QUALITY ASSESSMENT OF AGRICULTURAL WATER USED FOR FERTIGATION IN THE BOLAND DISTRICT

by

Bulelani William Mgcoyi

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Supervisor: Mr. M.M. Sedibe

Co-supervisors: Prof. C. van der Westhuizen

Dr. N.J.J. Combrink

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DECLARATION

I, **Bulelani William Mgcoyi** the undersigned, hereby declare that the work contained in this dissertation is my own original work and has not previously in its entirety or in part been submitted at any university for a degree.

Date 03 October 2011

Signature

ABSTRACT

Quality assessment of agricultural water used for fertigation in the Boland district. The study was undertaken to determine the influence of seasonal changes on the water quality (chemical and microbial analyses) of five different rivers in the Boland. The data was collected in the five most important water sources that are used for irrigation purposes in the district, i.e. Berg river, Eerste river, Klapmuts River, Klippies river and Krom river. The samples were collected from all sites once every three weeks for a period of six months. The sampling was carried out during specific periods in summer (December, 2006 to February, 2007) and winter (June to August, 2007). The results of the study showed that Klapmuts river recorded the highest levels of chloride and iron, especially in summer. However, chloride levels were far below the levels set by the Department of Water Affairs and Forestry. Results obtained from this study show the presence of pathogens in some of the rivers assessed which may have resulted from the leaching of these pathogens from nearby agricultural land, livestock watering or informal settlements in the catchment areas.

The bigger rivers recorded low levels of micro-elements and this might have been affected by winter rainfall. In the Berg River, many sources of nitrate pollution seem to be present in the catchment area. The levels of iron in all the rivers assessed were far more than the levels set by the Department of Water Affairs and Forestry in all rivers assessed and these might be due to the pH levels and interaction between the rivers and seasons. Iron and manganese levels should be kept low as this may cause production problems by blocking irrigation drippers.

The water samples tested for bacterial and fungal density showed Klapmuts and Eerste rivers were positive for *Phytophthora cinnamomi* during winter. *Phytophthora citricola* and *Phytophthora cactorum* were detected in the Klapmuts and Klippies rivers in summer. The Berg-, Klapmuts-, Krom- and Eerste rivers tested positive for species of the genera *Pythium* and *Fusarium*. Similar organisms were detected in the Eerste river mainly during summer on the fourth sampling date, while Krom river only tested positive for *Pythium* during summer. The total bacterial and algal density differed significantly between the seasons and was highest in winter. This might be due to high rain water influx and efflux and/or moist and aerobic conditions and air temperature. There is an increased need for farmers to sterilize feeding water (chlorination) due to high microbial count.

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ABBREVIATIONS

S	Sulphur
B	Boron
Ca	Calcium
C	Carbon
$N0_3$	Nitrate
Mn	Manganese
MNA	Modified Nutrient Agar
CV	Critical Value
Mg	Magnesium
Na	Sodium
pH	Pondus Hydrogenii
EC	Electrical Conductivity
SAR	Sodium Adsorption Ratio
L. INDEX	Longevity index
R. INDEX	Rayznar index
A. INDEX	Aggressiveness Index
Zn	Zinc
Fe	Iron
ESP	Exchangeable Sodium Percentage
DWAF	Department of Water Affairs and Forestry
Cl	Chloride
Cu	Copper
$mS\ cm^{-1}$	Milli-Siemens per centimetre
K	Potassium
N	Nitrogen
P	Phosphorus
^{O}C	Degrees Celsius
DOC	Dissolved Organic Compounds
TDS	Total Dissolved Salts
TOC	Total Organic Carbon
NFT	Nutrient Film Technique
WRC	Water Research Commission

ICP	Inductively Coupled Plasma
LSD	Lysergic acid diethylamide
Mg l^{-1}	Milligram per litre
µg per mg	Micrograms per milligram
µm	Micrometre
SASS	South African Scoring System Version 4
DEDP	Department of Energy, Development and Promotion
NRF	National Research Foundation
NDA	National Department of Agriculture
CUT	Central University of Technology

CHAPTER 1

Introduction

1.1 Background

Fertigation is the application of fertilizers, soil amendments, or other water soluble products through an irrigation system. Fertilizer solutions and suspensions are injected into irrigation systems via calibrated injection pumps ensuring precision. Effective fertigation requires knowledge of certain plant characteristics, such as optimum daily nutrient consumption rate and root distribution in the soil (North Carolina Department of Agriculture and Consumer Services, 2009). Irrigation water quality factors such as pH, mineral content, salinity and nutrient solubility must also be considered. The moisture requirements of plants are the main determining factor in fertigation, because the irrigation system is primarily installed to provide water. The Boland area is known for producing grapes, citrus and vegetables (potatoes, carrots etc.)

Water used for irrigation can vary greatly in quality depending upon type and quantity of dissolved salts, pH, mineral content, and nutrient solubility. Salts that are present in irrigation originate from dissolution or weathering of the rocks and soil (lime, gypsum and other slowly dissolved soil minerals). The suitability of water for irrigation is determined not only by the total amount of salt present but also by the kind of salt. Increased total salt content of the soil may result in the development of various soil and cropping problems. To maintain acceptable crop yields the development of special management practices may be required (Ayers and Westcot, 1994).

Water supply for irrigation may originate from large reservoirs, farm dams, rivers, ground water, municipal suppliers and industrial effluent (Department of Water Affairs and Forestry, 1996). Most irrigation schemes rely on an adequate supply of water from untreated water sources, while home gardeners receive their water supply from conventionally treated water of a good quality (Department of Water Affairs and Forestry, 1996). The quantity and quality of water from rivers is highly variable and this is due to seasonal droughts or floods, the quality of ground water also varies greatly (Department of Water Affairs and Forestry, 1996). Some water quality problems are associated not only with the presence of a chemical composition, but with the interactions between compositions, for example, infiltration of water into the soil which is affected by both the sodium adsorption ratio and the total dissolved solids of water (Department of Water Affairs and Forestry, 1996).

The agricultural sector in South Africa represents about 5% (R22.814 billion) of the gross domestic product. In the Western Cape, agriculture supports about 11 000 farmers with an annual output of about R9 billion, and the provision of about 1.6 million employment opportunities (Department of Water Affairs and Forestry, 2001). Most of the cultivated area in the Boland district of the Western Cape Province is under irrigation. The Department of Water Affairs and Forestry (1999) has reported that the annual average rainfall for the Western Province is 515 mm more than South African annual average of 497 mm. The Western Cape's climate differs considerably from prevailing climatic conditions in the rest of South Africa. Most of the province, especially the extreme southwest, experiences a Mediterranean type climate that is characterized by cool, wet winters and warm, dry summer seasons (Department of Water Affairs and Forestry, 1999).

Water is essential for sustaining life and is a primary agricultural production factor. It has also been identified as an economic resource and its use has a major impact on the creation of wealth and the well being of people (Du Preez *et al*., 2000). Moreover, human activities over the years have led to the drastic deterioration of the quality of available water. These losses result from the increasing use of water for civil and industrial settlements, road networks and agriculture. Agriculture uses about 60% of the available water throughout the world (Tognoni *et al*., 1998). Irrigation water is used to supply the water requirements of a wide variety of plants under widely varying degrees of infestation, with a range of different distribution and application systems, to a wide range of soil over all climatic ranges in South Africa, a wide spectrum of problems may be encountered where water does not meet requirements (Department of Water Affairs and Forestry, 1996).

In South Africa, however, agriculture uses about 50% of our available water (Department of Water Affairs and Forestry, 1996). Increasing water needs claimed for domestic, industrial and mining usages, may decrease agriculture's share to less than the current 50%. Inefficiency in water utilization is becoming a major constraint for the country’s vision of sustainable agriculture and rural development (De Villiers e*t al*., 2003). Thus, better utilization of this resource is imperative since less than 20% of South Africa has a sub-humid climate with a mean annual rainfall higher than 750 mm. In most parts of South Africa, water supplementation through irrigation is essential for economic production of crops (Backeberg *et al.,* 1996).

1.2 Problem statement

Irrigated agriculture is dependent on an adequate water supply of usable quality. Water quantity is not the only key factor for successful cultivation of crops in a soil-less production system. Water quality concerns have often been neglected in the past because good quality water supplies have been plentiful and readily available. This situation is now changing in many areas. Water quality is a crucial factor that is based on specific concentrations of ions, phytotoxic substances and the presence of micro-organisms (Schwarz *et al*., 2005). The contamination of surface water by micro-organisms is an area of great concern, because hydrological pathways may serve as vectors for the transmission of diseases. Only a few of these pathogens may then be transferred to the water source through rain (Oliver *et al.,* 2005). For soil-less production, growers use water sources of different origins (rivers, dams, lakes, boreholes, artificial ponds).

1.3 Objectives

The objectives of this study were:

1.3.1 to determine the water quality of selected rivers in the Boland region by focusing on the concentrations of specific ions and phytotoxic substances as well as the presence of micro-organisms;

1.3.2 to determine the influence of seasonal changes on the water quality (i.e. rainy season vs. dry season);

1.3.3 to assess whether the quality of water found in the Boland rivers conforms to the general guidelines required for open field fertigation.

CHAPTER 2

Literature Review

2. Literature Review

2.1 Introduction

Various general factors are used to define and describe water quality. All these factors are based on the actual purpose for the use of the water. However, for fertigation purposes, water quality can be limited to the following enumerated factors: The concentration of dissolved salts is used as an indicator of the potential quality of the irrigation water (measurable as the electrical conductivity); the concentration of micro-nutrients, although they usually do not affect the electrical conductivity (EC) of the nutrient solution, they might still be present at phytotoxic levels in the irrigation water; total alkalinity is used to calculate the pH adjustment; some water sources containing high concentrations of phytopathogens might require sterilization (Combrink, 2005; Schwarz *et al.,* 2005).

Schwarz *et al*. (2005) reported that rainwater contains a high diversity of non pathogenic bacteria (45 species from 25 genera), and poor diversity of algae (15 species from 4 groups). Therefore, the quality of rainwater is suitable for hydroponic production due to a lack of potential bacterial and algal development and conforms well to the water quality guidelines (Schwarz *et al*., 2005).

Water sources used for the production of crops in greenhouses include rain water, municipal water or water from wells and natural water reservoirs. Municipal water and natural water reservoirs in South Africa pose an increased risk for the accumulation of organic compounds and plant pathogenic micro-organisms. Cucumber mosaic virus and both *Erwinia carotovora* and *Erwinia chrysanthemi* were found in lakes, rivers, and reservoirs during the summer season. The presence of these microorganisms affected the water quality and consequently released allelochemicals inhibiting plant root development (Waechter-Kristensen *et al.,* 1999).

Water from low rainfall areas may contain high levels of salts which might have negative effects on some plant species (Combrink, 2005). Low rain may decrease agriculture's share and lowering the yield potential (Al-Jamal *et al.*, 2001).

2.2 Water characteristics that influence plant growth

2.2.1 Effects of water quality on plants

The electrical conductivity (EC) of rainwater is 0 mS cm^{-1} (Pienaar, 2005), implying that any crop can be grown successfully with rainwater by adding the entire complex of essential nutrients at the correct concentrations. Electrical conductivity is a parameter used to measure the concentration of salts in the solution, and higher salt concentrations can have a negative impact on the yield of a given crop (Pienaar, 2005). Therefore, it is crucial to maintain the EC of the nutrient solution at the correct level according to specific crops' requirements (Stanghellini *et al.,* 1998). There are however some crops (amaranthus, swiss chard, melon and cherry tomatoes) that are tolerant towards a relatively high EC of >3 mS cm^{-1} (Sedibe *et al.,* 2005; Combrink, 1998).

Schwarz & Kuchenbuch (1998) reported that the growth and yield of tomatoes decreased with an increasing EC. At 6 mS cm^{-1}, tomato yield was 50% less, compared to plants grown at 1 mS cm^{-1}. Water uptake decreased with an increasing EC. At an EC of 9 mS cm^{-1} water uptake was reduced to 60%, compared to plants grown at an EC of 1 mS cm^{-1}. This reduction in water uptake was mainly due to a decrease in leaf area. At an EC of 9 mS cm^{-1}, the leaf area was 20% smaller, compared to plants grown at the lowest EC (1 mS cm^{-1}). Water use efficiency (WUE) increased at increasing EC levels when related to the total biomass and decreased when related to tomato fruit yield. Increasing the EC from 1 to 6 mS cm^{-1} caused a rise of up to 50% in the dry matter content of the fruits, while the total dry matter of the vegetative parts of the plant was reduced by about 10%. When using a nutrient solution with an EC of 6.3 mS cm^{-1} or more, tomato production was unprofitable due to the negative correlation between water consumption and EC. Water use efficiency expressed as fruit yield per litre of water uptake per day, at EC values of 2.7, 6.3, 9.8 and 13.0 mS cm^{-1}, was 2108, 2172, 1327, and 2405 g l^{-1} respectively. Water uptake was shown to be the limiting factor for tomato fruit production under saline conditions. The quantity of water that was taken up was transformed into fruit at a similar rate for the four EC treatments (Soria & Cuartero, 1998). Combrink (1998) found that the reduced tomato fruit yield with increasing salinity levels was directly related to a reduction in fruit size and that salinity level did not cause any significant difference in the number of fruit harvested. Where 18.50 mmol NaCl was added to a standard nutrient solution to increase the EC from 2.2 to 3.9 mS cm^{-1}, yield was reduced by 30% and fruit mass by 33%.

According to Leornardi (1998), celery seems to be more tolerant to saline conditions compared to tomatoes. He reported that an increase in the EC of a nutrient solution up to 10.5 mS cm^{-1} did not affect plant dry matter production of celery. Plant dry weight only decreased at the highest salt concentration (16 mS cm^{-1}). At this high EC treatment, total N production per plant was significantly lower due to a reduction in plant weight.

Karam *et al.* (1998) reported that tuber yield of potatoes and evapotranspiration were sensitive to both salinity and soil texture. Water use efficiency was not affected; although the tuber yield on clay soil was 30% lower than that on loam soil. Tuber dry yield equalled 1.75 and 1.52 kg m^{-2} on loam and clay soils respectively, with averages of 4.69 and 4.60 kg m^{-3} for water use efficiency.

In any re-circulating system, waterborne pathogens may accumulate and diseases may spread. Algae may develop where nutrient solutions are exposed to light. Apart from the hazard of blocked filters caused by the presence of algae in the re-circulating water, big vein virus can be transmitted to lettuce, causing enlargement of the vascular bundles. Most prominent pathogens in re-circulating hydroponic units are *Phytophthora cinnamomi* and *Randopholus similis* (Van Os *et al.,* 1999).

2.2.2 Root exudates and accumulation of ions

It is known that when a re-circulating system is used, a build up of impurities from the water or from applied chemicals may change the original balance of nutrients and other sources of impurities may originate from the plant itself (Hurd, 1978). A whole range of substances are known to be exudates by plant roots, including cytokinins (Hurd, 1978). Waechter-Kristensen *et al.* (1999) reported that most of the organic compounds in closed hydroponic systems originated from the incoming water, the substrate, microbial activity and root exudates.

The release of these organic compounds by the roots differs between species and cultivars and also depends on plant developmental stage and other external factors affecting plant growth such as light, CO_2, O_2, nutrient supply, temperature and micro-flora (Waechter-Kristensen *et al.,* 1999). Cucumber seedlings are affected by several peptides (Waechter-Kristensen *et al.,* 1999). According to Sundin *et al.* (1997) ferulic acid found in the nutrient solution of lettuce, inhibited root hair formation, root elongation and growth. Turkey (1977) found peaks of growth substance concentrations in the solution at times when the lettuce roots were dying. It was difficult to decide whether the roots were killed by the build up of these growth substances or whether the substances were liberated by dying roots.

2.2.3 Substrate and microbial activity

Organic compounds in nutrient solutions are monitored by measuring the total organic carbon (TOC) which reflects a complex matrix, containing different types of carbon occurring in the nutrient solution (Waechter-Kristensen *et al*., 1999). This includes damaged roots, micro-organisms and dissolved organic compounds (DOC). It was found that the DOC values in filtered (>0.22 µm) water varied between greenhouses (Waechter-Kristensen *et al*., 1999). During the measuring of DOC it was found that for five open systems containing rockwool, mean DOC varied from about 10 to 40 mg L^{-1}. For three closed systems tested, the mean DOC varied from 11 mg L^{-1}, measured at the end of the gutters for lettuce in NFT, to 53 mg L^{-1} between cucumber plants in rockwool. In a commercial tomato culture, using closed hydroponics with drip irrigation on rockwool slabs, the DOC value ranged from 10 to 40 mg L^{-1}. There is, however, little information on the TOC and DOC values for closed hydroponic systems. The values reported are within the recommended range for healthy vegetable crop production in hydroponics (Waechter-Kristensen *et al*., 1999).

2.2.4 Water and soil-borne pathogens

2.2.4.1 *Erwinia carotovora*

According to Cappaert *et al.,* (1998) *Erwinia carotovora* commonly occurs in irrigated fields and its soft rot symptoms range from general wilting of the foliage to a light brown to inky black coloration of the stems. Soft rot (*Erwinia* spp.) also has been found in ground water, rivers, oceans, aerosols and rain water (Cappaert *et al.,* 1998). Cappaert *et al*., (1998) detected *Erwinia* cv. *carotovora* in both surface and well water in Oregon and Colorado in the USA.

2.2.4.2 *Erwinia chrysanthemi*

This is a soft rot bacteria that degrades succulent fleshy plant organs such as tubers, stem cuttings, thick leaves and roots (Cappaert *et al.,* 1998). It is also reported as a vascular wilt pathogen, colonizing the xylem and becoming systemic within the plant (Cappaert *et al.,* 1988).

High temperatures (25-30^{o}C) and high humidity in free water favour the spread and penetration of these bacteria. *E. chrysanthemi* causes similar symptoms to *E. carotovora*. However it depends mostly on the environment, plant cultivar and part of the plant affected. *E. chrysanthemi* also occurred in Oregon surface water samples and was detected in Colorado (Cappaert *et al*., 1998).

2.2.4.3 Phytophthora *cinnamomi*

Phytophthora cinnamomi is a parasitic fungi causing brown rot in plants. The *P. cinnamomi* body appears like white hair threads. Spore sacs are produced on the mycelium under moist and aerobic conditions and at temperatures of 22-28^{o}C (Department of Environmental Affairs and Development Planning, 2004).

The severity of *P. cinnamomi* is determined by a range of factors e.g. temperature, soil type and rainfall (Department of Environmental Affairs and Development Planning, 2004). *P. cinnamomi* is generally found in areas where:

- Average annual rainfall is greater than 500 mm.

- Soils **-** acid and neutral with low amounts of nutrients and organic matter.
    - have few micro-organisms.
    - have poor drainage.

P. cinnamomi was first recorded in many Australian states in 1960's and 1970's (Department of Environmental Affairs and Development Planning, 2004). In South Africa it was first identified in the Mount Lofty Ranges in 1972 (Department of Environmental Affairs and Development Planning, 2004). In Kangaroo Island it was first identified in 1993 (Department of Environmental Affairs and Development Planning, 2004). It mostly affects fruits, lupins, nuts, vegetables and ornamental plants (Department of Environmental Affairs and Development Planning, 2004).

2.2.5 Accumulation of heavy metals in field crops

Toxic metals can enter plant tissue from the soil, rainwater deposition and irrigation with sewage effluents (Sánchez *et al*., 1999). The uptake of heavy metals by plants can detrimentally affect growth and can cause health hazards to humans and animals feeding on these affected plants. The effect of any toxic element on plants depends not only on its chemical properties but also on the presence of other elements. Heavy metal contamination does not involve a single metal, but rather a combination of metals. Total plant dry weight in *Phaseolus vulgaris* decreased significantly as heavy metals increased (Sánchez *et al*., 1999). The dry mass of plants from a high concentration treatment was 49.5% less than the control. Plants in the high concentration treatment exhibited Zn, Cd, Ni, B, Mn and Cu toxicity symptoms as intravenous chlorosis on older leaves (Sánchez *et al*., 1999).

2.2.6 Effect of macro and micro elements on crop growth and development

There are sixteen elements currently considered to be essential for plant growth (Hochmuth and Hochmuth, 2001). The crop demand for nutrients changes through the seasons (Hochmuth and Hochmuth, 2001). Small amounts of nutrients are needed in the early stages and then the demand will increase as the crop grows, especially after fruit have been set on the plant (Hochmuth and Hochmuth, 2001).

Agrichem (2007) reported that the ratio of nutrients available for crops is important as an excess of one nutrient can result in a deficiency of another element. Micro elements (iron, manganese, boron, zinc, etc.) are essential for plant growth but they are required in smaller amounts than macro elements (nitrogen, phosphorus, calcium, etc.). To achieve maximum yield, crops require adequate supplies of essential plant nutrients. The nutrient uptake by plants is determined by:

- The availability of nutrients held on soil particles.
- The supply of nutrients to the plant’s root surfaces.
- The nutrient absorption rate at the root surface (Agrichem, 2007).

CHAPTER 3

Material and Methods

3. Materials and Methods

3.1 Study sites

This study was conducted in the Boland district region of the Western Cape Province. The Western Cape Province is one of the nine provinces of South Africa, and is situated between 30^{o}30 - 34^{o}45'S and 17^{o}50 - 24^{o}10'E, occupying an area of about 129 370 km^2. It is bound by the cold Atlantic Ocean to the west and the warmer Indian Ocean to the south east (Department of Environmental Affairs and Development Planning, 2004). The data was collected in the five most important water sources that are used for irrigation purposes in the district, i.e. Klapmuts River, Klippies River, Berg River, Eerste River and Krom River (see Figure 1).

Figure 1 GIS map of selected rivers of the Boland region (Adapted from Keyser, 2009).

The farmers in the Boland district use electric pumps and generators to pump water from the rivers, because it is cheaper than using municipal water. Some of these areas have no water supply infrastructure. Major pollution impacts to the rivers occur in their middle and lower catchment areas and are a consequence of agricultural practices (fertilizers and pesticides).

There is limited information available on the literature and on government documents that describe the Krom and Klippies rivers in detail. This lack of information might be due to the size and the area that these rivers cover. The only Information available is on the three of the five rivers evaluated on this study, and it is listed below:

3.1.1 Berg River

The Berg River is located between Franschhoek and Laaiplek in Cape Town in the Western Cape Province (Figure 1). It is approximately 294 km long with a catchment area of 7,715 km^2 and an outlet into the Atlantic Ocean (Department of Environmental Affairs and Development Planning, 2004). It is estimated that approximately 65% of the Berg River catchment area is utilized for agriculture. About 30% of the Berg River catchment area is natural shrub-land, bush-land, grass-land and water bodies and wetlands. Approximately 4% of the catchment area is degraded, comprising mainly shrub-land and bush-land. Water pollution is caused by residential, commercial and industrial waste (Department of Environmental Affairs and Development Planning, 2004).

3.1.2 Klapmuts River

The Klapmuts River is located in Klapmuts, north of Cape Town (Figure 1). The water quality of the Klapmuts River is primarily impacted by agricultural-related activities rather than by urban activities, based on SASS4 data. This river is mainly used for irrigation and livestock (Department of Water Affairs and Forestry, 1999). It is reported that the Klapmuts River has lost its summer flow in certain areas due to the construction of in-stream dams directly resulting in the subsequent invasion of the habitat by exotic invasive plants (Boucher, 2009).

3.1.3 Eerste River

The Eerste River is a short river covering a distance of about 40 km (Figure 1). It arises on Dwarsberg 60 km east of Cape Town at the head of Jonkershoek. The Eerste River catchment area covers the eastern part of the Cape Flats lying to the west of the Hottentots Holland Mountains and south of the Tygerberg. The most important land use in the catchment area is viticulture (River Health Programme, 2005*).* The Department of Water Affairs and Forestry (1996) reported that the water from the Eerste River is highly polluted. It is believed that this is a biological indication of the severe pollution of the water. Some bacteria and viruses have been found in this river (e.g. *Phytophthora, Pythium, Fusarium* etc.).

3.2 Data collection

3.2.1 Data sampling

Water samples were collected from five rivers in the Boland area. The samples were collected from all sites once every three weeks for a period of six months. The sampling was carried out during specific periods in summer (December, 2006 to February, 2007) and winter (June to August, 2007). Water samples were collected on the following dates: 9 December 2006, 6 January 2007, 3 February, 25 February, 10 June, 1 July, 29 July and 26 August 2007. The eight samples collected from each river were kept in sterilized 500 ml glass bottles. The sub-samples were collected from 2 horizontal and 2 vertical positions in each river. The water samples were collected at 0.5 m below water surface and 0.5 m above the bottom of the river. These sub-samples were combined together and then divided into two samples, for analysis of nutrient concentration and determination of microbial species (Schwarz *et al.,* 2005). The samples were stored in a cooler-box, before being transported to the laboratory. Water temperature was measured continuously at two vertical points in the middle of the river at 0.5 m below the water surface (Appendix B). Air temperature was also monitored at 2 m above water level and the sampling was done in river flow conditions (Appendix B).

3.2.2 Sampling procedures

The following procedure was followed when collecting the samples, as recommended by the Water Research Commission (2000):

- At the sampling point care was taken not to contaminate the inner surface of cap and neck of the sample bottle with the hands;
- The samples were then taken by holding the bottle by hand near its base and plunging the sample bottle, neck downward, below the water surface. Gloves were worn to prevent contact with the water;
- The bottle was turned until its neck points slightly upward and directed into the current (can also be created artificially by pushing the bottle forward horizontally in a direction away from the hand);
- The sample bottle was filled with water;
- Before closing the sample bottle, ample space was left (at least 2.5 cm) to facilitate mixing by shaking before analysis;
- Each bottle was labeled and placed in a cooler box.

3.3 Data analysis

3.3.1 Chemical analysis

The Inductively Coupled Plasma (3120-B) method was used to measure the levels of Ca, Mg, Na, K, P, S, Cu, Zn, Mn and Fe. Boron and Cl were measured by the 4500-Cl B Argentometric method. Nitrate and NH_4^+ were measured reflectometrically by the Reflectoquant, Merck® test kit (Clesceri *et al.,* 1989; Manahan, 1979).

3.3.2 Microbiological analysis

Erwinia carotovora and *E. chrysanthemi* from the water samples were cultured in Modified Nutrient Agar (MNA) (yeast extract, glucose and nutrient agar (Difco, Bacteriological)) and Kings Medium B (KMB) (Proteose Peptone (DifCo®)), dipotassium hydrogen phosphate, magnesium sulphate, glycerol, agar (Difco, Bacteriological®) and distilled water, before identifying and purifying these colonies on MNA plates (Hossain *et al.,* 2005). Conversely, *Phytophthora* spp. from the water samples were cultured in PARP (Ampicillin, Rifampicin, PCNB, Cornmeal Agar (Difco®), and distilled water); PARPH (PARPH is the same as PARP except for Hymexazol added after sterilization of Hymexazol) and BNPRA (Rhizolex, PCNB, Benomyl, Ampicillin, Rifampicin, Agar (Difco, Bacteriological®) and Distilled water)).

3.4 Statistical analysis

Significant results were analyzed using Tukey's Least Significant Difference test, described by Steel and Torrie (1980), at 5% level of significance to determine statistically significant differences between treatment means using the General Linear Model (GLM) of the Statistical Analytical System (SAS, 2004) package.

CHAPTER 4

Results and Discussions

4. Results and Discussion

4.1 Chemical composition of the water

The crops that are produced in the Boland district are peppers, tomatoes, grapes, cucumbers, cauliflowers, sunflowers, spinach, cabbages, apricots, apples, etc. Crops like tomatoes, cucumbers, lettuce, pepper, apricots, apples and grapes are normally irrigated by fertigation (River Health Programme, 2005*).* These crops are grown on open fields and in tunnels and are mostly fertigated by drip irrigation systems.

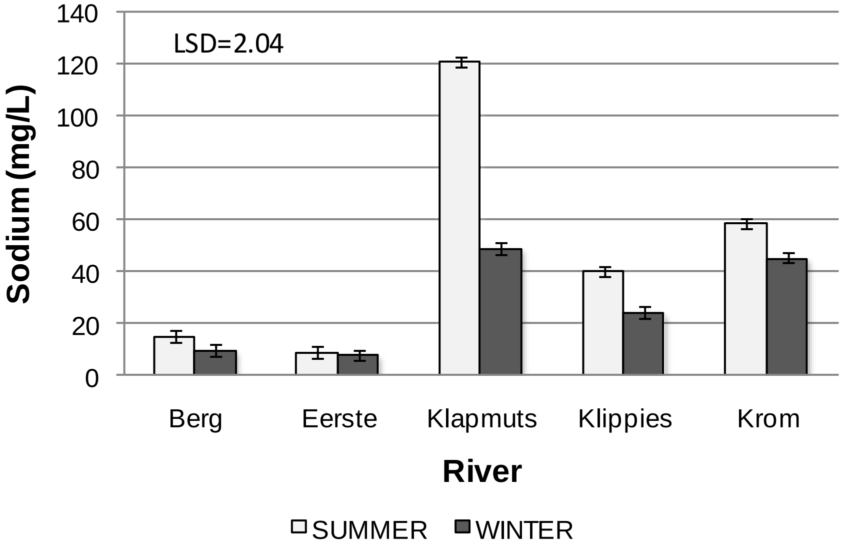

Figure 2 Sodium levels for different rivers during summer (9 December 2006, 6 January 2007, 3 February & 25 February) and winter (9 June, 1 July, 29 July & 26 August 2007).

There was a significant (P<.0001) interaction between rivers and seasons (Appendix A, Table A1) for cations composition. Sodium levels were significantly high in the Klapmuts, Klippies and Krom rivers during dry summer season when compared to the Berg and Eerste rivers (Figure 2). The greatest change in concentration occurred in the smaller rivers (Klapmuts, Klippies and Krom rivers) with their relatively high Na concentrations. By far the greatest change between summer and winter was found in the Klapmuts River (Figure 2).

The levels of Na obtained in this study are very low compared to the recommended levels (115–460mg L^{-1}) of the Department of Water Affairs and Forestry. The water from all five rivers would thus be suitable during winter months. Only the Klapmuts River may contain too much Na for saline sensitive crops such as almonds, apricots, citrus and plums. However, the 120mg L^{-1} Na obtained in summer can be used for saline tolerant crops such as grape, pepper, potato and tomatoes. Crops vary in foliar absorption rates of Na (Combrink, 2005). The sodium absorption rates of avocados are low while those of citrus, stone fruits and almonds are high (Combrink, 2005). According to Combrink (2005), saline sensitive crops can be grown in soil-less conditions with <70mg L^{-1} Na in solution.

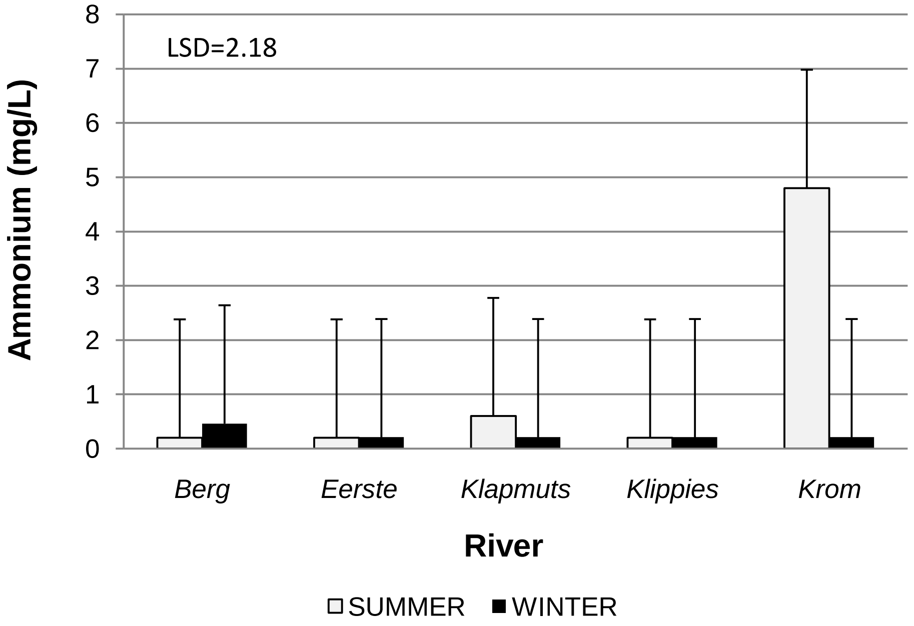

Figure 3 Ammonium levels for different rivers during summer (9 December 2006, 6 January 2007, 3 February & 25 February) and winter (9 June, 1 July, 29 July & 26 August 2007).

The average measured levels of ammonium are presented in Figure 3. Ammonium levels were influenced significantly (P<.0001) by the interaction between rivers and seasons (Appendix A, Table A1). Only the Krom River had high levels (4.8 mg/L) of NH_4^+ in summer (Figure 3). Ammonium levels recorded from other rivers are lower than the maximum level (1mg/L) allowed for vegetable crops, but it is high enough to satisfy the total NH_4^+ need of peppers (Combrink, 2005).

There is limited information available on the literature that describe Krom River and crops irrigated from this river. The ammonium levels reported on this study are suitable for most sensitive crops like grapes and fruit trees that are grown on open field and hydroponic production. Modern soil-less growers use small quantities of ammonium in their nutrient solutions for its acidifying effect, preventing rises in pH and the precipitation of Fe and Zn (Combrink, 2005). Care should thus be taken to use NH_4^+-free fertilizers when using this water in summer to grow peppers. Since the NH_4^+ level in the Krom River rises substantially during summer, the possibility of pollution by dairy farmers in the catchment area does exist. Growers using this water may note that the pH of drained fertigation water decreases, since only a slight increase in NH_4^+ concentration may lower the pH of a nutrient solution applied to plant roots (Combrink, 2005).

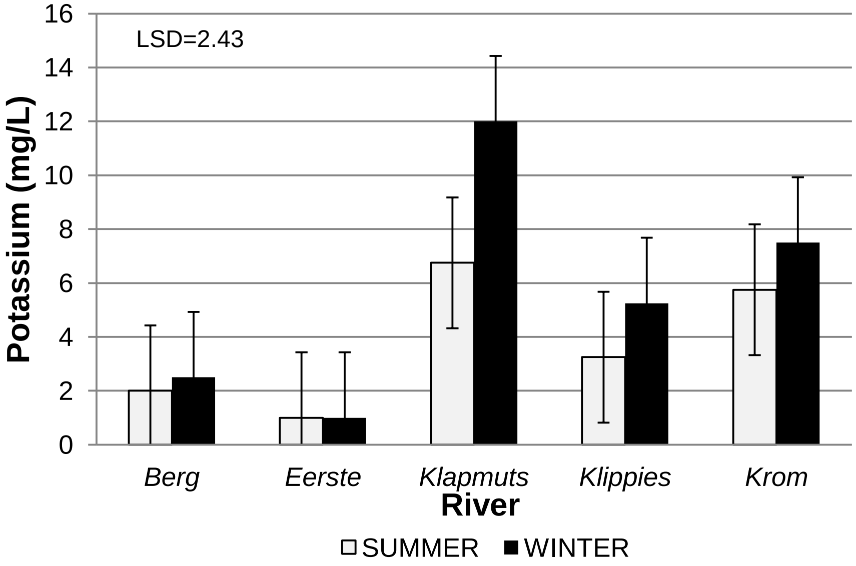

Figure 4 Potassium levels for different rivers during summer (9 December 2006, 6 January 2007, 3 February & 25 February) and winter (9 June, 1 July, 29 July & 26 August 2007).

The average measured levels of potassium are presented in Figure 4. The levels of K^+ were significantly (P=0.02) influenced by the interaction between seasons and rivers (Appendix A, Table A1). The Klapmuts-, Klippies- and the Krom rivers had high levels (5-12 mg/L) of K^+ which were especially prevalent during the winter season.

Since salts tend to accumulate in dry seasons, the increased K^+ concentrations during the wet winter months cannot be explained, but as expected, the Berg and Eerste rivers contained less K^+. However, most levels were relatively lower than 7 mg/L and would not affect fertigation practices in hydroponic plant production systems.

Table 1 Calcium levels of different rivers evaluated during summer (9 December 2006, 6 January 2007, 3 February & 25 February) and winter (9 June, 1 July, 29 July & 26 August 2007).

River	**Parameters**
	Ca^{2+} (mg/L)
Berg	5.75±1.75
Eerste	2.38±0.74
Klapmuts	30.50±10.35
Klippies	15.50±6.44
Krom	34.25±7.94
$LSD_{0.05}$	9.29
CV%	2.05
Shapiro-Wilk (P value)	0. 25

CV% = Critical Value of t
± = Standard deviation
LSD = least significant difference

Calcium levels differed significantly (P<.0001) between the rivers (Appendix A, Table A1). Klippies-, Klapmuts- and Krom rivers had higher levels (15-34 mg/L) of Ca^{2+} than the Berg- and Eerste rivers (<6mg/L, Table 1).

These levels were high enough (15-35 mg/L) to be taken into account when using Klapmuts-, Klippies- or Krom river water for fertigation (Combrink, 2005). Water sources may contain low levels (<5mg/L) of calcium in low rainfall areas, and relatively high levels calcium (>15mg/L) may be found in saline water (Combrink, 2005). Calcium difficiency in crops like tomatoes, peppers and cucumbers is usually die-back of the growing tips, fruit failing to ripen properly, restricted growth, scorched leaf margins and dark green, small leaves which later turn yellow or orange or even purple (Niederwieser, 2001).

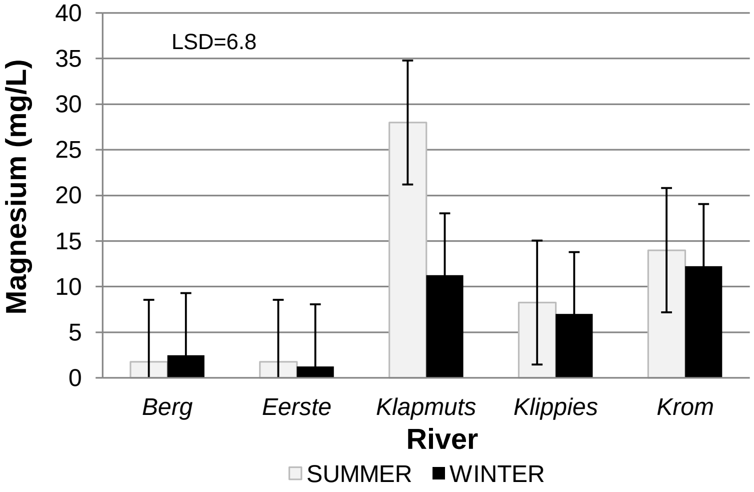

Figure 5 Magnesium levels for different rivers during summer (9 December 2006, 6 January 2007, 3 February & 25 February) and winter (9 June, 1 July, 29 July & 26 August 2007).

An interaction between seasons and rivers (Appendix A, Table A1) significantly (P<0.001) affected the levels of magnesium. Only the Klapmuts River had a higher concentration (28mg/L) of Mg^{2+} during the dry summer months (Figure 5). This might be due to the low rainfall during summer. The change in Mg content between summer and winter will force growers to change their Mg^{2+} applications at least twice in a year.

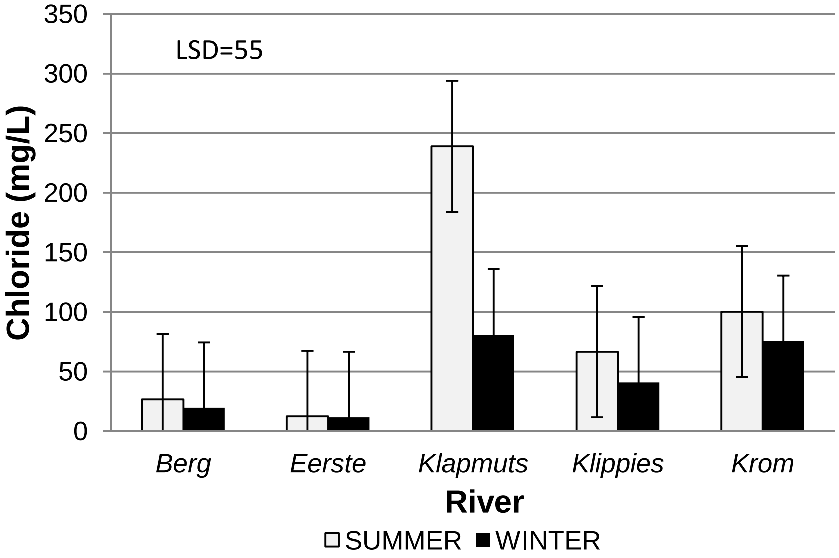

Figure 6 Chloride levels for different rivers during summer (9 December 2006, 6 January 2007, 3 February & 25 February) and winter (9 June, 1 July, 29 July & 26 August 2007).

Chloride levels were significantly (P<.0001) influenced by an interaction between rivers and seasons (Appendix A, Table A2). Only the Klapmuts River had a significantly higher (P<0.0001) level of chloride during summer, than during winter (Figure 6). High levels of chloride might limit the uptake of nitrate (Combrink, 2005).

Table 2 Nitrate levels of different rivers evaluated during summer (9 December 2006, 6 January 2007, 3 February & 25 February) and winter (9 June, 1 July, 29 July & 26 August 2007).

River	**Parameters**
	NO_3^- (mg/L)
Berg	7.13±6.79
Eerste	3.00±0.00
Klapmuts	7.75±5.42
Klippies	3.25±0.71
Krom	4.13±1.55
$LSD_{0.05}$	2.18
CV%	2.04
Shapiro-Wilk (P value)	0.0001

CV% = Critical Value of t
± = Standard deviation
$LSD_{0.05}$ = least significant difference

Nitrate levels differed significantly (P=0.02) between rivers (Appendix A, Table A2). The Klapmuts- and Berg rivers had significantly higher levels of NO_3^- than the other three rivers. The nitrate level (7.13mg/L) of the Berg River is higher than expected for such a big river (Table 2). However, many sources of nitrate pollution seems to be present in its catchment area. This might be caused by leaching of nutrients and water pollution by commercial and industrial waste.

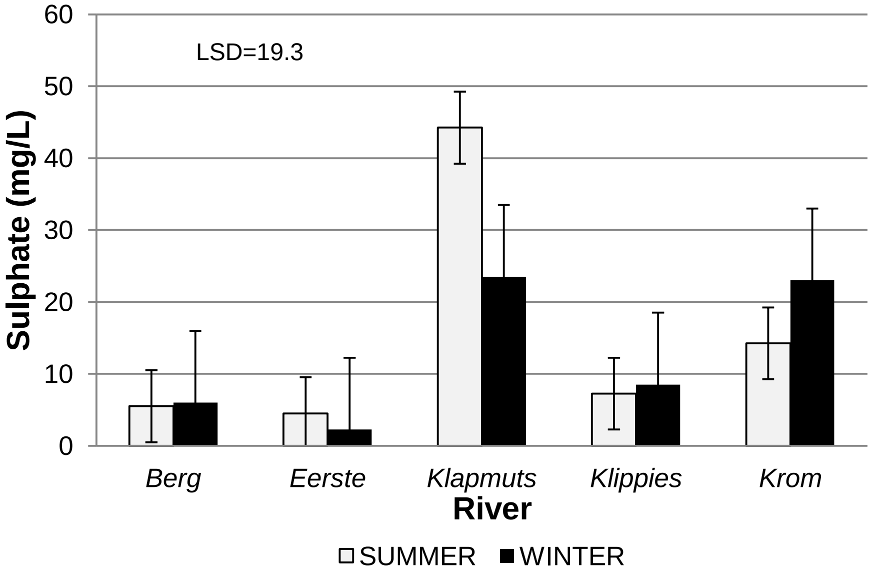

Figure 7 Sulphate levels for different rivers during summer (9 December 2006, 6 January 2007, 3 February & 25 February) and winter (9 June, 1 July, 29 July & 26 August 2007).

Sulphate levels of the rivers evaluated in summer and winter seasons were influenced by the interaction between season and rivers. The Klapmuts River contained a significantly (P=0.02) higher level of sulphate during summer (Figure 7) compared to the Krom River with a sulphate level of 22mg/L that increased in winter. The increased sulphate level during winter in the Krom River may be due to pollution, but the levels are low enough not to affect any fertigation program. However, the relatively high (43 mg/L) sulphate level during summer in the Klapmuts River should be taken into account for fertigation. This is in line with the study of Combrink (2005) who reported that, in low rainfall areas, water may contain high levels of essential ions such as sulphate.

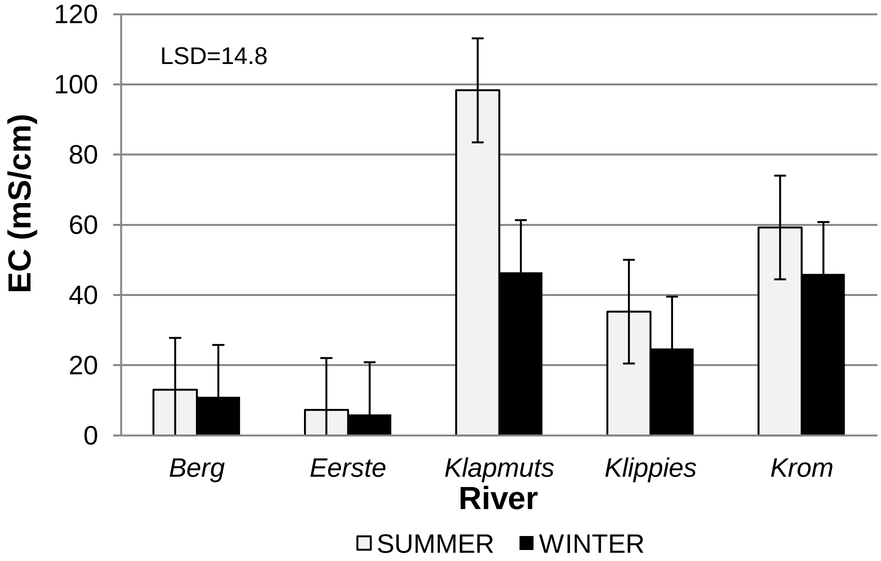

Figure 8 Electric conductivity levels for different rivers during summer (9 December 2006, 6 January 2007, 3 February & 25 February) and winter (9 June, 1 July, 29 July & 26 August 2007).

The EC levels of the water analysed during the different seasons showed that there was a significant interaction (P<.0001) between the rivers and seasons (Appendix A, Table A3). The EC levels were at 22-99 mS/cm in summer, notably in the three small rivers (Klapmuts-, Klippies- and Krom rivers; Figure 8). The seasonal difference in (P<.0001) EC was significant in the Klapmuts River (Figure 8). The EC levels reflected the trends noted with the macro-nutrients (excluding the unexplainable higher K levels in winter).

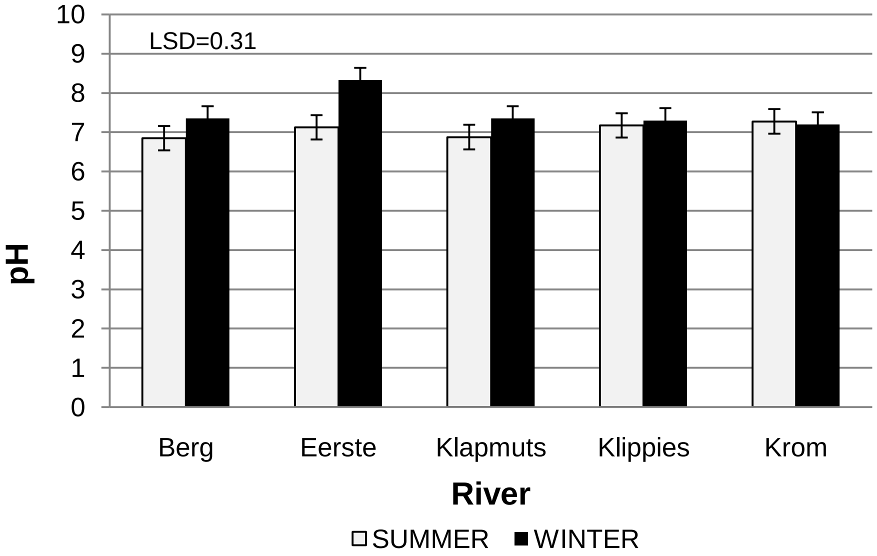

Figure 9 The pH levels for different rivers during summer (9 December 2006, 6 January 2007, 3 February & 25 February) and winter (9 June, 1 July, 29 July & 26 August 2007).

The pH of the water analysed during summer and winter was significantly influenced (P=0.007) by an interaction between rivers and seasons (Appendix A, Table A3). The Department of Water Affairs and Forestry (1996) has reported that the pH levels of unrefined water lies in the range of 6.5 and 8.5 and this corresponds with the results recorded in this study. The pH levels in the Eerste River were 1.2 higher in winter than in summer (Figure 9). The pH levels obtained on this study will be suitable for grape production. Crops differ in pH sensitivity, most crops that are grown in soil-less production systems tend to grow well with nutrient solutions that has a pH that ranges between 5.3 and 6.3.

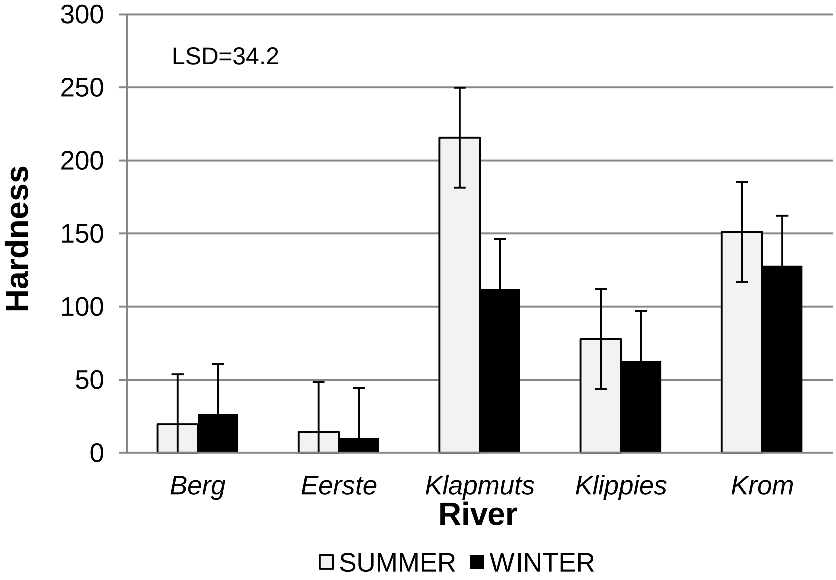

Figure 10 Hardness levels for different rivers during summer (9 December 2006, 6 January 2007, 3 February & 25 February) and winter (9 June, 1 July, 29 July & 26 August 2007).

The hardness levels of the analyzed water showed a significant (P=0.0003) interaction between rivers and seasons (Appendix A, Table A3). The Department of Water Affairs and Forestry (1996) reported that the standard total hardness of surface water rarely exceeds 100mg/L. The results of this study showed that high levels (150–210 mg/L) of hardness occurred in the3 Klapmuts- and Krom rivers during summer and to a lesser extent in the Klippies River (Figure 10), whereas the Berg- and Eerste rivers showed significantly lower (P=0.0003) levels when compared to the standard levels reported above.

Table 3 Manganese levels of different rivers evaluated during summer (9 December 2006, 6 January 2007, 3 February & 25 February) and winter (9 June, 1 July, 29 July & 26 August 2007).

River	**Parameters**
	Mn (mg/L)
Berg	0.02±0.02
Eerste	0.01±0.01
Klapmuts	0.09±0.11
Klippies	0.08±0.05
Krom	0.08±0.05
$LSD_{0.05}$	0.06
CV%	2.04
Shapiro-Wilk (P value)	0.04

CV% = Critical Value of t
± = Standard deviation
$LSD_{0.05}$ = least significant difference

During the summer and winter seasons, the manganese levels of the water of the five rivers measured, differed significantly (P=0.001) between rivers (Appendix A, Table A4). Klapmuts-, Klippies- and Krom rivers had significantly higher levels of Mn than the two other bigger rivers (Table 3).

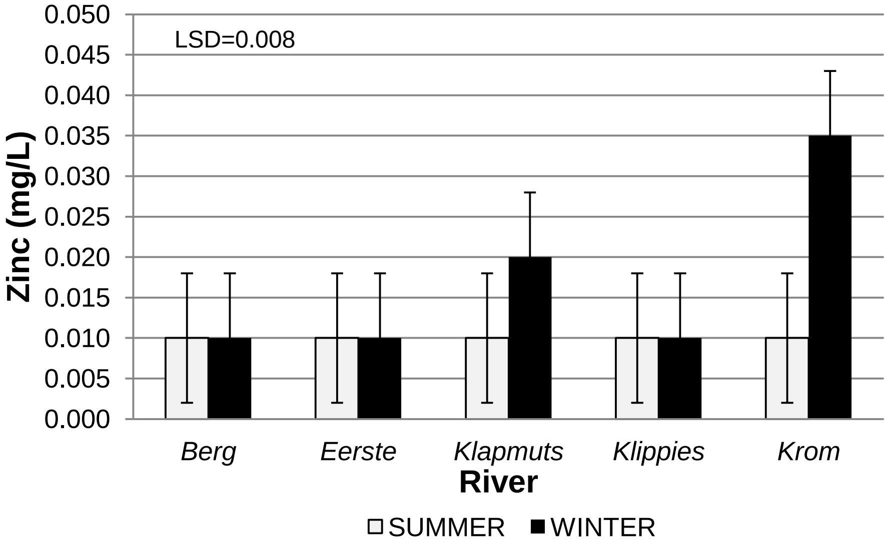

Figure 11 Zinc levels for different rivers during summer (9 December 2006, 6 January 2007, 3 February & 25 February) and winter (9 June, 1 July, 29 July & 26 August 2007).

The levels of Zn was significantly (P=0.01) influenced by an interaction between rivers and seasons (Appendix A, Table A4). The Krom- and Klapmuts rivers had levels of 0.04 mg/L and 0.02 mg/L respectively, which is the highest level of Zn during winter (Figure 11) with no seasonal differences in the other rivers. Although these levels were comparably higher in the Krom- and Klapmuts rivers, they were, however, within the range set by the Department of Water Affairs and Forestry (1996).

The concentration of Zn in water is usually low, typically around 0.005 mg/L. Due to the formation of sulphides, zinc has a very low utility under this form (Department of Water Affairs and Forestry, 1996). The higher concentrations of zinc become toxic and as a result, it will induce iron deficiency. Toxicity levels are induced at 0.3-10 mg/L, depending on the plant species (grown in nutrient solution).

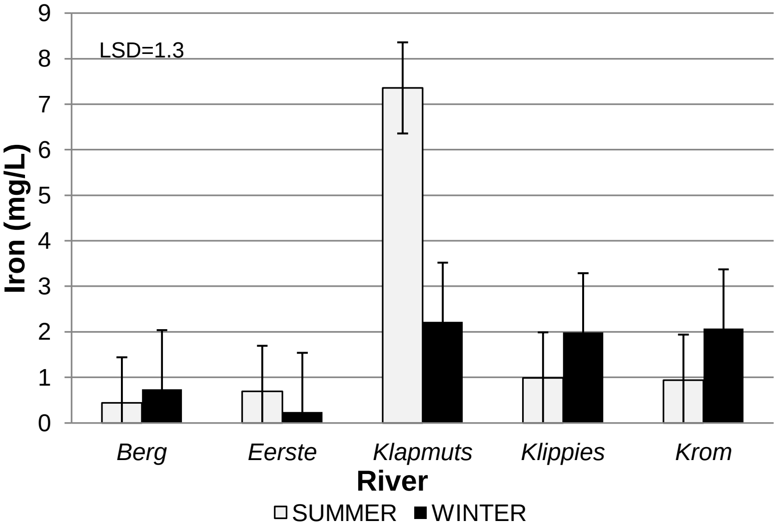

Figure 12 Iron levels for different rivers during summer (9 December 2006, 6 January 2007, 3 February & 25 February) and winter (9 June, 1 July, 29 July & 26 August 2007).

The levels of iron were significantly (P<0001) affected by an interaction between rivers and seasons (Appendix A, Table A4). The Klapmuts River recorded Fe levels as high as 6.5 mg/L in summer, while the Klapmuts, Klippies and Krom rivers showed the same levels (2 mg/L) of Fe during winter (Figure 12).

The levels of Fe in all the rivers assessed were above the levels (0.001-0.5 mg/L) set by the Department of Water Affairs and Forestry (1996). Water that contains up to 1.0 mg/L of Fe can result in clogging of drip irrigation system (Combrink, 2005). Iron can be present in water in different forms (e.g. soluble, chelated, organic and precipitated) and may not be apparent to the eye (Zinati & Shuai, 2005). Deckers (2002) reported that, growers who make use of drip irrigation should remove as much as possible of the iron in the feeding water and it should then be replaced with the correct concentration of chelated iron. The Fe levels recorded on this study are not suitable for sensitive crops and precipitated iron can be removed by filtration. Reportedly, the oxidation process is extremely slow in acidic water and therefore this problem can be dealt with by increasing the pH of the water, allowing Fe and Mn to be oxidized and removed much quicker.

Table 4 Boron levels of different rivers evaluated during summer (9 December 2006, 6 January 2007, 3 February & 25 February) and winter (9 June, 1 July, 29 July & 26 August 2007).

River	**Parameters**
	B (mg/L)
Berg	0.018±0.009
Eerste	0.011±0.003
Klapmuts	0.041±0.009
Klippies	0.017±0.004
Krom	0.040±0.012
$LSD_{0.05}$	0.0076
CV%	2.04
Shapiro-Wilk (P value)	0.05

CV% = Critical Value of t
± = Standard deviation
$LSD_{0.05}$= least significant difference

Boron levels (Table A4, Appendix A) were significantly influenced by seasons (P=0.01) and rivers (P<0001). The Krom- and Klapmuts rivers had higher levels of B than Berg-, Eerste- and Klippies rivers (Table 4). Recorded values of B for summer and winter were 0.029 mg/L in the Krom River and 0.023 mg/L in the Klapmuts River.

Should concentrations of micronutrients in feeding water exceed prescribed levels for nutrient solutions, the water should be avoided or handled with care (Combrink, 2005). Usually, low concentrations of micronutrients are found in the feeding water of most production areas. In arid regions, feeding water may contain high levels of micronutrients. Guidelines have been compiled which prescribe specific micronutrient levels for different substrate-grown crops (Combrink, 2005). These prescribed micronutrient levels can be used as norms for determining maximum levels in feeding water (Combrink, 2005).

4.2 Microbial analysis

The water samples were tested for bacterial and fungal density (Table 5). Only samples collected from Klapmuts and Eerste rivers during winter in week 27, tested positive for *Phytophthora cinnamomi*. *Phytophthora citricola* and *P. cactorum* were found in the Klapmuts River in summer and in the Klippies River in summer and winter. None of the samples tested positive for *Erwinia carotovora* and *E. chrysanthemi*.

The samples from the Berg-, Klapmuts-, Krom- and Eerste rivers collected during winter in weeks 23 and 35, tested positive for species of the genera *Pythium* and *Fusarium*. Similar organisms were detected in the Eerste River mainly during summer in week 9. The Krom River tested positive for *Pythium* spieces during summer and winter in weeks 9, 23 and 35.

The total bacterial and algal density differed significantly between the seasons and was highest in winter. This might be due to high rain water influx, efflux and/or moist and aerobic conditions and air temperature. Farmers using some of the rivers (e.g. Berg River) in the Boland experience problems with high microbial count. There is an increased need for farmers to sterilize feeding water with chlorine gas.

Table 5 Summary of analysis of biological samples collected in selected rivers during summer (9 December 2006, 6 January 2007, 3 February & 25 February) and winter (9 June, 1 July, 29 July & 26 August 2007).

RIVER	SEASON	WEEKS	BIOLOGICAL ANALYSIS						
			Phytophthora cinnamomi	***P. citricola***	***P. cactorum***	***Erwinia carotovora***	***E. chrysanthemi***	***Pythium sp.***	***Fusarium sp.***
Berg	Summer	49	-	-	-	-	-	-	-
Berg	Summer	1	-	-	-	-	-	-	-
Berg	Summer	5	-	-	-	-	-	-	-
Berg	Summer	9	-	-	-	-	-	-	-
Berg	Winter	23	-	-	-	-	-	+	+
Berg	Winter	27	-	-	-	-	-	-	-
Berg	Winter	31	-	-	-	-	-	-	-
Berg	Winter	35	-	-	-	-	-	+	+
Klapmuts	Summer	49	-	-	-	-	-	-	-
Klapmuts	Summer	1	-	-	-	-	-	-	-
Klapmuts	Summer	5	-	-	-	-	-	-	-
Klapmuts	Summer	9	-	+	-	-	-	-	-
Klapmuts	Winter	23	-	-	-	-	-	+	+
Klapmuts	Winter	27	+	-	-	-	-	-	-
Klapmuts	Winter	31	-	-	-	-	-	-	-
Klapmuts	Winter	35	-	-	-	-	-	+	+
Klippies	Summer	49	-	-	-	-	-	-	-
Klippies	Summer	1	-	-	-	-	-	-	-
Klippies	Summer	5	-	-	-	-	-	-	-
Klippies	Summer	9	-	+	-	-	-	-	-
Klippies	Winter	23	-	-	+	-	-	-	-
Klippies	Winter	27	-	-	-	-	-	-	-
Klippies	Winter	31	-	-	-	-	-	-	-
Klippies	Winter	35	-	-	-	-	-	-	-
Krom	Summer	49	-	-	-	-	-	-	-
Krom	Summer	1	-	-	-	-	-	-	-
Krom	Summer	5	-	-	-	-	-	-	-
Krom	Summer	9	-	-	-	-	-	+	-
Krom	Winter	23	-	-	-	-	-	+	+
Krom	Winter	27	-	-	-	-	-	-	-
Krom	Winter	31	-	-	-	-	-	-	-
Krom	Winter	35	-	-	-	-	-	+	+
Eerste	Summer	49	-	-	-	-	-	-	-
Eerste	Summer	1	-	-	-	-	-	-	-
Eerste	Summer	5	-	-	-	-	-	-	-
Eerste	Summer	9	-	-	-	-	-	+	+
Eerste	Winter	23	-	-	-	-	-	+	+
Eerste	Winter	27	+	-	-	-	-	-	-
Eerste	Winter	31	-	-	-	-	-	-	-
Eerste	Winter	35	-	-	-	-	-	+	+

- Negative and + Positive

CHAPTER 5

Conclusion and Recommendations

5. Conclusion and Recommendations

From the data examined, it appears that the environmental quality of the Berg River is pristine during summer. The bigger rivers recorded low levels of micro-elements and this might have been affected by winter rainfall. In the Berg River, many sources of nitrate pollution seem to be present in the catchment area. The levels of iron in all the rivers assessed were far more than the levels set by the Department of Water Affairs and Forestry in all rivers assessed and these might be due to the pH levels and interaction between the rivers and seasons. Iron and manganese levels should be kept low as this may cause production problems by blocking irrigation drippers. An interaction between seasons and rivers showed significantly higher levels of certain elements (e.g. Na, Mg, Iron, Cl, EC, and Fe) in the Klapmuts River during summer.

However, it is clear that all the rivers studied are moderately affected by bacteria and algal activities during winter. The water samples tested for bacterial and fungal density showed Klapmuts and Eerste rivers were positive for *Phytophthora cinnamomi* during winter. *Phytophthora citricola* and *P. cactorum* were detected in the Klapmuts and Klippies rivers in summer. The Berg-, Klapmuts-, Krom- and Eerste rivers tested positive for species of the genera *Pythium* and *Fusarium*. Similar organisms were detected in the Eerste River mainly during summer on the fourth sampling date, while Krom River only tested positive for *Pythium* during summer. The total bacterial and algal density differed significantly between the seasons and was highest in winter. This might be due to high rain water influx and efflux and/or moist and aerobic conditions and air temperature. The presence of abnormally high concentrations of pathogens in some rivers may be the result of leaching from agricultural land, livestock watering or informal settlements in the catchment areas. There is an increased need for farmers to sterilize feeding water (chlorination) due to high microbial count.

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APPENDIX A

Analysis of Variance

Table A1 Summary of ANOVA for cations composition

		Parameters (P values)				
Source	DF	Na^+	NH_4^+	K^+	Ca^{2+}	Mg^{2+}
Replication	3	0.0027**	<.0001***	0.0544ns	0.1770 ns	0.0021**
Rivers (R)	4	<.0001***	<.0001***	<.0001***	**<.0001*** **	<.0001***
Seasons (S)	1	<.0001***	<.0001***	0.0006**	0.0734 ns	0.0002**
R x S	4	**<.0001*** **	**<.0001*** **	**0.0193* **	0.4954ns	**<.0001*** **
Error DF		38	37	39	39	38

*** highly significant at <1% , ** significant at 1%, *significant at 5% , ns not significant
DF degrees of freedom
Values in bold fonts are discussed

Table A2 Summary of ANOVA for anions composition

		Parameters (P values)		
Source	DF	Cl^-	NO_3^-	SO_4^{2}
Replication	3	0.0028**	0.2680 ^{ns}	0.1057^{ns}
Rivers (R)	4	<.0001***	**0.0207***	<.0001***
Seasons (S)	1	<.0001***	0.8485 ^{ns}	0.0123*
R x S	4	**<.0001*****	0.2803 ^{ns}	**0.0209***
Error DF		38	38	38

*** highly significant at <1% , ** significant at 1%, *significant at 5%, ns not significant

DF=degrees of freedom
Values in bold fonts are discussed

Table A3 Summary of ANOVA for other water quality parameters

		Parameters (P value)				
Source	DF	pH	EC	Anions	Cations	Hard^{a} .
Replication	3	0.2777 ^{ns}	0.0160*	0.2137 ^{ns}	0.0789 ^{ns}	0.0081^{ns}
Rivers (R)	4	0.2170 ^{ns}	<.0001***	<.0001***	<.0001***	<.0001***
Seasons (S)	1	0.0381^{ns}	<.0001***	<.0001***	<.0001***	0.0008**
R x S	4	**0.0069****	**<.0001*****	**<.0001*****	**<.0001*****	**0.0003****
Error DF	38	38	38	38	38	38

*** highly significant at <1% , ** significant at 1%, *significant at 5% , ns not significant
a=hardiness
b=aggressiveness
DF=degrees of freedom, Hard^{a}=hardness
Values in bold fonts are discussed

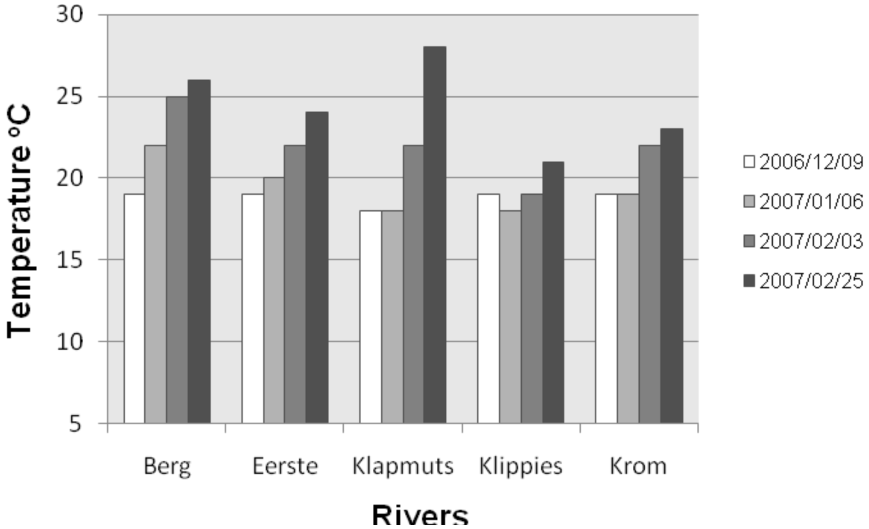
Table A4 Summary of the ANOVA for trace elements

		Parameters (P values)			
Source	DF	Mn	Zn	Fe	B
Rivers (R)	4	**0.0010****	0.0109*	<.0001***	**<.0001*****
Seasons (S)	1	0.6128 ^{ns}	0.0079**	0.0960 ^{ns}	**0.0100***
R x S	4	0.1913 ^{ns}	**0.0109***	**<.0001*****	0.0812^{ns}
Error DF		39	39	37	

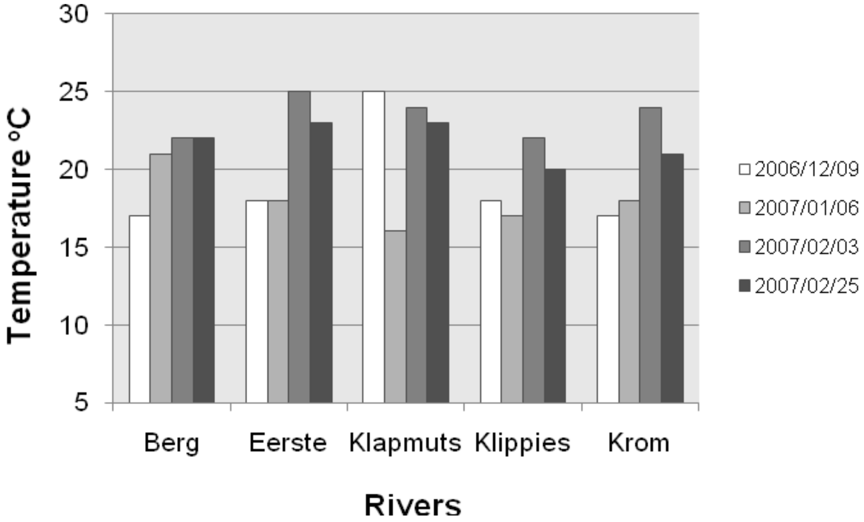
*** highly significant at <1% , ** significant at 1%, *significant at 5% , ns not significant
DF=degrees of freedom
Values in bold fonts are discussed

APPENDIX B

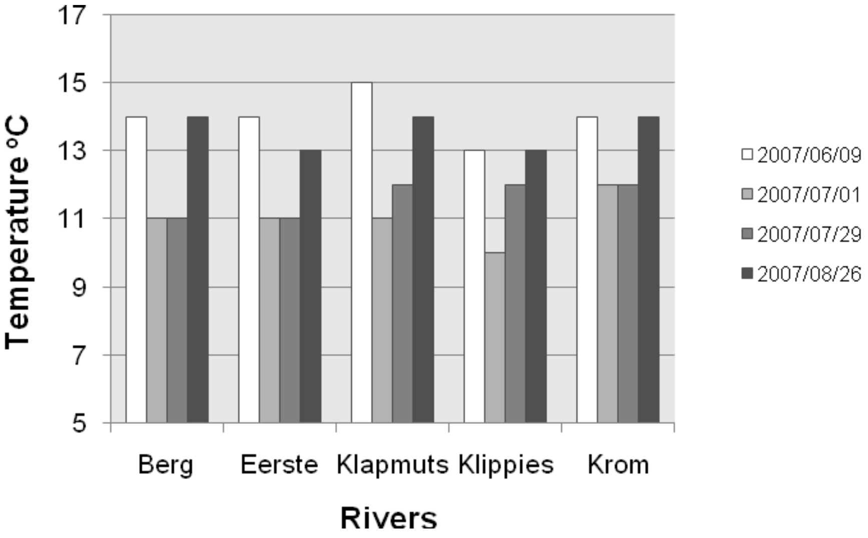
Water and air temperature (summer)



Appendix B1: Water Temperature collected in summer of 2006/2007



Appendix B2: Air temperature collected in summer season of 2006-2007.



Appendix B3: Water temperature collected in winter season of 2007.

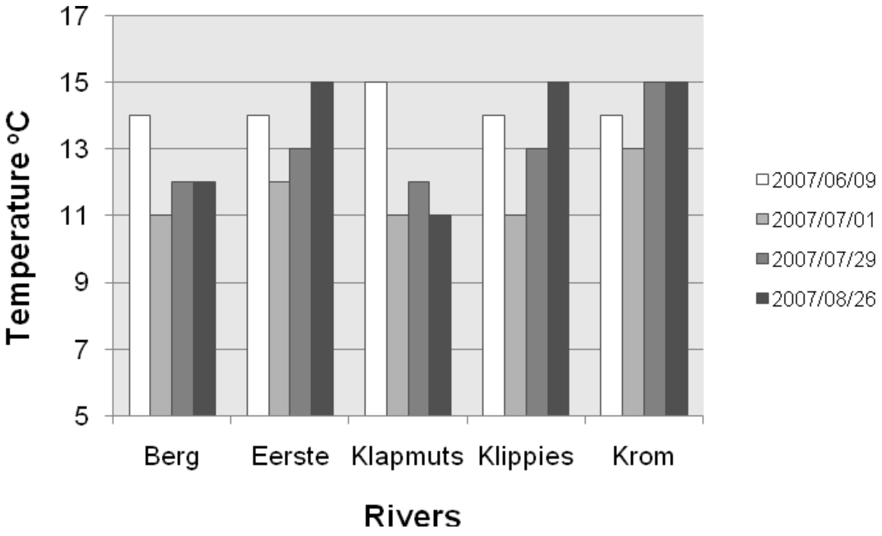


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Figure B4: Air temperature collected in winter season of 2007.