veral in die Wes-Kaap, daarom is dit noodsaaklik om dit behoorlik te bestuur. Daar is 'n aantal faktore, soos klimaatsverandering, wat waterbestuur besonder moeilik maak. Klimaatsverandering kan nie beheer word nie en hou baie onsekerheid in. Hierdie studie beoog om voorspellings te maak van moontlike hoë, normale en lae water vraag en voorsieningscenario's (Hoofstuk 4). Die resultate van die voorspellings kan aangewend word om bestuurders te help om doeltreffend te beplan vir watervoorsiening en vraag in die Breede Waterbestuursgebied. Verder sal hierdie studie bestuurders inlig oor die omvang en die bedreiging wat waterskaarste inhou vir die Breederiviervallei.

Alle scenario's het tekorte voorspel vir die vooruitskattingstydperk van 20 jaar. In die gunstigste projeksie, wat reeds ernstige watertekorte voorspel, sal watertekorte 12 jaar van nou af voorkom. In die ongunstiste projeksie sal tekorte 6 jaar van nou af begin plaasvind. Hierdie resultate toon dus dat die beplanners en ontwikkelaars ongeveer 6 jaar het om ‘n oplossing te vind en te implementer.

Een moontlike oplossing behels dat daar damme in die bergreekse wat parallel aan die Breederivier loop, gebou word. Sodoende kan die opvangsgebiede optimaal benut word. Die boere sal dan nie meer afhanklik van die Breederivier (asook die Brandvleidam) vir besproeiingswater wees nie. Die uitvoering van verdere studies word sterk aanbeveel om die haalbaarheid en die omgewingsimpak van sodanige veranderings aan die watertoevoerstelsel vas te stel.

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List of abbreviations

BOCMA	Breede Overberg Catchment Management Area
CCT	City of Cape Town
CMR	Cape Metropolitan Region
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
GCM	General Circulation Model
GDP	Gross Domestic Product
IWRM	Integrated Water Resource Management
mS/m	mili-Siemens per metre
WCDM	Water Conservation and Demand Management
WMA	Water Management Area
WWTW	Waste Water Treatment Works

Glossary

Afforestation	Conversion of previously unharmed land into plantations for paper, other agricultural activities or urbanisation
Autocorrelation	It describes the association or mutual dependence between values of the same time series at different periods. It is also used to determine if seasonality is present in the data (Makridakis *et al.*, 1983)
Durbin h statistic	Used to determine if there is autocorrelation between variables when one or more variables are lagged
Durbin-Watson statistic	Test the hypothesis that there is no autocorrelation between variables (Makridakis *et al.*, 1983)
Evapotranspiration	Evaporation from the soil, plants and other surfaces
Heteroscedasticity	Description of the case when errors do not have a constant variance across an entire set of values (Makridakis *et al.*, 1983)
Homoscedasticity	Description of the case when errors have a constant variance across an entire set of values (Makridakis *et al.*, 1983)
Salinity	Describes the salt content (quality) of water
Shale	Soft, finely stratified sedimentary rock that formed from consolidated mud or clay and can be split easily into fragile slabs
Tributary	River or a stream that flows into a larger river
Perennial	Describes a river flowing throughout the year

Chapter 1 Introduction

1.1 Background

South Africa is situated in a region with increasing levels of water scarcity and water quality problems which are compounded by continuous population growth and other issues of social and economic development (New, 2002). Water resources in the country are limited and additional stresses on water resources, such as those arising from climate change, could exacerbate water scarcity over much of the southern African region. For this reason the proper management of water resources in South Africa is vital. Droughts of varying extent are a regular occurrence in South Africa. Surface run-off, mostly due to rainfall, and surface water are the main sources of water for irrigation in the country.

In the Western Cape Integrated Water Resource Management (IWRM) Action Plan (2011) the threat of water scarcity in the Western Cape becomes clear:

> There are very few affordable conventional water resources left to develop in the Province, and alternative sources, such as water conservation and demand management (WCDM), groundwater, desalination and water reuse, are becoming the important alternatives. The City of Cape Town (CCT) is currently investigating at feasibility level, the use of groundwater from the Table Mountain Group Aquifer. The CCT is also intending to undertake feasibility studies on desalination and water re-use, commencing this year.

The impacts of climate change are predicted to raise global and regional temperatures as well as cause changes in other climate variables that drive the terrestrial hydrological cycle – most notably precipitation and potential evaporation (New, 2002). An increase in temperatures is predicted to result in increased water demand from the domestic, agricultural and industrial sectors. Supply capacity, on the other hand, is shown to decrease non-linearly as either precipitation decreases or potential evapotranspiration increases. Both of these changes in precipitation and evapotranspiration are predicted for the Breede River Valley (New, 2002). The Breede Overberg Catchment Management Agency (BOCMA, 2010) has recently stated that the effects of climate change, use requirements and the seasonal water scarcity has to be considered when catchment management strategies are formulated. This notion is supported by Steynor *et al.* (2009), the Department of Water Affairs and Forestry (DWAF) (2004) and New (2002).

The agricultural activities of this region are mostly dependent on the river. The water distribution system consists of the river itself, a series of canals and various pumping schemes (Kirchner *et al.*, 1997). Many factors affect the achievable levels of water supply and the volumes of water demanded in a water distribution system. These factors are constantly changing and, therefore, water distribution managers need reliable information to base their management strategies on.

1.2 Research objective

In this study factors that influence the supply and demand of water in the Breede River Valley will be identified. In order to provide information for managers to plan water supply and demand in the in the Breede River Valley effectively, the objective of this study is to forecast possible high, normal and low water demand and supply scenarios. The information obtained from the forecasted scenarios can be used to inform managers on the extent of the threat of the expected water scarcity occurring in the Breede River Valley.

Another objective of this study is to identify possible solutions to the potential water scarcity in the Breede River Valley.

1.3 Research methodology

In this study multiple regression analysis will be used to determine the influence that each underlying variable has on the supply and demand in the Breede River Valley. A forecast of the expected changes in the supply and demand variables will be done for the next 20 years. The underlying components of the supply and demand, such as precipitation and evapotranspiration, will be calculated according to certain high, normal and low scenarios. These scenarios will be determined from researchers', like New (2002), estimations of climate change and the effects that it might have. The result will be an estimation of the severity and time frame of the onset of water scarcity in the region.

With this expected water scarcity in mind, there will be looked at possible solutions to the problem in the region.

1.4 Course of the following chapters

Chapter 2 will serve as an introduction to the study area. It will describe the current situation in the Breede River WMA.

Chapter 3 gives an overview of the literature study that was done. The most important aspects are discussed in detail.

Chapter 4 describes the forecasting in detail. It discusses how the variables as well as the scenarios where chosen. It also discusses the adjustments that had to be made to the data and then finally the findings of the forecasts.

Chapter 5 takes the findings of Chapter 4 into consideration and then addresses possible solutions to the potential water scarcity problem in the Breede River Valley.

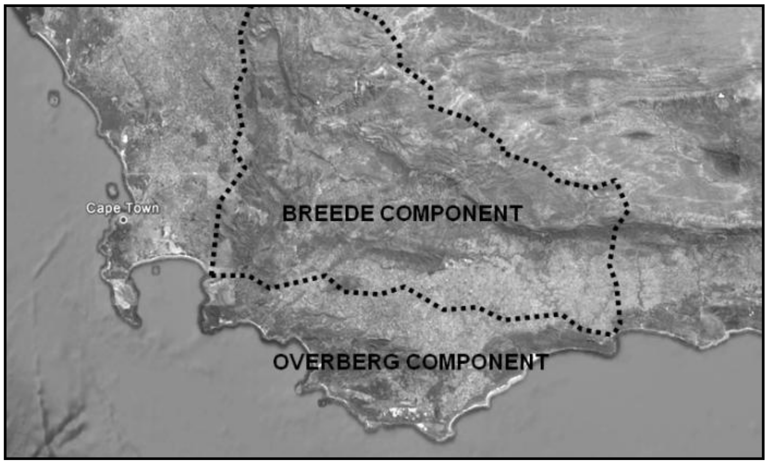
In the final chapter, Chapter 6, the conclusions and recommendations will be discussed.

Chapter 2 The Breede Water Management Area

The Breede River originates in the mountains surrounding the Ceres basin. Its flow fluctuations can be credited to the non-perennial behaviour of its tributaries (Kirchner *et al.*, 1997). Irrigation development in the Breede River Valley started between 1898 and 1918 (Kirchner *et al.*, 1997). At first, the water supply was dependent on the normal flow of the Breede River, but this soon became insufficient as the demand increasingly became more due to increased agricultural activities along the Breede River Valley. The solution was to build the Brandvlei Dam, which stabilised the supply of irrigation water to the Breede River Valley (Kirchner *et al.*, 1997). The Breede River Valley lies in the Breede WMA which is situated in the south-western region of South Africa.

The Breede WMA derives its name from the largest river within its boundaries, namely the Breede River. The Breede WMA is bounded by the Indian Ocean to the south, the Olifants/Doorn WMA to the northwest, the Berg WMA to the west and the Gouritz WMA to the east (Figure 1). The Breede WMA can be divided into two sub-management areas, namely: the Breede and the Overberg sub-management areas. The Breede sub-management area is further divided into the Upper Breede, Lower Breede and Riviersonderend sub-areas (DWAF, 2004).

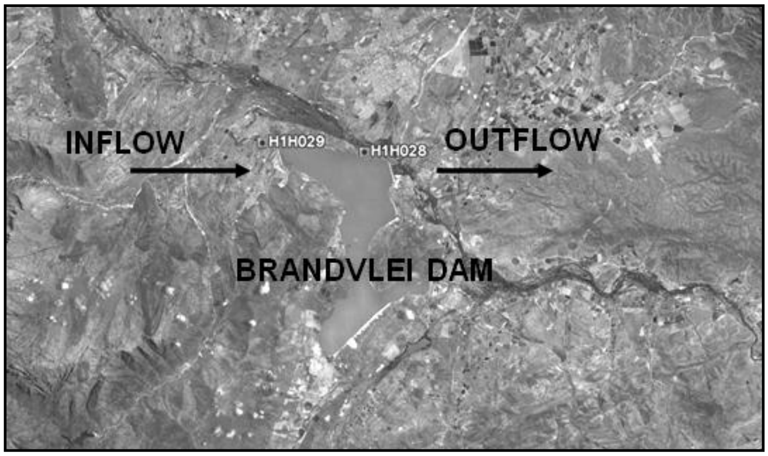
The topography of the Breede WMA is characterised by mountain ranges in the north and west, the wide Breede River Valley, and the rolling hills of the Overberg. Rainfall is highest in the mountainous regions in the south-west, where the mean annual precipitation is as high as 3000 mm per annum, whilst the central and north-eastern areas receive as little as 250 mm per annum (Western Cape IWRM Action Plan, 2011). Most of the WMA has a winter rainfall pattern, while an all year rainfall pattern prevails only in the far south-east. The average potential mean annual evaporation (S-Pan) ranges from 1200 mm in the south to 1700 mm in the north of the WMA. The mean annual temperature equals 17°C for the whole WMA. Frost and occasional snowfall occur in the winter (DWAF, 2004).



Source: Google maps

Figure 1 – Breede Component of Breede Water Management Area

A number of water supply schemes have been developed in the Breede WMA and, with the exception of the Lower Breede sub-area, the WMA is generally crisscrossed by canals and pipelines supplying water for irrigation of commercial crops. The Greater Brandvlei Dam, with a capacity of 475 million m^3, is filled mainly during the winter months with water from the Smalblaar River and the Holsloot River (BOCMA, 2010). During the summer irrigation period, water is released from the Brandvlei Dam into the Breede River to supplement river flows for use by a number of water users. The Greater Brandvlei Dam and its inflow and outflow canals can be seen in Figure 2. These inflow and outflow canals' data will be used in the forecasts in Chapter 4. The Brandvlei Dam is an off-channel storage dam fed by the Smalblaar and Holsloot Rivers (Murray Biesenbach & Badenhorst Ing., 1993).



Source: Google maps

Figure 2 – Greater Brandvlei Dam

Water is supplied to nearby irrigation districts through pumping schemes directly from the dam. The Theewaterskloof Dam (434 million m^3) is the source reservoir for the Riviersonderend-Berg-Eerste River

Government Water Scheme, an inter-catchment water transfer project, owned and managed by the DWAF and supplies water to the Berg WMA (BOCMA, 2010). Stettynskloof Dam, near Worcester, is the only dam of significant size in the Breede WMA that is owned by a local authority. Its primary purpose is to supply water for domestic use. Of the dams supplying water for irrigation, the Greater Brandvlei Dam (yield of 155 million m^3/a) is the largest. It has spare storage capacity of 133 million m^3 (DWAF, 2004). Other large dams used for irrigation include the Lakenvallei and Roode Elsberg Dams of Sanddrift Government Water Scheme (yield of 9 million m^3/a), the Keerom Dam (yield of 3.8 million m^3/a), the Elandskloof Dam (yield of 12 million m^3/a), the Buffeljags Dam (yield of 11 million m^3/a) and farm dams collectively providing about 83 million m^3 of storage (DWAF, 2004).

The total volume of water (made up of surface water, ground water, return flows and transfers) available for supply in the Breede River component in the year 2000 is listed in Table 1.

Table 1 – Sources of Water Supply in the Breede River Component (million m^3/a, year 2000)

Resource Category	Upper Breede	Riviersonderend	Lower Breede	Total
Gross surface water resource yield	428	262	59	**749**
Less impact on yield of:				
Preliminary ecological reserve	16	0	0	**16**
Invasive alien plants	25	13	7	**45**
River losses	5	0	0	**5**
Net surface water resource	382	249	52	**683**
Plus groundwater	94	5	4	**103**
Plus return flows	85	10	7	**102**
Total local yield	561	264	63	**888**
Transfers in	0	0	14	**1**
Total	**561**	**264**	**77**	**889**

Source: DWAF, 2004

The main elements comprising total water demand in the area are irrigation (95% of total demand) and urban settlements (approximately 5%) (BOCMA, 2010; DWAF, 2004). The total demand volumes for the year 2000 are provided in Table 2.

Table 2 – Sources of Water Demand in the Breede River Component (million m3/a, year 2000)

Category	Upper Breede	Riviersonderend	Lower Breede	Total
Irrigation	495	91	72	**658**
Urban	23	2	1	**26**
Rural	4	2	1	**7**
Impact of afforestation on yield	0	1	0	**1**
Total requirements	522	96	74	**692**
Transfers out	22	168	0	**177**
Total	**544**	**264**	**74**	**869**

Source: DWAF, 2004

Water for domestic use is primarily supplied out of schemes owned and operated by local authorities. Water is transferred from the Upper Breede area to the Berg WMA (9 million m^3/a) and the Olifants/Doorn WMA (2.5 million m^3/a). A further 10 million m^3/a is released to maintain acceptable water quality levels downstream in the Breede River. Transfers are made to the Overberg component (4 million m^3/a) and the Lower Breede area (2.5 million m^3/a) (BOCMA, 2010; DWAF, 2004).

When comparing the supply and demand figures, it was determined that a surplus of 20 million m^3/a exists (17 million m^3/a in the Upper Breede area). This is 2.3% of the total demand fot the Breede component. This surplus lies in the Koekedouw Dam (3 million m^3/a), the Stettynskloof Dam (14 million m^3/a) and the Buffeljags Dam (3 million m^3/a). The former two dams are not owned by the DWAF (BOCMA, 2010).

It can be concluded that the Breede Component’s water supply system is very close to capacity. In fact, shortfalls already occur during the dry summer season (BOCMA, 2010). New (2002) states that the system is already unable to provide a 1:50 year yield, and will only be able to do so in the future if projected increases in demand (due to socio-economic factors) are matched by efficient demand management practice. “If the climate of the region evolves as suggested by recent general circulation models’ predictions, the resultant supply decreases and demand increases will exacerbate the existing water resource problems in Cape Metropolitan Region” (New, 2002)

From the supply and demand data discussed, it is evident that the Brandvlei Dam is the main source of water for the Breede Component of the Breede WMA. The rest of this study is therefore limited to supply from the Brandvlei Dam and demand in the Breede Component.

Chapter 3 Literature study

3.1 Introduction

The aim of this literature study was to become acquainted with all the work published on the Breede River Valley and WMA. With all the studies read and information gathered, the issues most relevant to this study will be discussed in the following sections.

3.2 Water quality

To satisfy the demand for water, both the sufficient quality and quantities have to be supplied (Western Cape IWRM Action Plan, 2011). The Western Cape's water sources are deteriorating, which makes the task of supplying water of suitable quality and quantity increasingly more difficult. Some causal factors to the deterioration of water quality are (Western Cape IWRM Action Plan, 2011):

- Geology of the region – most notably areas of shale.
- Return flows from irrigation.
- Discharge of water not complying with the standard of waste water treatment works (WWTW).
- Runoff from urban settlements without adequate sanitation.

All of the above mentioned factors contribute in some way to the salinity of the water.

Factors that impact the Breede WMA specifically are the geology (shale) of the area and the contribution of agricultural runoff to the salinity of the Breede River. The salinity levels are managed through freshening releases from the Brandvlei Dam.

3.2.1 Salinity levels in the Breede River

A few studies have investigated the salinity level of the Breede River. It is believed that the high salinity levels are caused by the high volume of irrigation return flows, the geology of the area and other agricultural practices (Western Cape IWRM Action Plan, 2011). The salinity levels are especially high during the summer, because more water is used for irrigation. More irrigation means more return flows (Kirchner *et al.*, 1997).

The geology of the region certainly has a part to play in the salinity levels of the Breede River. Kirchner et al. (1997) found through isotopical and geohydrological investigation that natural groundwater can largely be ruled out as a major contributor to the salinity levels of the Breede River. The major contributor remains the irrigation return fows (Kirchner *et al.*, 1997).

3.2.2 Freshening releases from the Brandvlei Dam

The law requires that water of an acceptable quality has to be provided to the farmers. To supply water of a suitable quality in the Breede River the DWAF attempts to provide water with electrical conductivity corresponding with the values in Table 3 (Kirchner *et al.*, 1997).

Table 3 – Electrical conductivity standards

Percentage of the time (%)	Electrical conductivity (mS/m)
At least 50	70
Less than 20	120

Source: Kirchner *et al.*, 1997

The DWAF releases fresh water from the Brandvlei Dam to attain these quality levels. It is recorded that between 1985 and 1990 about 20% to 25% of all releases was made for freshening purposes (Kirchner *et al.*, 1997). Bruwer (1999) noted that in one irrigation season, it was necessary to release 25 million m^3 of water from the Brandvlei Dam.

3.2.3 Management of salinity by improving irrigation efficiency

In a study that was conducted by Murray Biesenbach & Badenhorst Ing. (1993), it was found that the irrigation systems implemented in the Breede River Valley are of a very high standard. It was, however, found that the farmers have very little knowledge of theoretical irrigation scheduling and they will rely on own experience to devise a scheduling plan. This often results in over irrigation and a big return flow in to the Breede River which raises the salinity levels.

There is a big opportunity for improvement in this area. Farmers could be educated on efficient irrigation practices and on the negative effects that over irrigation has. Improvement is this area can lead to an overall reduction in water use in the Breede River Valley.

3.3 Climate change

The expected effect that climate change will have on the south-western region of South Africa is a decrease in average precipitation (Western Cape IWRM Action Plan, 2011). A decrease in precipitation and possible raise in global temperatures, will result in less surface water runoff into rivers (Western Cape IWRM Action Plan, 2011). This translates into less water being available to satisfy a demand that will continuously grow as the precipitation decreases and temperature rises (Western Cape IWRM Action Plan, 2011).

There is consensus in the literature that there exists no concrete causal relationship between changes in temperatures (expected to be the main effect from climate change) and changes in rainfall (Buishand &

Klein Tank, 1996; Buishand & Brandsma, 1999; Buishand & Brandsma, 2001; Liu *et al.*, 2009). The only expected impact is that weather phenomena will become more extreme (in terms of rainfall or dry spells) as temperatures increase, although not necessarily more frequent. If one of the extremes occurs more frequently in a region, it could have a resulting positive or negative impact on the availability of water supply in that region.

A predicted result from climate change is that the occurrence of droughts will increase in the Western Cape (Western Cape IWRM Action Plan, 2011). Dams are filled during the rainy season so that water can be continuously supplied by it during the dry season. Without a regular “rainy season” in which the dams can be refilled, the water resources will have to be managed more carefully (Western Cape IWRM Action Plan, 2011). Steynor et al. (2009) agrees with this notion and stresses that climate change will have a significant impact on water management in the Breede River.

Furthermore, New’s (2002) estimate for the combined change in domestic and agricultural demand in the Cape Metropolitan Region (CMR) is an increase of about 0.6% per annum over the existing demand. Over the next 20 years, the regional water supply of the South-Western Cape will most likely have an average 0.32% stream flow reduction per annum. If the climate of the region evolves as suggested by the general circulation models’ (GCMs) predictions, the CMR’s supply system, which is already under pressure, will not be able to cope (New, 2002).

3.4 Invasive alien plants

“South Africa is a dry country with a mean annual rainfall of less than 500 mm and only about 9% of the rainfall ends up in the rivers” (Western Cape IWRM Action Plan, 2011). A factor contributing to the poor runoff is invasive alien plants. This notion is supported by van Wilgen et al (2006). Even though the stream flow reduction experienced at present is severe, it can increase even more if the infestation of alien plants are not controlled (van Wilgen *et al.*, 2006). Invasive alien plants are often ranked as the second most pressing threat (after direct habitat destruction) to global biodiversity. If the infestation of alien plants is not controlled, the threat could increase (van Wilgen *et al.*, 2007).

In rural areas people often rely on the rivers’ flow for the supply of water. There is usually no infrastructure, such as dams, to ensure the continuous supply of water. The threat that invasive species pose on the country’s water resources is thus also a major threat on human-wellbeing (van Wilgen *et al.*, 2006), especially so in the rural area of the Breede River Valley.

3.5 Conclusions

Water is a scarce resource in South Africa and especially in the Western Cape. It is, therefore vital that it must be managed properly. There are a number of factors that can make the task of managing water more difficult in the Breede River Valley. These factors are:

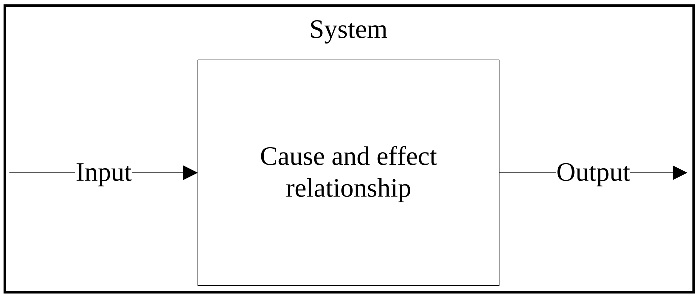
- Climate change
- Prevalence of invasive alien plants
- Freshening practices in the Breede WMA

Climate change is the only factor of the above mentioned that cannot be controlled locally and is difficult to predict. In order for managers to plan effectively for water supply and demand in the Breede WMA, information on the possible water demand and supply future scenarios is needed.

Chapter 4 Forecasting

4.1 Introduction

Forecasting methods can generally be classified into two groups: extrapolation and causal forecasting. Extrapolation methods forecast future values of a time series from past values of a time series. Here it is assumed that past patterns and trends will continue in the future. Causal forecasting methods attempt to forecast future values of a dependent variable using historical data to estimate the relationship between the dependent and one or more independent variables (Winston, 2004; Anderson *et al.*, 2008). Makridakis et al. (1983) describes causal forecasting as a system with inputs and outputs (Figure 3). Every input will affect the output in a certain way. The relationship between the inputs and outputs has to be determined in order to make accurate forecasts. Furthermore, if the independent variables can be forecasted and the relationship between them is known, the dependent variable can be forecasted.



Source: Makridakis *et al.*, 1983

Figure 3 – Causal relationship

In a multiple regression study there is a dependent variable that is to be predicted from several other independent variables (Makridakis *et al.*, 1983). The relationship between the dependent and independent variables is determined. An equation like the following will be obtained:

$$\boldsymbol{Y = b_0 + b_1X_1 + b_2X_2 + \ldots + b_nX_n + \epsilon} \qquad \text{[Eq 1]}$$

The dependent variable (Y) can now be predicted by the independent variables (X_1 ... X_n) (Makridakis *et al.*, 1983). To achieve this study's objectives, the prediction of one variable from several others was necessary. This was necessary because forecasts for the independent variables were available, but not for the dependent variable. It was therefore concluded that multiple regression was a suitable approach.

The demand and supply from the Brandvlei Dam are both influenced by many variables. For instance, the volume of precipitation, evapotranspiration and levels of the supplementary dams in the region have an influence on the demand from the Brandvlei Dam.

Historic data from 1987 until the end of 2010 was used. The data was obtained from the Department of Water Affairs' website (http://www.dwa.gov.za/Hydrology/)

4.2 Demand forecasting

There are many possible factors that could contribute to the volume of water demanded in a region. Some of these include demographics (population size), economic prosperity, the extent of agriculture, access to external water sources and meteorological factors. The DWAF (2004) stated that no significant increase in population is expected in the WMA over the next few years; hence this variable was excluded from the analysis. Moreover, the region's contribution to national gross domestic product (GDP) is less than 1% (DWAF, 2004). This, combined with the slow growth rate of GDP in South Africa, warrants the omission of GDP as a causal variable in the study.

The extent of agriculture in the region is assumed to remain relatively constant over the next 20 years. There are a number of supplementary dams in the region and it is expected that those dams can either serve to alleviate or exacerbate the water demand from the Brandvlei Dam. The independent variables that will be used to predict the volume of water demanded from the Brandvlei Dam over the next twenty years are the water available from supplementary dams, precipitation and evapotranspiration.

When multiple regression analysis was applied to the above mentioned data, the following equation is the result:

$$\boldsymbol{\textit{Water demand}_i = \alpha_0 + \alpha_1 \textit{Supplemetary dams} + \alpha_2 \textit{Precipitation} + \alpha_3 \textit{Evapotranspiration} + \epsilon} \qquad \text{[Eq 2]}$$

When doing multiple regression analysis, there are key assumptions that must be tested. Violation of any of these assumptions could render the study results void. These assumptions are that variables and errors must be normally distributed, that homoscedasticity is present (indicated by the Durbin-Watson statistic) and that errors are independent of each other (testing for autocorrelation) (Winston, 2004; Osborne & Waters; 2002).

It was found that both heteroscedasticity and positive autocorrelation was present in the data. The R^2 (goodness of fit) value for the original data was 0.75 and the Durbin-Watson statistic was 0.89. The complete results of the regression can be seen in Appendix A, while the original residual plots of the data can be seen in Figure 4.

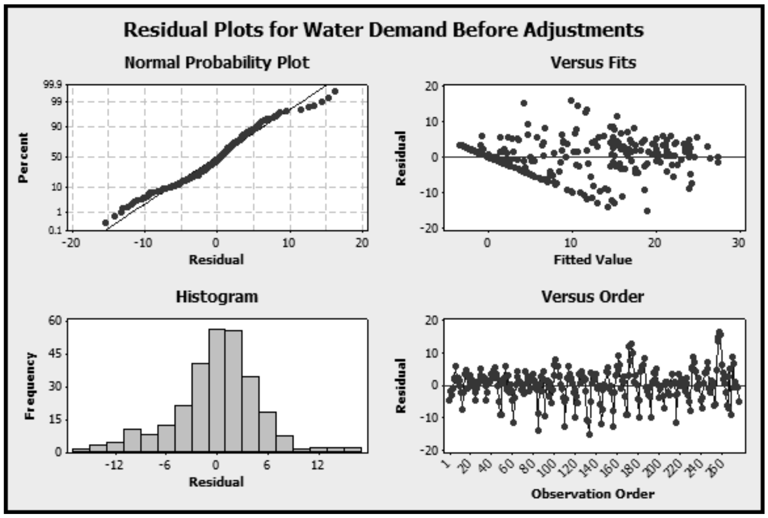


Figure 4 – Residual plots for water demand before adjustments was made to the data

The model was adjusted for heteroscedasticity by taking the square root of the water demand variable. Each of the independent variables was adjusted to remove the autocorrelation. The adjusted data's plots can be seen in Figure 5.

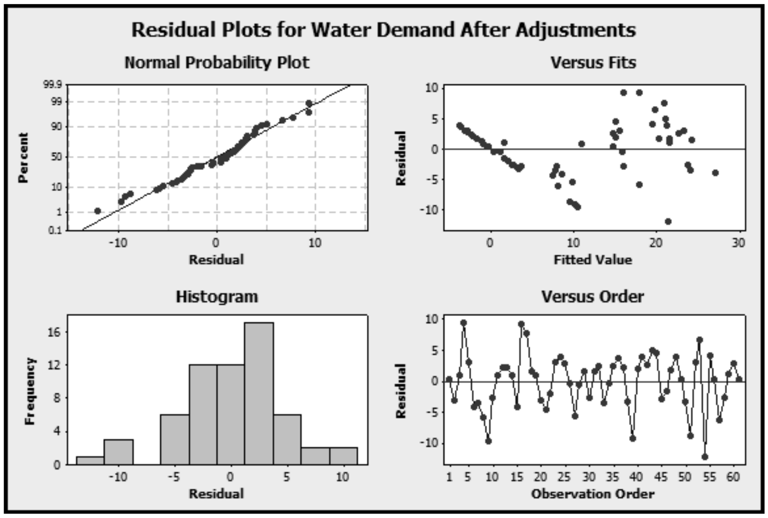


Figure 5 – Residual plots of the final Multiple Regression Model

The results from the adapted model were a great improvement on that of the first model. The final R^2 value is 0.83 and the Durbin-Watson statistic 1.67. Although the p-values of all the coefficients are not smaller than 0.05, none of them are greater than 0.25. Evapotranspiration is the most influential variable. The impacts of the supplementary dam levels and precipitation on demand are similar in size and positively correlated to demand. The complete results of the adjusted regression model can be seen in Appendix B.

The statistical tests' results of the adjusted regression model show that it is a good fit for the data. Therefore, the adjusted regression model can now be used to forecast water demand levels, based on expected changes in the precipitation, evapotranspiration and supplementary dams' variables. Uncertainties in estimating future water requirements (such as the impact of climate change, the impact of changes in land-use and the impact of water conservation and demand management) are abound (DWAF, 2004).

4.3 Supply forecasting

The total water available for supply (i.e. the Brandvlei Dam level plus the volume of water leaving through the outflow canal) is used as the dependent variable. This represents the total volume of water available for supply in the system. The dependent variable is again influenced by many independent variables. These independent variables are precipitation and evapotranspiration volumes, the inflow canal volume and the previous period's dam level. The previous period's dam level was determined by the following equation:

$$\boldsymbol{Dam_{t-1} = Dam_{t-2} + Inflow_{t-1} + Precipitation_{t-1} - Outflow_{t-1} - Evaporation_{t-1}} \qquad \text{[Eq 3]}$$

The precipitation and evaporation volumes used in equation 3 were calculated only for the precipitation and evaporation occurring over the area of the dam. The dam level and, therefore the dam's area, was calculated for each period to be able to determine the relevant amount of precipitation and evaporation for that period.

When multiple regression analysis was applied to the above mentioned data, the corresponding regression equation is the result:

$$\boldsymbol{Water\ supply_i = \beta_0 + \beta_1 Dam_{t-1} + \beta_2 Precipitation + \beta_3 Evapotranspiration + \beta_4 Inflow + \epsilon} \qquad \text{[Eq 4]}$$

Similar to the demand regression, the key regression assumptions had to be tested. All these assumptions were satisfied. The Durbin-Watson statistic's value was 1.8, which is acceptable. However, because the dam variable is lagged, the Durbin h statistic must also be calculated. It is a test used to determine if autocorrelation is present if one or more independent variables are lagged. The Durbin h statistic was 1.91, which indicates that no autocorrelation is present. The plots for the residuals from the supply forecast can be seen in Figure 6.

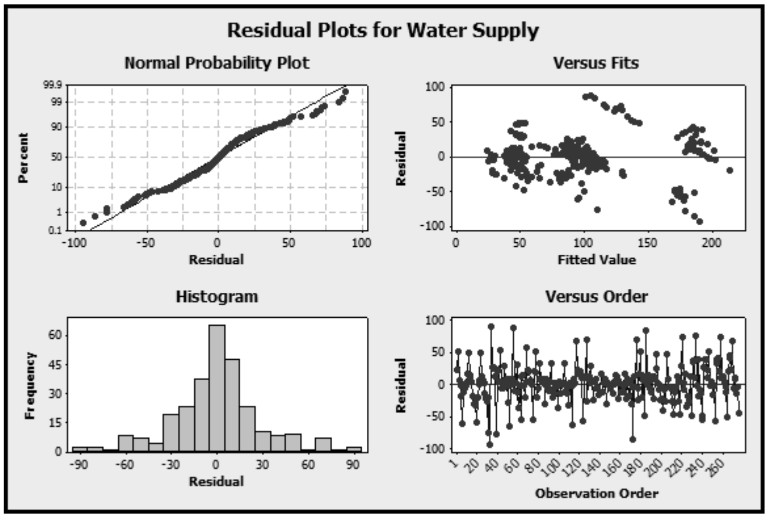


Figure 6 – Residual plots for the water supply

The final R^2 value is 0.74. The p-values of Precipitation, Inflow and Dam_{t-1} were all smaller than 0.05, indicating the statistical significance of the predictive power that the independent variables have over the dependent variable. The p-value of evapotranspiration was smaller than 0.1. The complete regression output can be seen in Appendix C.

4.4 Scenario forecasting

In his paper, New (2002) suggests that climate change will result in an annual reduction in stream flow in the South-Western Cape over the next twenty years. If this reduction is taken as the normal scenario, it is possible to have a scenario with an even more severe stream flow reduction. With lower stream flow, there will be lower supply potential. This supports the notion that it is reasonable to add a low supply scenario to the study. It is also possible to increase potential yield in catchment systems without the addition of new infrastructure (DWAF, 2004). A high supply scenario will reflect the implementation of such practices.

New (2002) suggested that a 5% decrease in precipitation can be expected by 2020. Assuming this is a linear decrease (New, 2002), a 2.5% decrease in average annual precipitation will have occurred by 2010. Evapotranspiration is calculated based on a formula that relies on both temperature and humidity data. In general, as temperature increases, humidity tends to decrease (an inverse relationship is present between these variables). A (linear) 1°C increase in average global temperatures is expected by 2020 (New, 2002). The above mentioned factors were used to develop the normal demand and supply scenarios.

The above mentioned forecasts will be used to forecast the normal scenario. There is, like with any forecasting model, a level of uncertainty present. To correct for this uncertainty, the forecasting of 2 more scenarios were deemed sufficient for this study. For this reason, the low and high supply and demand scenarios will be discussed in sections 4.4.1 and 4.4.2.

4.4.1 Demand scenarios

In addition to the forecast above for the normal scenario (section 4), the supplementary dams' contribution also has to be forecasted. A trend based on historic data was used to forecast the mean dam levels over the next twenty years.

To develop the high demand scenario precipitation forecast, a more severe 5% decrease in average annual rainfall was used. The corresponding evaporation forecast was based on an expected increase in average temperature of 1°C over twenty years. Furthermore, empty supplementary dams would increase demand for water from the Brandvlei Dam. To calculate this, a linear decrease in dam water levels to the minimum recorded historic dam levels was used for the high demand scenario.

Correspondingly, the low demand scenario is based on an expected increase in current precipitation levels of 2.5% over twenty years and no expected increase in temperature due to climate change. To determine the dam levels suited to this scenario, dam levels were trended to reach maximum dam capacity levels by 2031.

The high, normal and low demand forecast scenarios are summarized in Table 4. When the scenarios were forecasted using the demand regression equation obtained in section 4.2, it was found that the demand steadily increases over the forecasting period of 20 years (Figure 7) in all scenarios, but to various extents.

Table 4 – Demand forecasting scenarios

	Demand scenarios		
	High	**Normal**	**Low**
Precipitation	-5%	-2.5%	+2.5%
Supplementary dams	Trend to minimum capacity	Trend on historic data	Trend to maximum capacity
Temperature	+1°C	+0.5°C	0

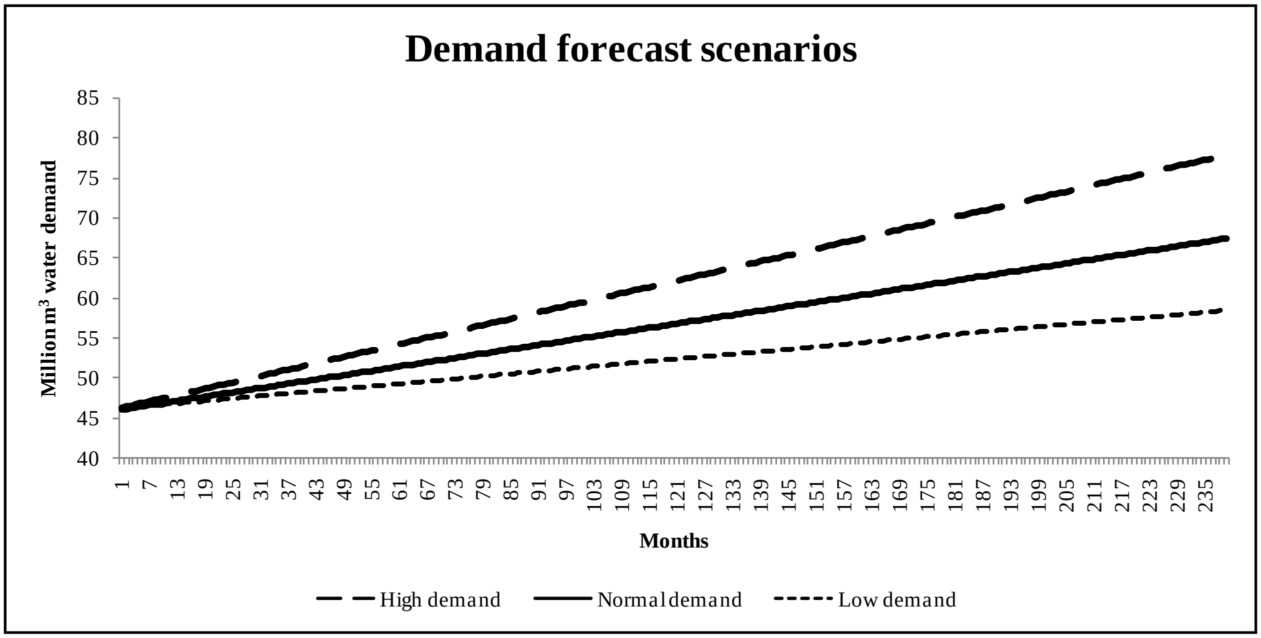


Figure 7 – Graphic representation of the three water demand scenarios

4.4.2 Supply scenarios

The precipitation and temperature normal scenario forecasts used in the supply scenario are the same as that for the demand scenario. The stream flow and the previous period’s dam level also have to be considered for the normal supply scenario. New (2002) suggested that stream flow will decrease with 6.4% by 2020. Assuming a linear decrease, a 3.2% decrease of stream flow would have occurred by 2010. In this study it is assumed that the linear decrease would continue for the next 20 years. The previous period’s dam level forecast was predicted using the same scenarios, but only calculated as applicable to the area of the dam.

For the high supply scenario, precipitation increases with 2.5%, temperature has no change, the stream flow decreases with 1%, the previous period’s dam level is predicted using the same factors, but only applicable to the area of the dam. The previous period’s dam level is calculated by equation 3 in section 4.3.

For the low supply scenario, precipitation decreases with 5%, temperature increases with 1°C and the stream flow decreases with 5%. The previous period’s dam level is again predicted using the same scenarios. Table 5 summarises the supply scenarios. These scenarios were forecasted with the regression equation obtained in section 4.3. The corresponding high, normal and low supply forecasts for equation 4 can be seen in Figure 8. It was found that the supply steadily decreases for all the scenarios over the forecasting period. The magnitude of the decrease, however, varies from one scenario to the other.

Table 5 – Supply forecasting scenarios

	Supply scenarios		
	High	**Normal**	**Low**
Precipitation	+2.5%	-2.5%	-5%
Temperature	0	+0.5°C	+1°C
Stream flow	-1%	-3.2%	-5%
Dam_{t-1}	Calculated the same as above with equation 3		

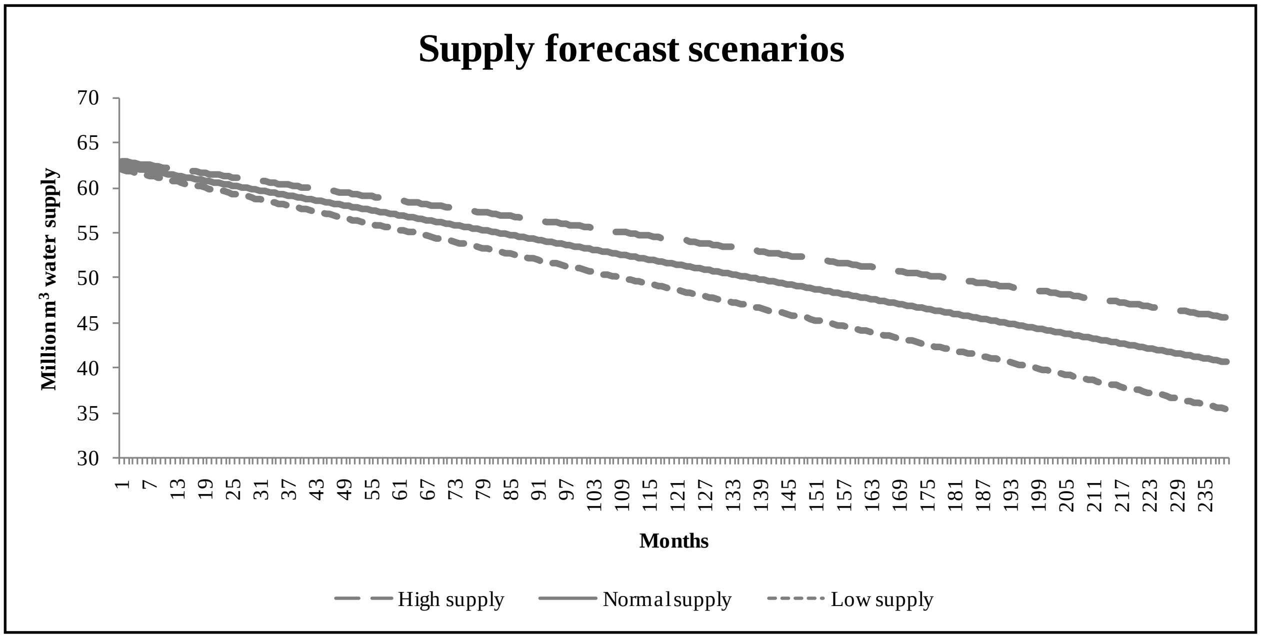


Figure 8 – Graphic representation of the three water supply forecast scenarios

4.5 Forecasting results and conclusions

Figure 9 is a graphic illustration of the simultaneous forecasts of water supply and demand in the Upper Breede sub-area of the Breede WMA. It was already seen that the demand steadily increases (Figure 7) while the supply steadily decreases (Figure 8) within the forecasting period. It comes, therefore, as no surprise that demand will at some point surpass supply. Figure 9 illustrates both the forecasted severity and time frames of expected shortfalls in water supply within the next 20 years. A summary of the expected magnitude of the shortfall (expressed as the percentage of demand that will not be met by 2031) and the expected timing of first occurrence of the shortfall is provided in Table 6. Shortfalls within the next 20 years are expected to occur in all combinations of scenarios included in this study.

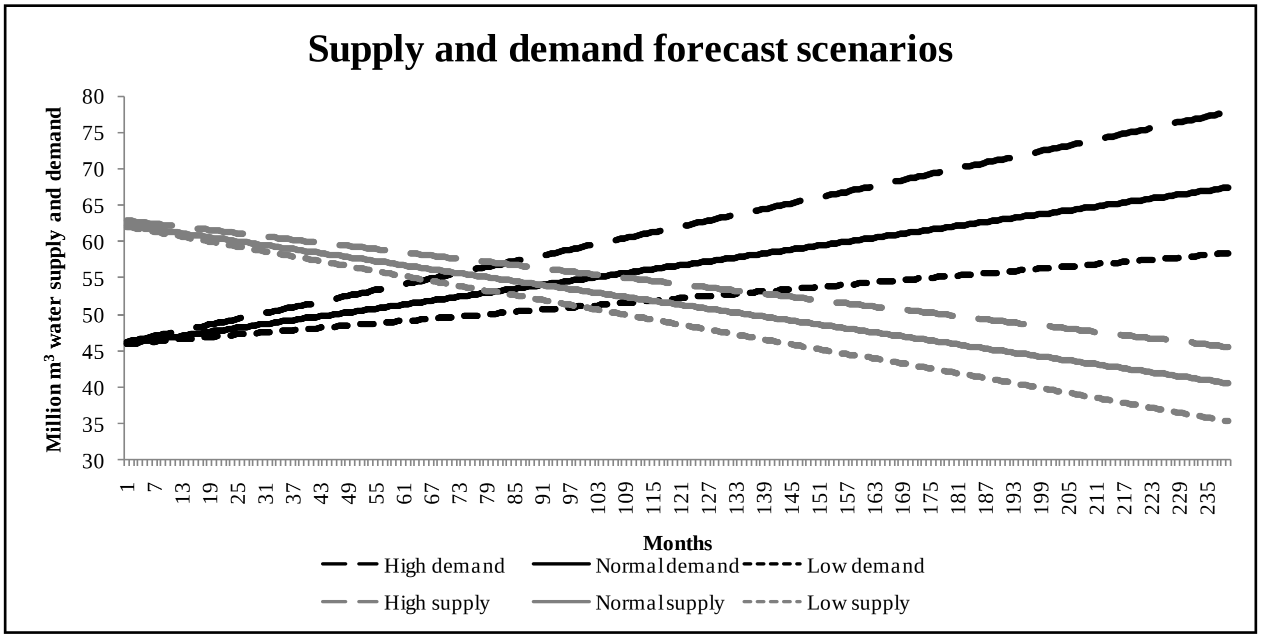


Figure 9 – Combined graph of supply and demand twenty year forecast scenarios

Table 6 – Summary table of the expected shortfall threats

			Water demand		
			High	**Normal**	**Low**
Water supply	**High**	Expected shortfall by 2031	41%	32%	22%
		Expected time frame (years)	7	9	12
	Normal	Expected shortfall by 2031	48%	40%	31%
		Expected time frame (years)	7	8	10
	Low	Expected shortfall by 2031	55%	47%	39%
		Expected time frame (years)	6	7	9

The worst case scenario, according to this study, will occur within 6 years from now and is a combination of high demand and low supply. The water shortage will be 55% by 2031; which means that about half of the people in the Breede WMA will not be able to access water as they previously did.

The best case scenario, according to this study, is that a water shortage only occurs 12 years from now. This will happen when there is low demand coupled with high supply. The water shortage in this case will be 22% by 2031; which means that about one fifth of the people in the Breede WMA will not be able to use water as they previously did.

The values on the y-axis of Figure 9 indicate the amount of water (in million m^3/month) when the forecasted demand surpasses the forecasted supply. The amount of water for the worst case and best case scenarios are 55 million m^3/month and 53 million m^3/month respectively. These values are in line with the demand values of Table 2 which, if given as a monthly amount, is 45 million m^3. The data from Table 2 dates out of 2000 and it can be expected that the forecasted demand amounts will be more. The fact that this model's results are in line with those of Table 2 serves as validation for the forecasting models used.

The results show that planners and developers are afforded a lead time of between 6 and 12 years to affect the required interventions to prevent a shortfall. Although there are a number of methods for increasing water supply capacity to choose from, there is not a lot of guidance on the method that would be best suited to the Breede WMA.

Chapter 5 Possible solutions to manage the expected water scarcity in the Breede River Valley

5.1 Introduction

The problem that the Breede River Valley faces in terms of water supply was already identified in the literature study done in Chapter 3. This problem was further investigated in Chapter 4 using forecasting methods. Although the findings of Chapter 4 are only an estimate, it supports the notion that that there is an imminent water shortage looming which will worsen in the future.

The following section will investigate potential solutions that have been suggested by other researchers. A solution and its implications will briefly be discussed in more detail.

5.2 Solutions as suggested by other researchers

There may be ways to delay or prevent the onset of a water shortage. Several methods that can be implemented to increase water supply capacity have been proposed in the literature. The first and most obvious method is to fully exploit any spare storage capacity that is underutilised in the system. Secondly, existing infrastructure can be expanded (by raising dam levels, for example). Thirdly, new infrastructure can be developed. Other methods include the verification of lawful use and management of water, water conservation initiatives and demand management interventions.

The main opportunities to save water in the Breede River Valley lie in the maintenance and upgrading of water conveyance and distribution systems, as well as improved management of releases from the Greater Brandvlei Dam (DWAF, 2004). Trading of existing authorisations is a way of shifting water towards more beneficial use or higher paying use, without increasing total volume demand. Clearing of invasive alien plants can result in water gains. Priority areas include the upper reaches of the Riviersonderend and Upper Breede sub-area (DWAF, 2004). The use of bio-control presents a cost-effective and sustainable form of control. Further to this, abstracting groundwater (which only has weak links to surface water and can be abstracted without significantly impacting on surface water yields) can prove to be a solution to the problem. However, within the Ceres catchment (Upper Breede sub-area), groundwater abstraction currently exceeds what is considered to be sustainable abstraction (DWAF, 2004).

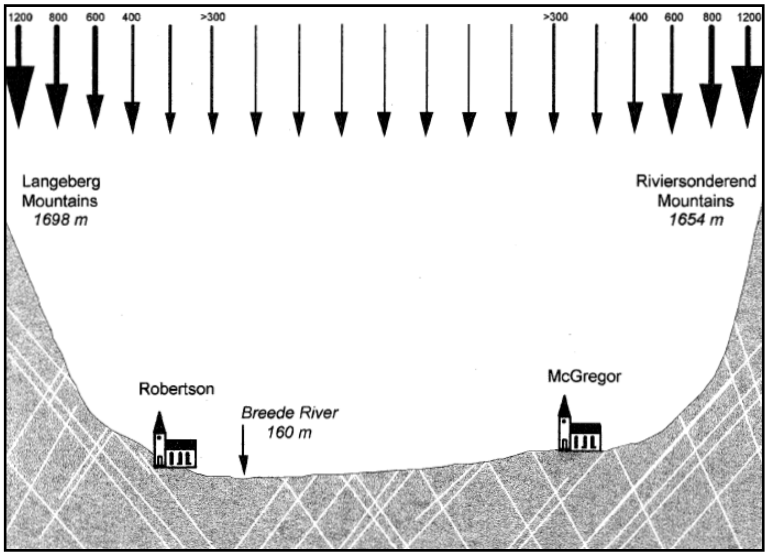
5.3 Closer look at a promising solution

The problem that this solution will attempt to address is the release of fresh water to manage the salinity of the Breede River. The causes of salinity in the river were narrowed down to two possible causes, namely the irrigation return flow and the geology of the area (Kirchner *et al.*, 1997).

By managing the salinity of the Breede River downstream, the freshening releases required from the Brandvlei Dam can be reduced. Therefore, it seems sensible to modify the current water supply system in the Breede River Valley to reduce the freshening releases necessary from the Brandvlei Dam. The water that is saved by these modifications can be put to use elsewhere.

5.3.1 Proposal to reduce the freshening releases from the Brandvlei Dam

A schematic representation of the Breede River and its tributaries can be seen in Appendix D. In Figure 10, the rainfall distribution for a section of the Breede River Valley can be seen. It is clear from the distribution that the rainfall in the mountain ranges is higher than in the valley.



Source: Kirchner *et al.*, 1997

Figure 10 – Rainfall distribution over a section of the Breede River Valley

The proposal is to build dams on strategic places in the mountain ranges. Water will then be caught in dams along the length of the mountains. This will ensure that the catchment area is fully exploited. The water that does not end up in the dams will flow to the Breede River as it always did. It is recommended that further studies be done to determine the environmental impact and the potential capacity that these dams may have.

As an additional benefit, farmers along the river will be supplied of water from the dams in the mountains instead of the river. To distribute the water with minimal losses, pipes or canals can be used. The water will be gravity fed, which adds the additional bonus of no pumps and electricity requirements. The water will be of a good quality, as it has had minimal exposure to factors that can taint it.

As the farmers use “fresh” water from the dams in the mountains, the irrigation return flows adding salt to the river will not affect the farmers downstream, as they will not need water from the river. The return flow from irrigation will not be as saline as usual, because water of better quality is used to start off with. The only releases that will be necessary form the Brandvlei Dam is to sustain the normal, healthy flow of the Breede River.

5.4 Conclusions

It was mentioned that a number of solutions have been proposed to the water supply problems in the Breede River Valley. A very promising solution involves building dams in the mountain ranges to fully exploit the catchment potential of the area. Gravity fed water will be supplied to farmers from these dams, rendering it no longer necessary to source irrigation water from the Breede River and therefore the Brandvlei Dam.

As the investigation of the threat of water scarcity in the Breede WMA was the focus of this study, no further analysis was done on the details of the proposed solution. It is, however, recommended that further analysis be done to determine the feasibility and the environmental impact of such modifications. Furthermore, it needs to be determined to what extent this proposed idea will be able to reduce the expected water shortfall in the Breede WMA.

Chapter 6 Conclusions and recommendations

6.1 Conclusions and recommendations

The objective of this study was to forecast possible high, normal and low water demand and supply scenarios. The information obtained from the forecasted scenarios can be used to inform managers on the extent of the threat of the expected water scarcity occurring in the Breede River Valley.

In this study a multiple regression analysis was used to determine the influence that each underlying variable has on the supply and demand in the Breede River Valley. The result was an estimation of the severity and time frame of the onset of water scarcity in the region.

All supply and demand scenarios indicate that shortfalls will occur within the next 20 years. In the best case scenario, which is already severe, water shortages will occur 12 years from now. This will happen when there is low demand and high supply with a volume of 50 million m^3 required per month. The water shortage by 2031 will be 22%. In the worst case scenario water shortages will occur within 6 years from now.

Planners and developers are afforded a lead time of between 6 and 12 years to affect the required interventions. With this expected water shortage in mind, possible solutions to the problem in the region were investigated. A number of solutions to the water supply problem in the Breede River Valley have been proposed. The solution discussed in Chapter 5 is seen as a very promising solution and it is recommended that further studies be done to determine the feasibility and the environmental impact that such modifications may have.

As it seems that a water scarcity in the region is unavoidable, it is very important that managers attend to this problem urgently.

6.2 Personal reflections on this final year project

As part of my personal reflection I wrote a tongue in cheek passage of how I experienced this final year project:

> The goal of a final year project is certainly to use and even to show off the skills that you have gathered over the past four years. A topic is chosen and for several months you study it, love it, hate it and wrestle with it. Somewhere along the line you realise that things are falling into place. Then, without warning, things start to swing out of control. There comes a time when you are required to stop the madness and order the

> chaos of thoughts in your head. Carefully, and sometimes painstakingly, the applicable knowledge and insights are sieved from the rest. With precision, the finest golden thread is used to stitch together a magical fairy-tale of facts, tables and figures. The spaces in between is coloured with the best words in your vocabulary arsenal. Frustrating days consisting out of countless brain numbing hours in front of computers draw by and finally...
>
> Finally, the draft of the final year project emerges as gracefully as the first blossom of spring. This precious blossom is handed over to the study leader, who dissects it. Every slice of the scalpel is like a stab to your heart. Once the brutal, but well intended, dissection is completed, you are handed back the precious pieces to try again - another opportunity to create a blossom, an even better blossom. This second chance is the last chance to create something truly beautiful. With high hopes and determination you set about the task of improvement. Soon, as the end nears, a feeling arises that cannot be suppressed. This feeling is like a whisper at first, but the whisper breaks free into an uncontrollable shout of pure joy that: "this one, surely this blossom, will grow into a magnificent peach of a final year project!"

While working on this project I was given the great opportunity of writing a paper for ORSSA's conference proceedings. With the help of my study leader, I was able to submit a paper and present it at the conference. The experience of writing a paper was frustrating at times, but it was surely worthwhile.

While working on my final year project the past several months, I have surely learned a lot. I have not only learned about my topic, which I believe I have come to understand well, but also about myself, time management and working with others. These are valuable skills that will definitely help me in my career.

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Appendix A Demand regression output before adjustments

```
Regression Analysis: Water Demand versus Rain, Evap, Damme

The regression equation is:

Water Demand = - 4.85 - 0.0198 Rain + 0.0569 Evap + 0.393 Damme

Predictor    Coef        SE Coef     T        P
Constant     -4.850      1.259       -3.85   0.000
Rain         -0.01979    0.01051     -1.88   0.061
Evap         0.056946    0.007577    7.52    0.000
Damme        0.39299     0.03933     9.99    0.000


S = 4.97107   R-Sq = 75.3%   R-Sq(adj) = 75.0%


Analysis of Variance

Source             DF    SS          MS       F         P
Regression         3     20504.4    6834.8   276.58    0.000
Residual Error     272   6721.5     24.7
Total              275   27225.9


Source    DF   Seq SS
Rain      1    8623.4
Evap      1    9413.6
Damme     1    2467.4


Durbin-Watson statistic = 0.887642
```

Appendix B Demand regression output after adjustments

```
Regression Analysis: Water demand versus AC Damme, AC Evap, AC Rain

The regression equation is:

Water demand = 9.27 + 18.1 AC Damme - 35.3 AC Evap + 17.6 AC Rain

Predictor    Coef       SE Coef    T        P

Constant     9.2717     0.6077     15.26    0.000

AC Damme     18.06      10.82      1.67     0.101

AC Evap      -35.307    9.035      -3.91    0.000

AC Rain      17.62      13.86      1.27     0.209


S = 4.50394   R-Sq = 83.0%   R-Sq(adj) = 82.1%

Analysis of Variance

Source             DF   SS        MS        F        P

Regression         3    5627.9    1876.0    92.48    0.000

Residual Error     57   1156.3    20.3

Total              60   6784.2


Source      DF   Seq SS

AC Damme    1    5307.8

AC Evap     1    287.3

AC Rain     1    32.8


Durbin-Watson statistic = 1.66621
```

Appendix C Supply regression output

```
Regression Analysis: Supply versus Damt-1, Rain, Evap, H1H029
The regression equation is:
Supply = 4.13 + 0.815 Damt-1 + 0.115 Rain + 0.0610 Evap + 0.290 H1H029
Predictor    Coef       SE Coef    T        P
Constant     4.133      9.462      0.44     0.663
Damt-1       0.81454    0.03079    26.45    0.000
Rain         0.11484    0.05668    2.03     0.044
Evap         0.06101    0.03673    1.66     0.098
H1H029       0.29042    0.07149    4.06     0.000

S = 29.1987   R-Sq = 74.4%   R-Sq(adj) = 74.0%
Analysis of Variance
Source            DF   SS        MS        F        P
Regression        4    670395    167599    196.58   0.000
Residual Error    271  231044    853
Total             275  901439

Source      DF   Seq SS
Damt-1      1    649109
Rain        1    7139
Evap        1    76
H1H029      1    14071

Durbin-Watson statistic = 1.80168
```

Appendix D Schematic representation of Breede River and its tributaries