

Investigation of the drivers for water quality decline and risks thereof to agricultural activities in the Breede River catchment

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Dissertation accepted in partial fulfilment of the requirements for the degree *Master of Environmental Management* at the North-West University

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ACKNOWLEDGMENTS

My deepest and sincere gratitude go to both Dr Leandri Kruger and Mr Jurie Moolman for their academic support, guidance and supervision of this research. I will be forever grateful for the agricultural community of the Breede River for their willingness to participate in the study. Their honesty, kindness and enthusiasm made the research possible under the difficult conditions presented by the COVID-19 pandemic. I am also indebted to the many participants from government departments, NGOs, and private companies. Ms Elkerine Rossouw of the Breede-Gouritz Catchment Management Agency, Mr Louis Bruwer of the Central Breede Water Users Association, Annabel Horn of Department of Environmental Affairs and Development Planning, Western Cape Government and Mrs Marizanne McGregor are thanked for sharing their knowledge and contacts with me. I would also like to thank Mrs Mella Barry for assisting in organising interview appointments in the Swellendam area and Miss Shaunelle Pretorius for the GIS maps.

To my family, thank you for your support in the crazy idea of perusing a second Master's degree. To my fiancé Mr Wynand Sauerman, I remain indebted for the role you played in my research and for your patience, unconditional love and untainted support in my career change. I am so fortunate to have you in my life.

To God be the Glory!

ABSTRACT

Agriculture in the Breede River catchment contributes significantly to international exports and the economy of the Western Cape Province. The success of the agricultural sector in the Breede River catchment is an important driver for the expansion of urban and peri-urban areas. However, the expansion of the urban peri-urban footprint and intensified agricultural activities, such as water abstraction for irrigation and the return flows entering rivers, are linked to a decline in water quality in the catchment. Previous studies have shown that water quality in the Breede River catchment has been declining with some potential drivers identified as the rapid urbanisation, limited financial resources and technical capabilities available for the maintenance and upgrade of the capacity waste water treatment works. Although the risks posed to the agricultural industry in the Breede River catchment have been acknowledged, the nature and extent thereof were unclear.

The research study was aimed at investigating the key drivers and risks associated with the decline in water quality to the agricultural sector in the Breede River catchment. Subsequently, three Research Objectives were set: (1) to re-evaluate the water quality in the Breede River catchment; (2) to identify the key drivers of the decline in water quality of the agricultural sector in the Breede River catchment; and (3) to identify and evaluate the risks posed by the declining water quality in the Breede River catchment to agricultural activities. In order to meet these objectives, a review of the literature pertaining to water quality and the impact thereof on agriculture, in line with the research title, problem and objectives was conducted. Additionally, an empirical investigation utilising a mixed methods research approach was followed whereby qualitative and quantitative data was collected. The long-term water quality of the Breede River was evaluated through time series, Piper and Gibbs diagram as well as the calculation of the Water Quality Index and comparison of the water quality with national standards in order to evaluate the suitability of the surface water for agricultural activities in the Breede River catchment. In addition a total of 28 participated (farmers and environmental experts) in face to face or online interviews and the completion of questionnaires with both open and close-ended questions. Both the qualitative and quantitative data from the questionnaires were captured for analysis and a thematic analysis, using accepted data coding methods, was conducted.

The findings of the study in relation to the objectives were, firstly, that there is cause for concern regarding the water quality in the Middle Breede River section and the potential impact thereof on agriculture. The concern is related to salinity levels generally associated with the underlying geology and irrigation practices as well as the microbiological and nutrient levels, which points to contamination from domestic effluent from inefficient waste water treatment and un-serviced informal settlements. Farmers indicated the most dominant drivers of decline in water quality as:

domestic effluent > population growth > agricultural growth > co-operative governance > geology/ soil, whereas the Experts listing the dominant drivers as: domestic effluent > population growth > geology/ soil > co-operative governance/ industrial developments/ growth in agricultural activities > climatic conditions. The risks posed by the declining water quality in the Breede River catchment to agricultural activities were identified by Farmers as: risk to agricultural activities/ risk to economic growth of the area > risk of impact on socio-economic development > risk to quality of the crops/ products > risk of financial impact on farming operations/ risk to sustainability of agriculture > risk to environmental sustainability. Experts on the other hand listed the dominant risks of the water quality as: risk of impact on socio-economic development > risk to sustainability of agriculture > risk to economic growth of the area/ risk to environmental sustainability > risk of financial impact on farming operations > risk to agricultural activities.

Keywords: Breede River, water quality decline, agriculture, risks, drivers, salinity, nutrients, microbiological contamination, waste water treatment works.

ABBREVIATIONS AND ACRONYMS

ARC	Agricultural Research Council
AWS	Alliance of Water Stewardship
BGWMA	Breede-Overberg Water Management Area
BGCMA	Breede-Gouritz Catchment Management Agency
BOCMA	Breede-Overberg Catchment Management Agency
BVM	Breede Valley Municipality
CBRWUA	Central Breede River Water Users Association
CFB	Cape Fold Belt
CMA	Catchment management agency
CMS	Catchment Management Strategy
CWDM	Cape Winelands District Municipality
DCoG	Department of Cooperative Governance
DEA&DP	Department of Environmental Affairs and Development Planning
DPME	Department of Planning, Monitoring and Evaluation
DWA	Department of Water Affairs
DWAF	Department of Water and Forestry
DWS	Department of Water and Sanitation
EC	Electrical Conductivity
E. coli	Escherichia coli
FNAS-REC	Natural and Agricultural Sciences Research Ethics Committee
GDP	Gross Domestic Product

GIS	Geographic Information Systems
IPCC	International Panel on Climate Change
IWRM	Integrated Water Resource Management
MDG	Millennium Development Goal
NCMP	National Chemical Monitoring Programme
NEMA	National Environmental Management Act
NMMP	National Microbiological Monitoring Programme
NPO	Non-profit Organisation
NSDF	National Spatial Development Framework
NWA	National Water Act
NWRS	National Water Resource Strategy
ODM	Overberg District Municipality
RO	Research Objective
RQO	Resource Quality Objectives
RWQO	Resource Water Quality Objectives
SABI	South African Irrigation Institute
SANS	South African National Standard
SAR	Sodium Adsorption Ratio
SDG	Sustainable Development Goal
SSA	Statistics South Africa
TMG	Table Mountain Group
TDS	Total dissolved solids
TWQR	Target Water Quality Ranges

UN	United Nations
USEPA	United States Environmental Protection Agency
WARMS	Water Authorisation and Registration Management System
WCG	Western Cape Government
WEWUA	Worcester East Water Users Association
WHO	World Health Organisation
WMA	Water Management Areas
WRC	Water Resource Commission
WSA	Water Services Act
WSP	Water Service Providers
WUA	Water User Associations
WWAP	World Water Assessment Program
WWTW	Waste Water Treatment Works

KEY DEFINITIONS

Cations: Positively-charged ions (atoms or groups of atoms that have more protons than electrons due to having lost one or more electrons).

Anions: Negatively-charged ions (atoms or groups of atoms that have more electrons than protons due to having gained one or more electrons).

Water quality: Express the suitability of a water resource to sustain diverse uses.

Water scarcity: Shortage in the availability of renewable freshwater relative to demand.

Water stress: Measure of the amount of renewable freshwater that is available for each person annually.

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$SCB \% = 100 \times (cations - [anions]) / (cations + [anions])$	Equation 1.....	50
$WQI = \sum Q_n W_n / \sum W_n$	Equation 2.....	54
$Q_n = 100[(V_n - V_i) / (V_s - V_i)]$	Equation 3.....	54
$W_n = K / V_s$	Equation 4.....	54
$K = [1 / \sum 1 / V_s = 1, 2, \dots, n]$	Equation 5.....	54

CHAPTER 1 INTRODUCTION

1.1 Background

The sixth (6) Sustainable Development Goal (SDG) of the United Nations aims to ensure availability and sustainable management of water and sanitation for all (UN, 2021). However, in the recent report it was highlighted that the world is not on track to achieve this goal and that efforts to achieve integrated water management have to be hastened (UN, 2021). Despite progress made between 2015 and 2020, two billion people around the world still live without safely managed drinking water, with half of those lacking basic drinking water services (387 million) living in sub-Saharan Africa (UN, 2021). The COVID-19 pandemic highlighted the fact that governments need to speed up their efforts to ensure access to drinking water, sanitation and hygiene services (UN, 2021).

The United Nations' World Water Assessment Programme (WWAP) advocates that water resources, and the services it deliver, strengthen poverty reduction, economic growth and environmental sustainability which are fundamental to sustainable development (WWAP, 2015). Furthermore, water is essential for human well-being (food- and energy security, health- and social well-being), economic development and environmental health (WWAP, 2015; WHO, 2020). Water is required across all sectors to produce not only food but also energy, goods and services leading to a global increase in water use at twice the rate of the population growth (UN, 2021). The rapid increase in population accompanied by economic growth is linked to urbanisation, industrialisation and mechanisation which result in growing demand for water in many developing countries (Walter *et al.*, 2011). The pressure on freshwater resources is further exacerbated by climate change, pollution of existing water resources and governance failures (underinvestment and poor cooperation), among other things (Walter *et al.*, 2011; WWAP, 2015; UN, 2021). Unless the balance between demand and supply of the finite resource is restored, a global water deficit is imminent (WWAP, 2015).

Target 6.4 of the United Nations Sustainable Development Goal (SDG 6) focusing on water use and scarcity states that: *"By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity"* (UN, 2021:17). Water scarcity can broadly be described as a shortage in the availability of renewable freshwater relative to demand (Taylor, 2009).

1.1.1 Water stress

Based on the 'Falkenmark indicator' or 'water stress index', which measures water scarcity as the amount of renewable freshwater that is available for each person annually, South Africa is classified as a water scarce country (600 to 1 000 persons per flow unit) with large parts of the Western Cape moving from "low stress" in the 1990s to "absolute scarcity" in 2019 (Falkenmark *et al.*, 1989; McNally *et al.*, 2019). The impact of climate change on the country's low rainfall (average 500 mm annually) and variability in rainfall (wet eastern and dry western regions) poses an additional challenge to water security (Ziervogel *et al.*, 2014; Schulze, 2016). Climate change is expected to lead to higher temperatures, sporadic rainfall patterns, increased frequency of droughts and severe floods (Ziervogel *et al.*, 2014). Climate change is likely to exacerbate water availability and quality, which will have an impact on the agricultural industry, food security and economic growth (Rijsberman, 2006; DEA&DP, 2017; Rankoana, 2020).

Water stress is associated with negative impacts on economic development as well as conflict between users (UN, 2021). By increasing the water-use efficiency these impacts can be largely avoided. Globally on average around 34% of land surface is used in food production (pastures, rangelands and crops) with agriculture accounting for approximately 70% of total water consumption (Mancosu *et al.*, 2015; Owusu-Sekyere *et al.*, 2017). It is therefore essential that water is used more efficiently in the agriculture sector to be able to deliver on the increased global food demand and decouple economic growth from water use (Mancosu *et al.*, 2015; Owusu-Sekyere *et al.*, 2017; UN, 2021). Although water is critical for socio-economic development, socio-economic growth is also likely to result in a decline in water quality (Bobylev *et al.*, 2016). This is especially true in developing countries where the rate of urbanisation often lead to a decline in water resource quality and quantity (Cullis *et al.*, 2018).

1.1.2 Water quality overview

The term 'water quality' is used to express the suitability of a water resource to sustain diverse uses, such as domestic, industrial, agricultural and aquatic ecosystem functions with a range of variables limiting the use of water for a specific purpose (WHO, 1996). Water quality varies over time and is dependent on numerous factors such as natural (geological, meteorological, biological etc.) and anthropogenic (building of dams, pollution etc.) activities (Gibbs, 1970; WHO, 1996; Khatri & Tyagi, 2015). Water-dependent industries such as agriculture are particularly vulnerable to the decline in water quality. Declining water quality was therefore identified as a critical risk to production due to lower yield and food safety concerns globally and is therefore a major concern

to governments, policy makers, water managers and water-users (Owusu-Sekyere *et al.*, 2017; Nyam *et al.*, 2021).

1.1.3 Local perspectives on water use and quality

South Africa depends mainly on surface water with ground water utilised as water resource in rural and arid areas (DWA, 2013; Owusu-Sekyere *et al.*, 2017). In addition a substantial volume of water inputs into surface streams originate from return flows from major urban and industrial developments. Between 1.1% and 1.5% of South Africa's surface area is irrigated, with the Western Cape Province contributing the largest portion, and more than 60% of the available water used allocated to agriculture (DWA, 2013; Owusu-Sekyere *et al.*, 2017; WRC, 2018). To be able to produce sufficient food for the growing population it is estimated that water use would need to double by 2050 (WRC, 2018). However, since the available water in many catchments has already been fully or over-allocated to all water users, it is unlikely that any additional water would be allocated to agriculture (WRC, 2018).

Around 11,4% of South Africa's population lives in the Western Cape Province with the population of the province doubling between the 1990s and 2021 and is predicted to grow with approximately 20% by 2030 (SSA, 2019; Western Cape Government (WCG), 2020). The population growth has been cited as one of the causes of increased domestic water demand. Increased demand, prolonged drought conditions and insufficient storage capacity together resulted in Cape Town almost running out of water ("day zero") in 2017/2018 (Robins, 2019; Millington & Scheba, 2020). Jobson (1999) noted that the misalliance of spatial and temporal water resource distribution and the population distribution have, and will continue to have, a negative impact on social and economic development in South Africa.

The Breede River catchment (catchment H) is one of the main river systems in the Western Cape Province and a centre for agriculture (Figure 1-1). Water for irrigation purposes is abstracted directly from the Breede River and tributaries as well as a network of irrigation canals (Fliigel & Kienzle, 1989; Kirchner, 1994). Kirchner (1994) found that although ground water is encountered in some areas in the catchment, it is generally brackish. Previous studies have shown that water quality in the Breede River catchment has been declining since the 1960's (Kirchner, 1994; (Murray, Biesenbach and Badenhorst Inc. 1989; Cullis *et al.*, 2018). Water quality decline included increased salinity, nutrient enrichment and microbial activity linked to the functioning of the waste water treatment works (WWTW) in the catchment, as well as agrochemicals (fertilizer and pesticides) which entered streams through agricultural return flows throughout the catchment (DEA&DP, 2017; Cullis *et al.*, 2018).

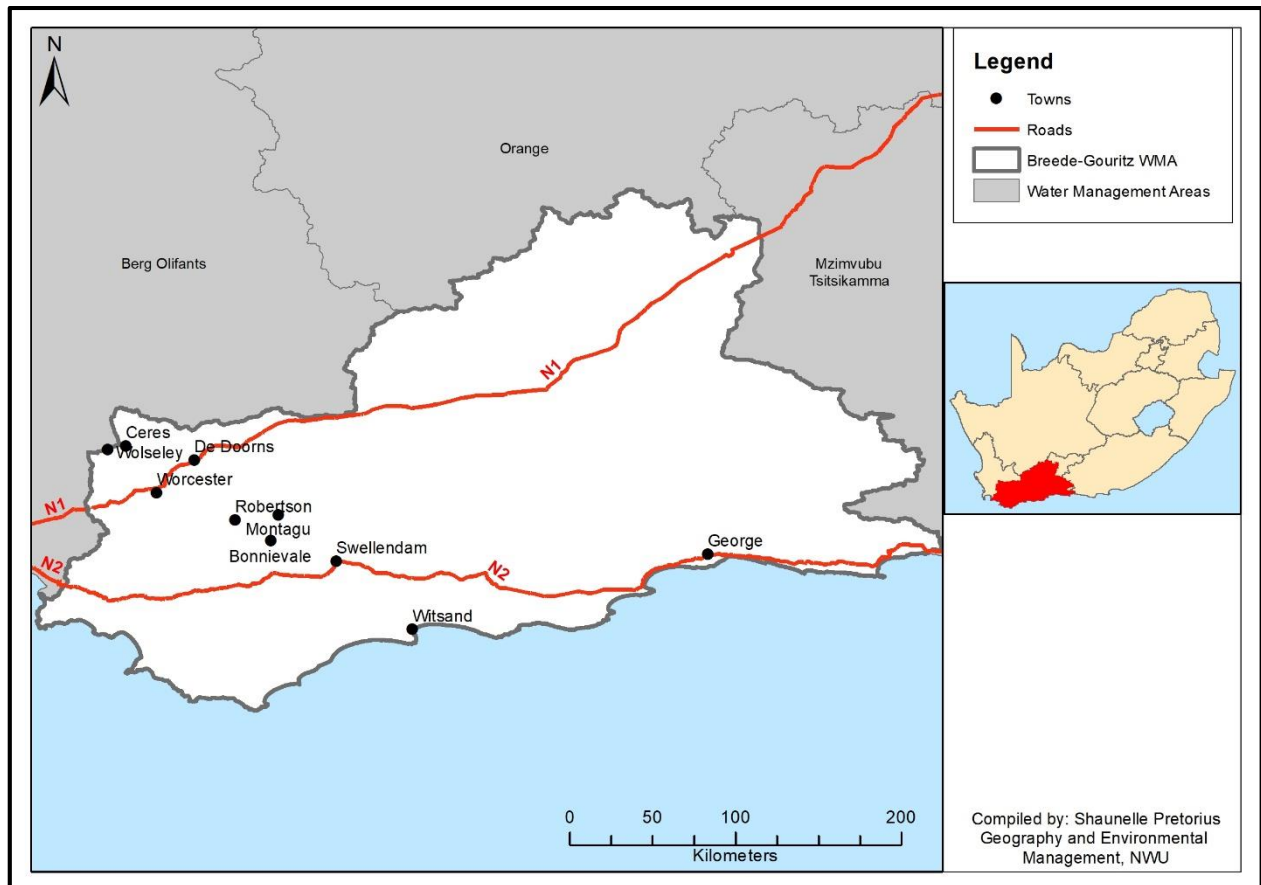


Figure 1-1: Locality of the Breede River catchment (study area).

1.2 Problem statement and rationale for the study

Globally the demand for water varies between countries due to different levels of socio-economic development and population size (Bobilev *et al.*, 2016). Water supplies continue to decrease due to the depletion and pollution of resources, while the population continues to grow and industrial and agricultural development further aggravate the water scarcity problem (Bobilev *et al.*, 2016). Although water is critical for economic development, economic growth is also the likely cause of declining water quality (Bobilev *et al.*, 2016). This is especially true in developing countries where the urbanisation rate often results in a decline in water resource quality and quantity (Cullis *et al.*, 2018).

Water quality in most of South Africa's rivers has deteriorated over the past 20 years (Oberholster & Ashton, 2008). Previous studies have shown that water quality in the Breede River catchment has been declining (DWA, 2003; WCG, 2017; Cullis *et al.*, 2018). The decline in water quality has been associated with the growth in urban and peri-urban areas and intensified agricultural activities amongst others (DWA, 2010; Cullis *et al.*, 2018). Water-dependent industries such as

agriculture are particular vulnerable to the decline in water quality. Although the risks posed to the agricultural industry in the Breede River catchment has been acknowledged (Cullis *et al.*, 2018), the nature and extent thereof are currently unclear. The research problem under investigation in this study is therefore the extent to which potential drivers contribute to poor water quality and also the risks posed by the decline in water quality to the agricultural industry along the Breede River catchment.

1.3 Research aim and objectives

The aim of the study is to investigate the key drivers and risks associated with the decline in water quality to the agricultural sector in the Breede River catchment.

The objectives of the study are:

- To re-evaluate the water quality in the Breede River catchment;
- To identify the key drivers of the decline in water quality of the agricultural sector in the Breede River catchment; and
- To identify and evaluate the risks posed by the declining water quality in the Breede River catchment to agricultural activities.

1.4 Scope of the research

The study was limited to the Breede-Gouritz Water Management Area (BGWMA) as an example of a highly utilised catchment serving the agricultural industry which is one of the main economic sectors in the Western Cape Province (Figure 1-1) (Cullis *et al.*, 2018). To narrow the scope further, the Upper, Middle and Lower Breede River sections of the BGWMA was selected for this study as previous studies reported water quality decline in these sections (Murray, Biesenbach and Badenhorst Inc. 1989; Cullis *et al.*, 2018). Although the study focused on water quality, the link between water quality and quantity could not be ignored and was taken into consideration where it was deemed relevant. The study focused on the impacts of the decline in water quality on irrigation agriculture, thereby excluding other economic sectors. The focus was on the surface water quality, excluding those activities relying on ground water; however, where it was deemed relevant mention was made of the potential contribution from ground water. Surface water quality data for the period between the 1970's and 2018 were available for the catchment, although more attention was paid to the past 20 years.

1.5 Brief overview of the research methodology

The study's research methodology entailed a literature review and an empirical investigation as means for the determination of water quality, key drivers and risks associated with the decline in water quality to the agricultural sector in the Breede River catchment.

The empirical research followed a mixed methods research approach, which utilised a combination of both quantitative and qualitative methods (Brannen, 2005; Ivankova, 2007) during the execution of Research Objective 1 to 3. Research Objective 1 focused on available water quality data gathered from databases (Department of Water and Sanitation (DWS) and Breede-Gouritz Catchment Management Agency (BGCMA)) and other sources (peer reviewed publications and research reports). The data was analysed by descriptive and inferential statistics (correlation matrix, etc.), evaluated against various guidelines, including irrigation water quality, and legal compliance values (DWAF, 1996; Van Schoor, 2005, Van Rensburg *et al.*, 2011). In the execution of Research Objective 1 the water quality data was presented as a Water Quality Index (WQI) which allowed for the presentation of water quality data in an easily expressible and understandable format (Wanda *et al.*, 2016; Banda & Kumarasamy, 2020) as well as tables, maps and graphs such as Piper diagrams (Russoniello & Lautz, 2020) and Gibbs diagrams (Gibbs, 1970; Day & King, 1995).

Research Objectives 2 and 3 were conducted through 28 semi-structured one-on-one interviews consisting of closed- and open-ended questions developed after the completion of Research Objective 1. The questions were based on aspects such as the participant's background, background on irrigation practices, irrigation water quality, drivers of water quality decline and the risks posed to agricultural activities of the Breede River catchment. A detailed discussion regarding the research methodology followed during this study is presented in Chapter 3.

1.6 Assumptions and limitations

The assumption was made that the impact of the decline in the irrigation water quality in the Breede River catchment was only associated with surface water. Ground water quality was not investigated. Two methodological limitations encountered in the study were concerning the availability of farmers for interviews and time limitations for the completion of the interviews. These limitations had no impact on the credibility of the research study and had no influence on the evaluation of the data and achievement of the intent of Research Objectives 2 and 3.

Limitations also included the quality of the data in the Department of Water and Sanitation (DWS) database and the limited number of sites which had uninterrupted long-term data available. The

DWS database had a limited number of sites which had biological data available and was therefore supplemented by the BGCMA data. This led to a slight mismatch in the localities of the sites from which chemical and biological data originated. Although these were limitations it had no influence on the evaluation of the data and achievement of the intent of Research Objective 1.

1.7 Structure and outline of the dissertation

Chapter 1: Introduction

This chapter presented the background to the research topic and the motivation for the study. Included in this chapter was the problem statement, aim, objectives, scope and limitations of the dissertation. The chapter commenced with a brief discussion on water management in South Africa, while also mentioning water quality requirements in agriculture. This chapter also presented background to the Breede River catchment as the study setting. The chapter concluded with the outline and structure of the dissertation.

Chapter 2: Literature review

This chapter focused on literature concerning the research problem and identified keywords. The intention of Chapter 2 was to investigate and inform the three research objectives. This chapter commenced with a brief discussion on water management in South Africa, while also mentioning water quality requirements in agriculture, water quality in the Breede River catchment, the water quality requirements and guidelines for irrigation as well as potential drivers for and risks associated with the decline in the water quality. This chapter included a description of the available water quality data, which provided perspective to addressing Research Objective 1. The literature review assisted in informing and developing the methods for the identification of the potential drivers for and risks to the agricultural sector in the Breede River catchment (Research Objectives 2 and 3) by providing context which informed the content of the questionnaires.

Chapter 3: Research methodology

This chapter concentrated on the research approach, ethical considerations, sampling, data collection, data analysis and discussion, and the limitations of the methodology adopted. The purpose of this chapter was to address Research Objectives 1 to 3. Water quality data was evaluated for the Upper, Middle, and Lower Breede River sections of BGWMA by plotting data on Piper and Gibbs diagrams to trace the sources responsible for the water quality. Time series plots were used to determine the trend for important parameters to achieve the goal of Research Objective 1. Interview data was presented as graphs and tables to present the differences

between the perceptions of Farmers and Experts. A risk matrix from responses were completed as well as themes identified from keywords and phrases generated from interviews and applied in achieving the goal of Research Objective 2 (identifying key drivers of the decline in water quality) and Research Objective 3 (identifying and evaluating the risks posed by the declining water quality in the Breede River catchment to agricultural activities).

Chapter 4: Results and discussion

This chapter presented the findings from the qualitative and quantitative investigations as well as discussion and analysis of the data to interpret the findings as a means to address the study aim as well as Research Objectives 1 to 3. Data were presented, interpreted and findings discussed and compared with findings from literature.

Chapter 5: Conclusion and recommendations

This chapter presented the summarised findings as well as the comments on the extent to which the research objectives have been met and the research question answered. Applicable recommendations for future research emanating from the findings were presented.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter contains a literature survey, which focuses on the available literature that is relevant to the study. The global perspective on sustainable development and water management as well as the local legislation pertaining to sustainable water management, institutional arrangements related to water management in the study area, water uses with the focus on agriculture and the link between water quality and economic growth are explored. Furthermore the impacts of natural factors as well as anthropogenic activities on water quality are discussed in this chapter.

This discussion provides the foundation for the later discussion on the water quality as well as key drivers and risks associated with the decline in water quality and the impact thereof on the agricultural sector in the Breede River catchment.

2.2 Sustainable development in water management

It is a well-known fact that water is essential for life, ecosystems, as well as social and economic development. The millennium development goals (MDGs) and the sustainable development goals (SDG), which superseded it, therefore had a strong focus on water resources to ensure that exploitation and the use thereof are planned and managed in a sustainable manner. The availability of water has been reduced due to overconsumption of surface and ground water resources, pollution, periodic droughts, and climate change. As the global human population grows the demand for water will continue to grow. The sustainable management of fresh water resources will become increasingly important in the future and need to be managed in an integrated way to achieve water, energy, and food security in the face of climate change and increased population pressure (Molobela & Sinha, 2011; Shimelis, 2015; Mathetsa *et al.*, 2019).

The developmental needs for social and economic development to use and exploit natural resources cannot happen in a limitless way. As tensions arise from the need for finite resources and the pursuit of equity in the use and allocation of natural resources, the importance of sustainable utilisation of natural resources and environmental protection are becoming more important as short-term gains eventually lead to long-term problems or even disasters (Shimelis, 2015). In an ideal situation all governance decisions will be based on the three-pillars of sustainable development (social, environmental, economic). However, it must be acknowledged that the three elements do not always carry equal weight in decision-making with decisions generally promoting the economic and social goals to the detriment of the environmental goal

(Molobela & Sinha, 2011; Shimelis, 2015). Sustainable development is therefore dependant on the perspective of the viewer, for instance for anyone promoting economic growth the main focus of sustainable development would be on the economic growth value. Whereas for those promoting social development the focus would be on the social value. This suggests that the original aim, that development should be sustainable to protect the environment against uncontrolled economic development, is no longer valid.

“The process of promoting the coordinated development and management of water in an equitable manner without compromising the sustainability of vital ecosystems, are referred to as Integrated Water Resources Management (IWRM)” (Shimelis, 2015:2). Integrated Water Resource Management was adopted globally and aims to assist in addressing challenges such as water scarcity, waterborne diseases, floods, droughts, and access to water and sanitation. The SDGs such as universal and equitable access to safe and affordable drinking water for all (6.1), access to adequate and equitable sanitation (6.2), improve water quality by reducing pollution (6.3), increase water-use efficiency (6.4), protect and restore water-related ecosystems (6.6) as well as poverty alleviation (1), food security (2), decent work and economic growth (8), can therefore be achieved through IWRM and further commits itself to balance socio-economic development of water resources with environmental sustainability, strengthening the relationship between sustainable development and environmental governance (Molobela & Sinha, 2011; Shimelis, 2015; Mathetsa *et al.*, 2019; UN, 2021).

Cullis *et al.* (2018) stressed that by 2050 up to 67% of the World’s population will be living in urban areas, with developing countries experiencing the most rapid urbanisation rates. It appears as though South Africa is following the predicted World growth and urbanisation trends with the majority of the estimated 75 million population predicted to be living in urban areas by 2050 (DPME, 2018). The urbanisation is described as a combination of the movement of people from rural to urban areas and the increase in the percentage of the population living in urban areas through natural accrual (DPME, 2018). The South African government has adopted the IWRM approach to water management through water legislation that promotes equity, sustainability, representatives and efficiency in an attempt to address rural poverty and inequalities (Molobela & Sinha, 2011). The legislation and approach to water management in South Africa will be explored in the following sections.

2.3 Legislative and statutory provisions relating to water management in South Africa

The National Environmental Management Act No. 107 of 1998 (NEMA) was enacted to give effect to section 24 of the Constitution of the Republic of South Africa (Act No. 108 of 1996) which

dictates that everyone has the right to have the environment protected for the benefit of the present and future generations, through legislative and other measures, thereby embracing the concept of sustainable development. A number of environmental management principles which apply to all organs of state are included in section 2 of the NEMA, reinforcing the state's commitment to sustainable development. The NEMA is the umbrella or framework legislation the main purpose of which is to regulate the governance of the environment in a co-operative fashion (Oosthuizen *et al.*, 2018). Co-operative governance by all the stakeholders involved is therefore considered as one of the most important mechanisms to achieve integrated and sustainable environmental management (Bray, 1999).

The co-operative governance principle section 2 (4)(f) of the NEMA makes provision for intergovernmental co-ordination and harmonisation of policies and legislation relating to the environment (Oosthuizen *et al.*, 2018). The Intergovernmental Relations Framework Act No. 13 of 2005 intends to “*establish a framework for the national government, provincial governments and local governments to promote and facilitate intergovernmental relations; to provide for mechanisms and procedures that contribute to the settlement of intergovernmental disputes; and to provide for matters connected therewith*”.

The Constitution of South Africa makes provision for the national government to be the custodian of the nation's water resources. The National Water Act (No. 36 of 1998) gives the directive to manage, control and protect the country's water resources in a sustainable and equitable manner, to the Minister of DWS. The mandate of the NWA is to promote the implementation of an IWRM framework. The National Water Act (Act No. 36 of 1997) (NWA) provides the legal framework for the effective and sustainable management of the country's water resources, whereas the Water Services Act (WSA) (Act No. 108 of 1997) sets the mandate on water service provision and the setting of licence criteria for discharges. The WSA controls drinking water and sanitation provision and management by local government/ municipalities through rules and regulations. DWS liaise with the Department of Cooperative Governance (DCoG) to ensure that the WSA is implemented and water-related bylaws developed in compliance with national norms and standards (DWAf, 2013). The leadership obligations of the DWS therefore include the facilitation of intergovernmental co-operation between public sector institutions and agencies, collaboration on intergovernmental relations and public participation, through liaison with DCoG.

The National Water Resource Strategy (NWRS) was introduced to encourage IWRM in the country to achieve a balance between the use and protection of water resources in an integrated, economically and environmentally sustainable manner for the benefit of all (DWAf, 2013). The main objective of the NWRS is to manage water resources in a way that guarantees that adequate water of suitable quality is accessible to users to ensure resilient economic growth, while at the

same time ensure a high quality of life while ensuring aquatic ecosystem health (DWAF, 2013). The transformation of the management of South Africa's water resources in the context of IWRM allow for citizen participation (Boyd & Thompkins, 2011; Claassen, 2013; Meissner *et al.*, 2016). Accordingly, the emphasis of the NWA is on decentralization and public participation in decisions made with respect to water resources management (Meissner *et al.*, 2016). To ensure effective water resources management the NWRS delegates responsibility and authority to catchment management agencies (CMAs) and water user associations (WUAs) (DWAF, 2013). The country was divided into 19 Water Management Areas in 1999 managed by CMAs that take responsibility for water resource management of all catchments in South Africa at a regional or catchment level (DWAF, 2013). The financial viability as well as the capacity, skills and expertise of staff to implement the mandate stipulated by the NWRS after which the decision was made in 2012 to consolidate the 19 CMAs into nine (9) CMAs (Figure 2-1) (DWAF, 2013). The boundaries of the CMAs took catchment and aquifer boundaries and financial viability into consideration. As a result, the boundaries of CMAs are not aligned with administrative boundaries such as provincial, district or local government boundaries.

It was envisaged that for each WMA a CMA would be established which would perform certain management functions, co-operate and seek agreement on water-related matters among various governmental and non-governmental stakeholders and interested parties (DWAF, 2013; Meissner *et al.*, 2016). The role of CMAs is to ensure that water resources are managed in accordance with national policies, guidelines and standards in the catchment, through the active participation of local communities and other stakeholders. Each CMA would be governed by a board to ensure representativeness and have a mandate to develop catchment management strategies (CMS), which constitute a plan to implement the protection, use, development, conservation, management, and control of water resources in their respective catchments (Meissner *et al.*, 2016).

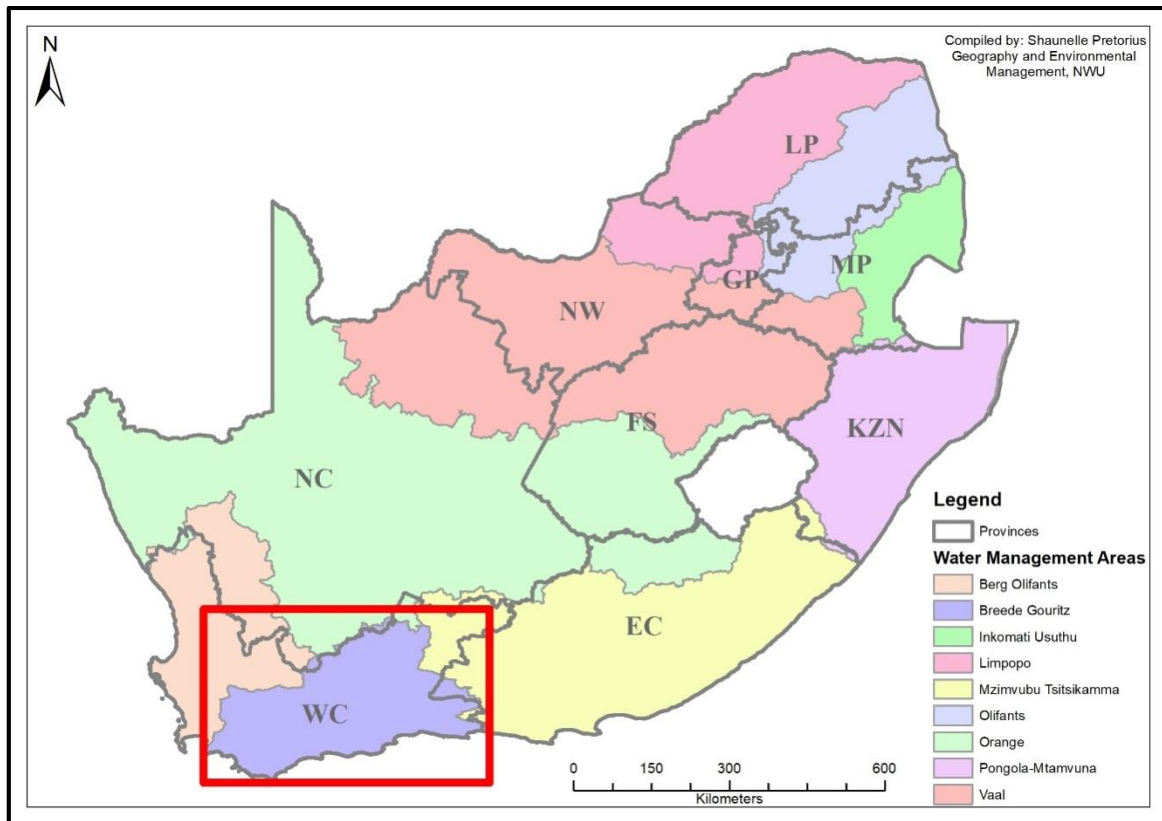


Figure 2-1: South African Water Management Areas highlighting the limits of the BGWMA (modified from SSA, 2021)

The historical overview of water management in the study area as well as the transition to a CMA and how the delegated water resource functions of the CMA were implemented in the study area will be discussed in the following section. The co-operation between various national, provincial and local government departments involved in the water management in the study area will also be highlighted.

2.4 Water management in the study area

The study will focus on the Breede River, the largest river in the Western Cape, which has its source in the Cape Fold mountains near the town of Ceres and discharges 322 km further downstream into the Indian Ocean near the towns of Infanta and Witsand (Steynor *et al.*, 2009; Meissner *et al.*, 2016; Seeliger *et al.*, 2018). The Breede River valley is flanked by the Franschhoek and Du Toit's Mountains in the west, the Hex River Mountains to the north and the Langeberg Mountains to the east.

With the consolidation of the WMAs the original Breede-Overberg Water Management Area was extended to incorporate the Gouritz catchment (Gouritz River and its major tributaries the Gamka,

Groot and Olifants Rivers) to form the Breede-Gouritz Water Management Area (BGWMA) and is the southernmost water management area in the country (Figure 2-1) (Meissner *et al.*, 2016). The BGWMA is bound by the Indian Ocean to the south, the Berg-Olifants WMA to the west, the Orange WMA to the north and the Mzimvubu-Tsitsikamma WMA to the east (Figure 2-1). The BGWMA straddles several administrative boundaries including provincial, district and local municipality boundaries and includes the following relevant district and local municipalities, i.e. (1) Cape Winelands District Municipality (CWDM) with local municipalities: Witzenberg, Breede Valley, and Langeberg; and (2) Overberg District Municipality (ODM) with local municipalities: Theewaterskloof, Overstrand, Cape Agulhas, and Swellendam (Figure 2-2).

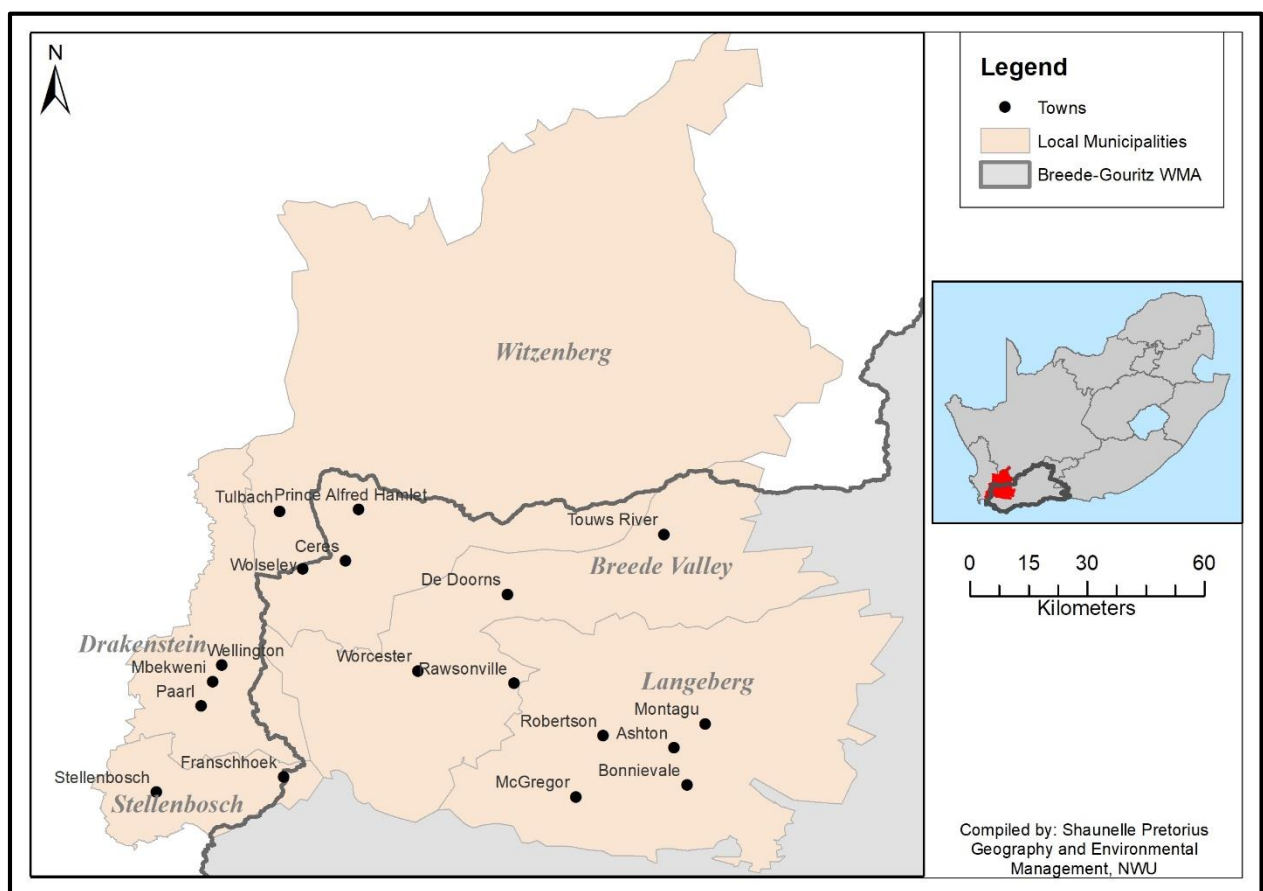


Figure 2-2: Local municipalities of the Cape Winelands District Municipality (modified from WCG, 2017).

The original Breede-Overberg Catchment Management Agency (BOCMA) was incorporated into the Breede-Gouritz Catchment Management Agency (BGCMA) (Meissner *et al.*, 2016). The Minister of Water and Sanitation (then Water Affairs and Forestry) established the BGCMA in July 2005 in terms of the NWA which subsequently became operational after the BGCMA Governing

Board was appointed and is accountable to the Minister of Water and Sanitation (DWS) (BGCMA, 2019). The co-ordinating and regulatory role of BGCMA requires a close co-operative relationship with DWS, mainly through the DWS Regional Office, but also with important line functions of the National Office (BGCMA, 2019). The DWS Regional Office has been withdrawing its operational presence in support of the BGCMA's capacity development and is currently essentially involved in an oversight and regulatory capacity (BGCMA, 2019; E Rossouw personal communication, 12 June 2021). BGCMA furthermore plays a central co-ordinating role with regards to water use, protection, development, conservation and management of water resources under its jurisdiction. Therefore, BGCMA plays a central role in co-ordinating efforts of several national, provincial and local government departments as well as multiple sectorial partners and stakeholders. The BGCMA is key in ensuring that available water is appropriately shared amongst all water users through the management of water allocations and acting as a mediator between competing water use groups (BGCMA, 2019).

Existing irrigation boards were transformed to act as Water User Associations (WUAs) through the amalgamation of a number of irrigation boards to facilitate access to water for irrigation purposes (DWAF, 2013). The WUAs can, however, also be established to assume the operation and maintenance functions of a government water scheme or the establishment of a new WUA where a group of water users come together to co-operatively manage local water use (DWAF, 2013). WUAs were established under the NWA to provide a formal system which operates at a local level for the joint benefit (pooled resources and mutual benefit) of the association members. WUA are local implementing agents to:

- Manage water for own and mutual benefit of all WUA members;
- Provide rules that support localised water resource management through delegated powers, duties and agreements; and
- Give effect to the overarching principles of the NWA including the implementation of IWRM at local scale (DWAF, 2013).

Original irrigation boards were amalgamated and transformed into several WUAs in the BGWMA with the original irrigation board canals and pipelines, supplying water to commercial farms, truncating the study area. The largest and most active WUA in the study area is the Central Breede River Water Users Association (CBRWUA) which is a multi-sectorial institution (Pegram & Mazibuko, 2003). CBRWUA's membership is made up of different water use sectors including:

- Commercial farmers i.e. grape farmers, fruit farming and dairy farming;
- Municipalities including Breede Valley, Robertson, Ashton;
- Commercial wine industry, distilleries, fruit packaging and processing;

- Tourism and recreation; and
- Communities living around the area constituting mostly ordinary water users, and emerging farmers.

The main function of the CBRWUA is the general control of water supply and equitable sharing of water among all users. The current function is mainly based on supplying water to qualifying users and the collection of relevant revenue. The CBRWUA ensures that the water resource is well maintained and has a continuous water quality monitoring system installed which provides real time data to ensure water is supplied at the quality required for different uses (L. Bruwer personal communication, 28 June 2021). The CBRWUA supports local government, DWS and BGCMA in water related issues.

Several dams of various sizes are also used to store run-off from rainfall, of which 80% falls in the winter months (April to September), for summer crop irrigation and urban water supply. The rainfall is as high as 2 300 mm/a in the mountains to the south-west whilst the central and north-eastern areas receive as little as 250 mm/a (Murray, Biesenbach and Badenhorst Inc. 1989; Steynor *et al.*, 2009; WCG, 2011). The largest dam, the Greater Brandvlei Dam, is mainly used for irrigation purposes with four canal and five pumping schemes transferring water to commercial farms (DWAf, 2003a).

The Breede River catchment (excluding the Gouritz section of BGWMA) was divided into sub-management areas (Figure 2-3):

- Upper Breede River section between Ceres and Worcester (H1) up to the inflow of the Brandvlei Dam (including the Holsloot, Smalblaar and Hex rivers (H2));
- Middle Breede River section from the outflow of the Brandvlei Dam to Robertson and Swellendam (H3-5);
- Lower Breede River section (from Swellendam to the estuary and outflow at Witsand) (H7);
- Riviersonderend (H6) section; and
- Overberg section (G4-5).

2.5 Water institutional arrangements in the study area

The nature of relationships between relevant institutions involved in water management in the catchment are presented in Table 2-1 (Pegram & Baleta, 2014; Ncube, 2018). BGCMA engages with nine local municipalities in the region regarding water management and planning, thereby including the needs of the municipalities (Ncube, 2018). In terms of Section 12 of the Municipal

Systems Act (Act 32 of 2000) local municipalities are water services authorities (WSA). The responsibility of a WSA is to regulate the provision and ensure access to water services (water supply and sanitation). WSAs may provide these services themselves or contract an external entity (Water Services Providers (WSP) to provide these services on their behalf. The abstraction of water and discharge of waste water to the water resource by any WSA require licences from the DWA or CMAs (DWAF, 2013). Municipalities report to DCoG whereas the WUA and CMA report to DWS.

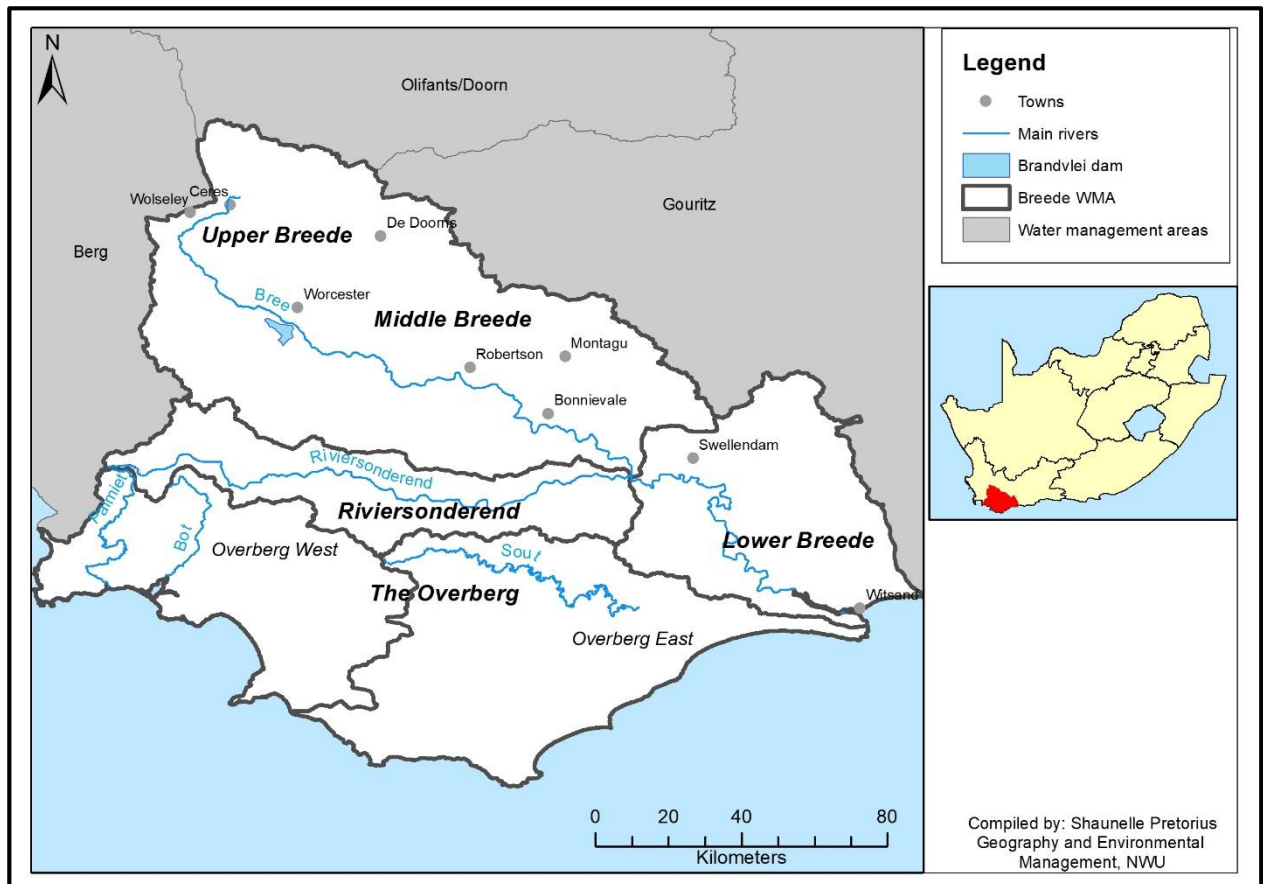


Figure 2-3: Sub-management areas of the BGWMA (modified from BGCMA, 2019).

There is, however, a disconnect between resource management and supply since water resources are managed at a local level by the CMAs, while water service provision occurs at municipal level (Ncube, 2018). This leads to complications when more water is allocated for supply purposes than is practical from an ecological standpoint.

Several stakeholders are involved in conservation in the study area (Table 2-1) and a number of stakeholders are involved in projects related to protection of threatened plant and fish species, removal of alien species and the evaluation of ecosystem services of wetlands (Papenkuils

wetland) have been listed (Jordaan *et al.*, 2021; DEA&DP, 2021; J. van Biljon personal communication, 30 June 2021). However, these are only the most recent studies related to both water quality and quantity in the Breede River with many others conducted over the years not included in the current list.

Table 2-1: Water institutional arrangements in the BGCMA

Institution	Nature of relationship
DWS	National Office and Regional Office in an oversight capacity supporting BGCMA. Water quality monitoring.
Western Cape Provincial government	Department of Environmental Affairs and Development Planning (DEA&DP) Western Cape: Implements initiatives which seek to address the challenge of water security and environmental sustainability in the Western Cape Support and coordination, ensuring that other districts are not unfairly prioritized over that of the Breede development corridor Research study coordination. Western Cape Department of Agriculture's LandCare: Manages River Maintenance Management Plans (RMMPs) along the Breede River which include controlling invasive species to assist in flood and drought management.
District municipalities	The BGWMA straddles four district municipalities with the main part of the study area falling within the Cape Winelands District municipality. The district municipalities only has a co-ordinating role for the local municipalities in its jurisdiction. The executive authority over the municipalities functions lie with the local municipalities rather than the district municipalities. The CWDM (Municipal Health Services) works with BGCMA in strategic planning, monitoring and improvement projects in the Breede River.
Local Municipalities	The WMA straddles several local municipalities with the Breede Valley and Langeberg local municipalities covering the main part of the study area Local government is responsible for water services provision and manages water in urban areas including supply and WWTW.
BGCMA	Breede-Gouritz Catchment Management Agency (BGCMA), previously BOCMA, perform certain management functions, co-ordinate and seek agreement on water-related matters among various governmental and non-governmental stakeholders and interested parties.
WUA	WUAs are co-operative associations of water users made up of previous irrigation boards, commercial and emerging farmers, municipalities and communities living around the area. WUA were established to undertake water-related activities for the mutual benefit of all its members and the equitable sharing of water to all users. WUAs are partners in a project for alien vegetation clearance
Cape Nature	Cape Nature is a public entity that promotes and ensures biodiversity conservation in the Western Cape. Manages several nature reserves and contributes to the management of the Province's natural water resources to ensure a sustainable and equitable supply of this precious resource to communities, industry and agriculture.
Environmental conservation organisations and NPO	Each of the stakeholders has a different reason for being involved in various areas in the catchment. Organisations identified include but are not limited to: Intaba Environmental Services, Fynbos Forum, Grootvadersbosch Conservancy, World Wide Fund for Nature South Africa (WWF-SA), Living Lands, Land Life Company, Alliance for Water Stewardship (AWS), Conservation Leadership Programme (Papenkuils wetland)
City of Cape Town	BGCMA supplies supplementary water to the City of Cape Town through inter-basin transfers.

2.6 Water use in the study area

Irrigation (68% of total demand) is the main surface water user in all three sub-management areas (Upper-, Middle- and Lower Breede River sections) with 18% exported to other catchments, 4% used by urban settlements, 1% by rural users, invasive species take up as much as 7% and the reserve 2% (DWAF, 2004; BOCMA, 2010; Pegram & Baleta, 2014). When comparing the supply and demand it is clear that the water supply is very close to capacity with only a 2.3% surplus (BOCMA, 2010).

Irrigated agriculture is dominated traditionally by wine production in the Upper and Middle Breede River sections (jurisdiction of CWDM) and all indications are that this would remain the main agricultural activity (Murray, Biesenbach and Badenhorst Inc. 1989; BOCMA, 2010; Breede Valley Municipality (BVM), 2019). Developments (including agriculture) along the tributaries use up all of the normal water flow before it reaches the Breede River (Murray, Biesenbach and Badenhorst Inc. 1989).

Although the amount of water used for domestic (urban) purposes in the BGWMA is low compared to agricultural use the urban demand by 2030 would exceed 43 million m³/a (DWAF, 2003b). Urban areas are supplied from several sources including dams, boreholes and surface streams with limited resources and storage capacity. The demand would be determined by the population growth and economic activity in the Breede River catchment with towns like De Doorns, Ashton and Bonnievale expected to experience impending water shortages (DWAF, 2003b).

The rapid population growth, industrial development, and improved living standards in the Greater Cape Town area are placing increasing pressure on the water resources in the region requiring augmentation of the available water by transferring water from other catchments such as the BGWMA (DWAF, 2003a). Inter-basin transfer schemes (Riviersonderend-Berg-Eerste River Government Water Scheme and Palmiet Pumped Storage Scheme) transport water from the BGWMA into the Berg WMA which feeds into the Western Cape Water Supply System including supplying the City of Cape Town (Steynor *et al.*, 2009; BOCMA, 2010; Pegram & Baleta, 2014). However, inter-basin transfers between the Breede River and adjacent catchments further complicate the water balance in the BGWMA. Some of the smaller towns (Rawsonville, Tulbagh) experience shortfalls in water supply with others expected to experience a shortfall in the near future (Swellendam, Touwsrivier, Wolseley) (Pegram & Baleta, 2014).

The study area is located in a primarily winter rainfall region, which implies that there is disconnect between periods when excess water is available (ie. during winter storms) and the requirements during summer (low rainfall) periods when irrigation of crops are at a peak. This significant

seasonal variability implies that only about half of the total average annual stream flow can be used reliably. Abstraction during summer low flow periods already exceeds what is available with even winter requirements during drier years also exceeding availability (DWAF, 2003). To ensure water supply during the summer irrigation periods (September to April) several large storage dams were constructed in the catchment (Murray, Biesenbach and Badenhorst Inc. 1989).

Supplying irrigation purposed water for commercial crops throughout the catchment relies on surface water through a distribution system which includes the Breede River, a series of canals, pipelines and several pumping schemes (Kirchner *et al.*, 1997). The area served by irrigation systems increased over the years, more so after the construction of the Brandvlei Dam (constructed 1922) which stabilised the supply of water for irrigation purposes (Kirchner *et al.*, 1997). The Greater Brandvlei Dam (Brandvlei Dam and adjacent Kwaggaskloof Dam combined) eliminated periodic water shortages during low rainfall periods (summer months) (Murray, Biesenbach and Badenhorst Inc. 1989; Kirchner *et al.*, 1997). The Brandvlei Dam is an off-canal storage dam and is fed by the two Breede River tributaries, the Smalblaar and Holsloot Rivers (Murray Biesenbach & Badenhorst Ing., 1988). Other dams used for irrigation include Theewaterskloof, Lakenvlei, Keerom and Elandskloof in different portions of the catchment (BOCMA, 2010). Stettynskloof Dam, close to Worcester, is owned by the local authority and supplies water for domestic use only (BOCMA, 2010). Numerous mostly shallow earthen storage dams of varying size have been constructed on farms across the catchment (Murray, Biesenbach and Badenhorst Inc. 1989; BOCMA, 2010).

Apart from the importance for agricultural purposes, the Breede River catchment is of high ecological importance due to its locality within the greater Cape Floristic Region. However, many of the plant species occurring within the area are already threatened due to agricultural activities and the associated human settlements (WCG, 2017). The tourism industry was also identified as a water user which needs to be taken into consideration when water use (quality and availability) is planned (DWAF, 2003d). The tourism industry makes use of the Breede River for various recreational purposes including camping, fishing, and water sports but contributed only 14% to the region's economy. It is, however, expected to become a more important part of the region's economy in the future (DWAF, 2003d).

Rapid population growth linked to agricultural development and resultant economic growth will increase the pressure on water resources. The linkage between economic growth and water demand will be highlighted in the following section.

2.7 Agriculture in the Breede River catchment

Agriculture in the Breede River catchment went through several changes since the early settlement in the region in the early 1900s. Initial livestock farming made way for dry land wheat and rye which made way for grain crops after water canals were constructed in the low-lying areas in order to divert water for flood irrigation (DWAF, 2003c). Flood irrigation of grape and deciduous fruit followed but diseases prompted short lived ostrich farming for the feather industry in the early 1900s. Eventually wine and deciduous fruit returned and expanded over the last century to the current situation where fruit (apples, pears, peach, apricot) dominate the northern parts of the Upper Breede River section, wine and table grapes as well as citrus the remainder of the Upper Breede River section as well as the Middle Breede River section with livestock, grain and canola dominating the Lower Breede River section (DWAF, 2003c). Agriculture was the main driver which shaped the urban land use patterns. Factors which shaped development in the catchment include (DWAF, 2003c):

- Climate—mostly the Mediterranean climate dictated the nature of crops (grapes and citrus) in the valley with cold winters favouring fruit such as apples and pears towards the northern parts of the Upper Breede River section;
- Availability of water—winter rainfall water is stored for summer crops through irrigation infrastructure developed across much of the Middle Breede River section and parts of the Upper Breede River section and dry land agriculture in the Lower Breede River section;
- Availability of fairly good quality soils in close proximity of the main water source;
- Proximity of market and transport infrastructure—railway and road infrastructure has developed which supports access to local and international export markets; and
- Infrastructure—facilities such as wineries, distilleries, packinghouses and fruit processing industries were developed in the Breede River catchment which encourages the planting of specific crops.

Currently agriculture is dominated by high-value fruit cultivation (wine and table grapes, citrus and deciduous fruit), supported by grains (wheat and canola cultivation) and livestock farming (Murray, Biesenbach and Badenhorst Inc. 1989; Cullis *et al.*, 2018). Associated agricultural industries include wine cellars, distilleries as well as fruit processing and packaging.

2.7.1 Agricultural economy in the study area

The agricultural economy in the study area is strongly dependent on water, whether irrigation from surface and ground water or rain fed cultivation. The economy of the Breede River catchment is therefore closely dependent upon the availability and quality of water resources (DWAF, 2003c,d;

BGCMA, 2017a). The variation in water resource availability is mirrored in the unevenness of economic production between areas with the relatively water abundant Upper and Middle Breede River section dominating economic production, whereas the contribution in the water constrained Lower Breede River section being considered to be relatively minor. The transfer of approximately 250 million m³ of water per annum to the Berg WMA limits the water directly available for agricultural and other developments in BGWMA, introducing constraints on the economy in those parts of the BGWMA directly affected (Pegram & Baleta, 2014; BGCMA, 2017a). The main concern is the potential impact the export of water will have on the economic growth along the Breede River catchment (Pegram & Baleta, 2014).

Agricultural, industrial, commercial and urban developments compete for water resources in the BGWMA (BGCMA, 2017a). Irrigation based agriculture, as the largest consumer of water, dictates the social and economic benefits derived from the expansion of agriculture. Any growth in agriculture would require additional water. However, current water demands in the catchment are approaching and in some cases; already exceeds the average available water, leaving no room for expansion unless water is re-allocated (DWAF, 2003c; BGCMA, 2017a; Ncube, 2018). Growth in agriculture will therefore needs to be offset against the impact a reduction in the available water in the catchment will have on other sectors (DWAF, 2003c). The availability of water during winter rainfall does not coincide with the needs for summer irrigation with abstraction during summer low flow periods already exceeding what is available in many parts of the catchment (BGCMA, 2017a). To expand the volume available during summer irrigation periods would require that the storage capacity be expanded through the raising of some of the existing dam walls, new irrigation schemes, or the construction of small impoundments. However, apart from the infrastructure being very costly, there are only a limited number of feasible sites where dams could be constructed (BGCMA, 2017a).

Pegram and Baleta (2014) showed that agriculture (including processing) contributes more than 14% to the country's gross domestic product (GDP). The Western Cape Province contributed significantly toward the country's agricultural export with more than half of South Africa's agricultural exports originating from this province (Pegram & Baleta, 2014). More than 90% of national exports of blueberries, bulk wine and pears; and more than 80% of table grapes, bottled wine and apple exports in 2019 originated from this province (WCG, 2020). Although the Western Cape Province faced many constraints, including a series of droughts which slowed down economic growth, the Province still showed a 0.8% growth in GDP in 2018 (WCG, 2018). While the economy of the Western Cape Province suffered significantly due to the global COVID-19 pandemic in 2020, agriculture was the only sector which had a positive contribution to GDP growth (WCG, 2020).

The economy of the BGWMA is primarily dependent on agriculture with the majority of the manufacturing, construction, trade and services economies of the various small towns in the region essentially also associated with agriculture and the associated agro-processing industries such as wineries, distilleries, fruit packaging houses, fruit canneries and dairy factories (BGCMA, 2019). Roughly a third of the economic activities are directly linked to agriculture and when adding the associated manufacturing, construction and services industries almost three quarters of the economy is dependent upon agriculture (BOCMA, 2010; BGCMA, 2019). The economy of the Upper and Middle Breede River sections are dominated by the agricultural sector with land-use dominated by agriculture and crop processing activities with most economic sectors, including industrial activities, in the urban centres being largely in support of agriculture (Murray, Biesenbach and Badenhorst Inc. 1989; Pegram & Baleta, 2014; Cullis *et al.*, 2018). Agriculture in the Breede River catchment contributes significantly to international exports and the economy of the Western Cape (Cullis *et al.*, 2018; Western Cape Government, 2018). Minor tourism activities occur mainly along the south coast of the ODM with protected areas and conservation/ biosphere reserves spread throughout the Breede River catchment (Murray, Biesenbach and Badenhorst Inc. 1989; Cullis *et al.*, 2018). The success of the agricultural sector in the Breede River catchment is an important driver for the expansion of the local economy and will ultimately lead to expansion of urban and peri-urban areas (DWAF, 2003c; Cullis *et al.*, 2018, Seeliger *et al.*, 2018). On the other hand, the expansion of the urban peri-urban footprint and intensified agricultural activities, such as water abstraction for irrigation and the return flows entering rivers, are linked to a decline in water quality in the catchment (Cullis *et al.*, 2018).

Increased climate variability, encroachment into flood zones by developments and alien species are widespread, resulting in floods which cause costly infrastructure damage (BGCMA, 2017a). Agriculture in the BGWMA is therefore under economic, climatic, and social pressure. Adapting to these pressures require changes in crop type, such as transitioning from deciduous fruit to grapes and citrus, as well as increasing the intensity of agricultural production (BGCMA, 2017a).

Sustaining and growing the economy in the BGWMA is not only dependent on the allocation of adequate volumes of water between economic sectors and specifically among irrigation farmers, but also maintaining water quality at levels which will sustain agricultural activities. Important water quality indicators and agricultural requirements relevant to the study area will be discussed in the following sections.

2.8 Water quality

Water is both a resource and a medium to convey waste streams from processes that range from agricultural to industrial and domestic (sewerage) effluent. The norm is to discharge treated water back into the water resources. However, the disposal of such waste water can have an adverse impact on the water quality of the receiving environment (Hansen, 2015). In addition, the disposal of treated waste streams put downstream users of the water at risk due to potential impacts of contaminants derived from the effluent (Hansen, 2015).

In addition to the negative impacts from waste disposal associated with anthropogenic activities in urban environments, climate change and changes in land use practices are expected to have long-term negative impacts on the availability, quality, and suitability of fresh water (Claassen, 2013). Changes in land use in the South African urban areas continue to place pressure on the country's ability of supplying adequate potable water at a standard that meets the present-day needs (Otieno & Ochieng, 2004).

Sources for pollutants or emissions which enter the receiving water environment from an easily identifiable single source such as pipes from industries or water treatment works (WWTW) and, or feedlots are referred to as point-sources of pollution (DWAF, 2003e). Point sources in the study area include WWTW, wineries, distilleries, dairies, fruit processing plants and other industrial facilities (DWAF, 2003e). Any discharge into a water resource must, however, be authorised and operators registered (Hansen, 2015). Point sources such as WWTWs, which release their final effluent into the aquatic environment, are easier to regulate as both the quality and quantity discharged into the environment can be monitored at the point of discharge (DWAF, 2003a-e). The WWTW remove contaminants to levels that would make the water safe for disposal through direct discharge back into river systems (CSIR, 2010; Hansen, 2015). Industrial discharge of waste streams, some of which are hazardous, directly into domestic sewer systems complicates the treatment of waste water (Otieno & Ochieng, 2004; CSIR, 2010; Hansen, 2015). The removal of the varied contaminants by the WWTW are not only very difficult but also costly.

Malfunctioning and poor operation and maintenance of old and decaying sewerage infrastructure are cause for concern throughout South Africa (Mema, 2010). In most parts of the country the declining state of municipal WWTW infrastructure is considered one of the largest contributing factors which lead to surface water pollution and associated human health concerns (Mema, 2010). Potential concerns from WWTW discharges include high nutrient load and algae blooms.

Non-point sources of pollution is generally dispersed over an area which makes monitoring and regulation of these pollution sources difficult. Activities such as developments close to the river

bank, clearance of riparian vegetation, surface run-off, spillages, illegal dumping and the ever growing informal settlements are potential non-point sources of pollution (DWAF, 2003e). Agricultural return flow is also regarded as non-point sources of pollution and are linked to seasonal activities (DWAF, 2003d,e). Potential concerns from these non-point sources include:

- Soil erosion leading to sediments and suspended solids transported in the rivers;
- High nutrient loads from fertilizers, animal waste;
- Agro-chemicals (pesticides, herbicides, fertilizer); and
- High salt loads from agricultural return flow.

Anthropogenic sources of water pollution relevant to the study area include point sources from WWTW and agricultural-related industries, whereas non-point sources of pollution include domestic effluent emanating from urban developments (including un-serviced informal settlements), surface runoff and agricultural activities (DWAF, 2003d, e). Water quality concerns in the Breede River catchment associated with domestic effluent include algae blooms under low flow conditions and clogging of canals by algae and aquatic weeds, whereas increased salt loads are generally associated with agricultural activities (DWAF, 2003e).

2.8.1 Important water quality indicators

Water quality is monitored by the evaluation of parameters of concern. The list of water quality parameters relevant to the current study are limited to the parameters included in the national water quality database of DWS and monitoring data from the BGCMA (BOCMA, 2010). Relevant facts regarding these parameters will be highlighted briefly.

2.8.1.1 Total dissolved solids (TDS)

Inorganic salts (mainly calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulphates) as well as dissolved organic matter are collectively referred to as Total dissolved solids (TDS) (DWAF, 1996a-f; WHO, 2008). TDS originates from natural sources, sewage, urban and agricultural runoff and industrial waste water. TDS is a consequence of the dissolution of minerals in rocks and soils as well as disintegrating plant material. The variations in TDS concentrations are related to the differences in the solubility of minerals in contact with water (WHO, 2008). The underlying geological units therefore have an important influence on the TDS of natural waters (DWAF, 1996a-f).

The palatability of water with a TDS level of less than 600 mg/l is normally regarded as good. At TDS levels greater than 1 000 mg/l drinking-water becomes unpalatable (DWAF, 1996b, c). High TDS levels may also lead to excessive scaling in water pipes (WHO, 2008).

2.8.1.2 Electrical Conductivity (EC)

Electrical conductivity (EC) is a measure of the ability of water to conduct an electric current leading to a salty/brackish taste of water (USEPA, 2021). The EC in the water is directly proportional to TDS and an indication of the salt load in water (DWAF, 1996a, f). The water EC levels may increase naturally, but may also be related to anthropogenic activities with domestic effluent. The high salt content may also arise from agricultural activities, particularly where chlorine and sulphate is present (DWAF, 1996a) and industrial waste water discharges and surface run-off contributing to pollution load. Elevated EC may also be an indication of excessive evaporation specifically during droughts (USEPA, 2021). Electrical Conductivity is a useful measure of water quality with each water body inclined to have a relatively constant EC range. Any substantial change in EC is indicative of a discharge which decreases the condition or health of the water resource (USEPA, 2021).

Irrigation with water containing high salt loads leads to salt build-up in the soil profile. Crops cannot be grown successfully in soil with extreme salinity (DWAF, 1996a). When no or little salt is leached from the soil profile, salt accumulates and may affect crops sensitive to soil salinity, leading to reduced yield. When irrigating with saline water it is common practice to over-irrigate to leach salts from the root zone (ARC, 2018). Salinity management depends on the salinity of the water for irrigation purposes, climate, the permeability and chemical properties of soils, as well as the salt sensitivity of crops (ARC, 2018).

Grapevines are considered to be moderately salt tolerant to moderately salt sensitive. There is some evidence that grapevines still seem to perform reasonably well if the EC does not exceed 2.5 dS/m (ARC, 2018). It is therefore possible to irrigate with saline water for one or two seasons in the absence of better quality irrigation as a temporary measure to manage the survival of vineyards during prolonged droughts (ARC, 2018). However, it is critical to leach any salts that could have accumulated in the soil when better quality irrigation water becomes available (ARC, 2018). Frequent evaluation of the quantity and extent of salt accumulation in vineyard soils when irrigated with highly saline water is essential (ARC, 2018). Technologies such as reverse osmosis and electro-dialysis used to remove salts from saline water are prohibitively expensive and therefore not economically viable to desalinate large volumes of water for irrigation purposes (DWAF, 1996a; ARC, 2018). Overhead sprinkler irrigation systems using saline water cause leaf

damage in vineyards; consequently, in order to prevent direct contact with the leaves, under-vine irrigation systems, e.g. micro-sprinklers and drippers are used (ARC, 2018). These irrigation systems can result in salt deposits on grapevine trunks; however, trunks can be protected from the saline water to evade possible salt damage (ARC, 2018).

Salinity is considered to be water quality constituents that are potentially hazardous and have a detrimental effect on animal health, potentially rendering water unpalatable to livestock. Although common salt, such as sodium chloride (NaCl), is frequently added to livestock foods to regulate feed intake and enhance palatability, excessive salinity may negatively affect palatability (DWAF, 1996a, f). Water quality constituents such as chloride, sulphate, magnesium, bicarbonates and calcium are generally associated with compromised palatability (DWAF, 1996a, f).

2.8.1.3 pH

Although pH does not generally impact water users, lower-pH water is likely to be corrosive to pipes (WHO, 2008). Safe water has a pH which is almost neutral, ensuring support to plant and animal life. Both high and low water pH values are, however, toxic to plant and animal species (WHO, 2008). Changes in stream water pH may affect other aspects of water chemistry, for instance acidic water (low pH levels) conditions can increase the solubility and bio-availability of plant nutrients, furthermore, some heavy metals are more easily absorbed at levels toxic to organisms (DWAF, 1996a-f).

Recommended pH for water for irrigation purposes ranges from 6.5 to 8.4 (ARC, 2018). Water pH levels below 6.5 and above 8.4 and may be unsuitable for irrigation purposes as it may cause corrosion, encrustation or fouling of irrigation infrastructure (ARC, 2018). Furthermore, most micro-nutrients are available to plants at pH levels between 6.5 and 8.4 (DWAF, 1996a; ARC, 2018). Direct contact of either very high or low pH waters may damage crop foliage, leading to decreased yield or damage to marketable products such as fruit (DWAF, 1996a). Irrigation methods that will not wet the foliage or products are therefore ideally used (ARC, 2018).

Potentially toxic constituents such as heavy metals are rendered unavailable for uptake by plants at alkaline (high soil pH levels) water conditions whereas it is available, often at toxic levels, at lower pH levels. It is often easier to address soil pH for agricultural purposes rather than to treat water for irrigation purposes. For instance adding agricultural lime to soil is used widely to maintain soil pH (DWAF, 1996a; ARC, 2018).

2.8.1.4 Nutrients

Nutrients are essential for plant growth and reproduction (ARC, 2018). Nutrients occur naturally; however, at elevated levels they can be harmful and pose risks to humans and animals and promote the growth of waterweeds including hyacinth and grasses (De Villiers & Thiar, 2007; USEPA, 2021; ARC, 2018). High nutrient levels result in eutrophication of surface water resources through stimulation of algal blooms which pose a serious risk to the aquatic life (De Villiers & Thiar, 2007). The two most common nutrients found in water are nitrogen and phosphorus. Although they occur naturally, elevated levels mostly originate from anthropogenic activities such as agricultural runoffs (return flows which contain excess fertilizer), raw domestic effluent and industrial waste stream discharges (DWAf, 1996a; ARC, 2018).

Nitrite (NO_2^-) and nitrate (NO_3^-)

A series of reactions known as the nitrogen (N) cycle regulate the flow of nitrogen from inorganic soil, water, air and organisms (DWAf, 1996a-f). Nitrogen denotes all inorganic forms of N present in the water, i.e. NO_3^- , NO_2^- , NH_4^+ and NH_3 (DWAf, 1996a-f; ARC, 2018). The inorganic N present in water include the reduced forms of inorganic nitrogen, i.e. ammonia (NH_3) and ammonium (NH_4^+), the end product of the oxidation of organic nitrogen and ammonia, i.e. nitrite (NO_2^-) and nitrate (NO_3^-). Nitrate is generally the more stable form and more abundant in the soil and water environment. High levels of nitrate (NO_3^-) and nitrite (NO_2^-) are indicators of agricultural activity (including surplus fertilizers and manures), domestic waste water (household detergents and industrial chemicals) as well as oxidation of nitrogenous waste products in human and animal faeces (WHO, 2008). NH_4^+ commonly occurs in waste water and is therefore linked to sewage effluent and contamination with waste water and an indication of WWTWs inefficiency (WHO, 2008; ARC, 2018). However, some nitrogen production may also be natural as part of the N-cycle where atmospheric deposition during lightning storms lead to increased N in soil. Surface water nitrate concentrations may change rapidly due to uptake by phytoplankton and denitrification by bacteria (WHO, 2008).

Nitrate is the dominant form of nitrogen in irrigation water. However, the amounts of nitrate and ammonia applied as fertilizer or released by the mineralisation of organic matter generally surpass that from irrigation water as a source (DWAf, 1996a). Although nitrogen is one of the essential plant macro-nutrients, high concentrations may stimulate excessive vegetative growth during some growth stages and lead to poor quality crops. High levels of nitrogen on pastures used as

livestock feed can cause the nitrogen to accumulate to levels that are toxic to animals (DWAF, 1996c).

High levels of nitrogen (N) in water for irrigation purposes will leach out, and contaminate ground water resources and may stimulate algae and aquatic plant growth in irrigation equipment (DWAF, 1996; ARC, 2018). Sensitive crops such as grapes and most other fruits are sensitive to nitrogen concentrations in water for irrigation purposes exceeding 5 mg/l (DWAF, 1996). When grapevines are irrigated with high levels of N it may lead to delayed poor yield of grapes with low sugar (ARC, 2018). To reduce the effects of high levels of N in water for irrigation purposes, farmers need to either reduce the amount of N fertilizer or address the amount of N from irrigation water by either diluting with an additional water source or switch water sources entirely (ARC, 2018). Algae growth in irrigation equipment is addressed by treatment with CuSO_4 (DWAF, 1996a; ARC, 2018).

Phosphate (PO_4)

Elevated concentrations of phosphate (PO_4) arises from domestic detergents, industrial and human waste water (DWAF, 1996a-f; De Villiers & Thiart, 2007; WHO, 2008). The most likely cause of increased phosphate levels is effluent from dysfunctional sewage works and un-serviced informal human settlements. However, it may also indicate the impact of agricultural land uses (fertiliser in agricultural run-off) on water resources (De Villiers & Thiart, 2007). Phosphorous is a vital nutrient necessary for plant growth but above 0.05 mg/l the risk for algal blooms and eutrophication developing due to nutrient loading increases the probability of bio-fouling in irrigation equipment (DWAF, 1996a-f; ARC, 2018).

2.8.1.5 Sulphate (SO_4)

The presence of sulphate in drinking-water can have a conspicuous taste leading to a laxative effect at very high levels. Sulphates occur naturally in numerous minerals but can also originate from industrial waste discharges as well as from atmospheric deposition; however, the highest levels usually occur in ground water which are mainly associated with natural geological units as a source (WHO, 2008).

2.8.1.6 Fluoride (F)

Fluorine is a common element in a number of minerals, such as fluorite and apatite (WHO, 2008). The concentration of fluoride in unpolluted surface water is < 0.1 mg/l (DWAF, 1996a). Although

fluoride is beneficial to humans and animals, excessive amounts result in tooth damage in the young and bone lesions (fluorosis) that may cause crippling in older humans and animals (DWAF, 1996a-f). Fluoride uptake is determined by factors such as soil type, as well as soil pH, Ca and P (ARC, 2018). Continuous applications of fluoride to soil over extended periods result in accumulation in the soil to concentrations where either crop yield or crop quality is affected (DWAF, 1996a).

2.8.1.7 Chloride (Cl)

Sources for chloride in water include natural sources (rock, soil, and aerosols), irrigation return flows, sewage and industrial effluents (Day & King, 1995; WHO, 2008). Chloride is mainly of concern in water supplies due to the unpalatable taste of water when present in high concentrations. Concentrations in excess of 250 mg/l can give a salty taste to water and beverages (WHO, 2008). Water for irrigation purposes containing high Cl concentrations is known to cause toxicity (ARC, 2018). Extreme chloride concentrations also increase the corrosion rates of metals. This may lead to increased concentrations of metals in water. The effect of chlorite depends on the interaction with other water quality constituents such as associated cations, the pH and the calcium carbonate concentration (DWAF, 1996a-f).

Due to the affect complexes formed by Cl may have on plants, the upper threshold for overhead irrigation for South African vineyards were set at 150 mg/l although levels of 70 to 175 mg/l may still cause foliar injury and yield decrease. To avoid these impacts, irrigation methods that do not wet leaves are recommended along with a reduction in the number of wetting and drying cycles or the application of surplus irrigation in order to leach excess Cl from the soil (ARC, 2018). At high chloride concentrations water is unpalatable to most livestock with pigs and poultry more susceptible to excess chloride than sheep or cattle (DWAF, 1996a).

2.8.1.8 Sodium (Na)

In areas of high rainfall the levels of sodium in surface water are generally low, whereas in arid areas with low mean annual precipitation sodium levels are elevated (Day & King, 1995; DWAF, 1996a). Water in arid areas often contains elevated sodium concentrations due to the high solubility of sodium in water and the fact that it does not precipitate when water evaporates (unless saturated). Other sources of sodium include industrial wastes, especially processes generating brines, and domestic waste water (DWAF, 1996a-f).

Sodium often accumulates in saline soils, particularly in low rainfall areas where leaching might be limited (Arienzo *et al.*, 2009; ARC, 2018). Sodium is not considered an essential plant nutrient

with many crops accumulating sodium to elevated levels in plant tissues, leading to toxicity (ARC, 2018). Sodium sensitivity varies considerably between species with woody crops being especially sensitive (DWAF, 1996a). Crops wetted by water for irrigation purposes containing toxic levels of sodium are affected at the root zone as well as by absorption directly through the leaves, causing leaf burn (DWAF, 1996a; ARC, 2018). Accumulation of Na in the soil may also lead to Ca and Mg deficiencies in plants (ARC, 2018). Sodium accumulates in leaves, leading to toxicological and palatability effects in livestock including lower feed and water intake (DWAF, 1996c).

Excessive sodium in irrigation water stimulates soil dispersion and structural break-down when the sodium levels exceed calcium levels by three times (ARC, 2018). Excessive sodium in irrigation water may therefore affect crop yield and quality. Common management practices to cope with increased sodium concentrations in water for irrigation purposes are to switch to an irrigation method that does not wet the leaves, add Ca and Mg to the soil to counter sodium toxicity as it is reduced when there is sufficient Ca in the soil or to switch to crops that are more tolerant to sodium. The sodium content in wine production in South Africa is restricted to 100 mg/l; therefore the threshold for overhead irrigation is set at a concentration of 115 mg/l (DWAF, 1996a; ARC, 2018).

The sodium adsorption ratio (SAR) is an index of the potential of water for irrigation purposes to induce sodic soil (measured by the percentage of a soil's cation exchange capacity occupied by sodium ions) conditions calculated from the sodium, calcium and magnesium concentrations in the water (DWAF, 1996a). Any reasonably soluble calcium (agricultural gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) or magnesium salt can be added to water for irrigation purposes to reduce the SAR; however, plant nutritional imbalances can be introduced when large quantities of either calcium or magnesium are added to the soil (DWAF, 1996a). Excessive concentrations of sodium present in soil in the root zone may result in the accumulation of sodium to levels that are toxic to plant growth, and may cause reduced yield or compromised crop quality (including the fruit size and appearance).

2.8.1.9 Calcium (Ca) and magnesium (Mg)

Although there are no guidelines for Ca and Mg levels in water for irrigation purposes, their levels are important in the calculation of SAR of the water source (ARC, 2018). However, the potential detrimental effect of Na may be aggravated when the Ca: Mg ratio in the water is less than one (1) (ARC, 2018). High concentrations of Mg in water for irrigation purposes may induce Ca deficiency resulting in low crop yields (ARC, 2018).

2.8.1.10 Bicarbonate and carbonate (HCO_3^-)

Although there are no recommended guidelines, high levels of bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) in water for irrigation purposes may impact negatively on plants, soils and irrigation equipment (ARC, 2018). Irrigation water with high HCO_3^- concentrations leads to high soil pH which can limit the uptake of certain ions and can be detrimental to plants (ARC, 2018). High levels of HCO_3^- may also impact on the SAR indirectly and therefore have an impact on the physical properties of soil (ARC, 2018). Irrigation by means of overhead sprinklers with water containing high concentrations of HCO_3^- may cause crystalline deposits on grapes which, although not necessarily toxic to grapevines, may impact on the product quality and market (ARC, 2018).

2.8.1.11 Other elements

In addition to the elements discussed above, ARC (2018) also provides permissible levels for the elements and information on how grapevines and soils would respond if water for irrigation purposes contains excessive levels of these elements. However, since the available data from the DWS archive do not include these elements as part of the routine monitoring dataset it will not be discussed in detail here.

The presence of metals (Pb, Hg, Mo, Cr, Cd, Zn, Mn, Fe, Cu) and other elements in surface water can occur naturally at low concentrations due to rock weathering and leaching from soils, or as a result of anthropogenic activities such as discharges of untreated domestic and industrial waste water, fuel spillages, dumping of solid waste, etc (DWAF, 1996; ARC, 2018). Accumulation of metals in the aquatic environment has negative impacts on both humans and the ecosystem itself. Many metals are only required in small amounts and can accumulate to levels that are toxic to plants including grapevines (ARC, 2018). The uptake of most metals are pH dependent and both excess and deficiency can cause harm to plants (ARC, 2018).

Most metals mentioned are removed as part of the sludge during the water treatment process (Manugufala *et al.*, 2011). However, most WWTW upgrades do not keep up with the increase in population resulting in a lower efficiency in the removal of pollutants, including metals, in the treatment process. The efficiency of the WWTW is lower when forced to treat higher volumes of influents than its designed capacity (Manugufala *et al.*, 2011).

2.8.1.12 Microbiological parameters

The identification of the presence of microorganisms in water is essential as it provides an overview of the potential for the transmission of water-borne diseases and possibly the presence of faecal contamination (DWAF, 1996a). When irrigation water contains these organisms crops and vegetables can become contaminated with human and animal pathogens and parasites. Produce eaten raw or consumed as animal feed are particularly high risk for the transmission of water-borne diseases when these microorganisms survive on the surfaces of produce. Although, coliforms are found in natural water affected by animal faecal waste, the majority of these organisms originate from municipal and industrial waste, including food processing plants, slaughter houses, poultry processing operations, feed lots and runoff from un-serviced high density/ informal housing areas (DWAF, 1996a).

The bacteriological indicators used world-wide in water quality studies are *Escherichia coli* (*E. coli*), enterococci, total and faecal coliforms. Faecal coliforms have been shown to represent 93 - 99 % of coliform bacteria in faeces from humans, poultry, cats, dogs and rodents and normally used as an indicator when evaluating the quality of waste water effluents (DWAF, 1996b). *E. coli* has been considered as the best bacterial indicator of faecal contamination in drinking water. *E. coli* may be released into the aquatic environment by humans and animals or as a result of poorly functioning and/or overloaded WWTWs or due to run-off from informal settlements and agricultural land-use (DWAF, 1996a). Health risks as a result of exposure include diarrhoea (cholera), urinary tract infections, typhoid, hepatitis and cryptosporidiosis (WHO, 1996).

The impacts on crop quality when irrigated with microbiologically contaminated water are related to secondary growth of algae and aquatic weeds which clog irrigation equipment (DWAF, 1996a). The presence of microbiological contaminants renders water not suitable for consumption and requires disinfection to kill the bacteria and microorganisms (DWAF, 1996a-f). However, removing human and animal pathogens and parasites from water for irrigation purposes is mostly too costly. Conventional water purification processes, including sedimentation, absorption, coagulation and flocculation can be used to remove these contaminants. However, these treatment processes only partially remove these micro-organisms with disinfection required as part of the treatment process (DWAF, 1996a-f). The treatment options for water for irrigation purposes include disinfection (mostly chlorine) and filtration to physically remove the pathogens. Other mitigation measures include not irrigating crops which will be consumed raw and the use of an irrigation method that does not wet the produce (e.g. drip irrigation) (DWAF, 1996a-f).

2.8.2 Resource Quality Objectives (RQO)

The NWA makes provision for the development and implementation of Resource Quality Objectives (RQO) which are a set of water quality goals to ensure that the country's water resources are protected (DWAF, 2013). The protection and utilization requirements for a specific water source are balanced by the RQOs. Water in a catchment is evaluated against the RQOs to assess whether or not a water resource is in its desired state (or moving towards it). Resource Water Quality Objectives (RWQOs) explicitly state where in the water resource (and when) certain targets should be achieved in order to ultimately achieve the overall RQO. The RQOs are published in the Government Gazette and have legal status (DWAF, 2013).

All water resources are classed in terms of the level of protection required and the intensity of utilisation (DWAF, 2013). The classification of South Africa's water resources is required by the NWA. The NWA management classes are:

- Class I- minimally used, minimally altered resource (A-B ecological condition of the water resource);
- Class II- moderately used, moderately altered resource (C ecological condition of the water resource); and
- Class III- heavily used, significantly altered resource (D ecological condition of the water resource).

The Breede River in its entirety was classified as class III and Recommended Ecological Category (REC) and water quality category D (indicating the system is largely modified), and RQOs highlighting the requirement to ensure the ecosystem's health and suitability for different uses through the improvement of the salt and nutrient levels (DWS, 2019). However, specific classes and RQO for individual sections of the Breede River were published (SA, 2018). The Upper Breede River section was classified as Water Resource Class II- a moderately used, moderately altered resource (C ecological condition of the water resource) with the Middle and Lower Breede River and Riviersonderend River sections classed as Class III- a heavily used, significantly altered resource (D ecological condition of the water resource).

2.8.3 Water quality monitoring

Water quality is used to express the fitness for the intended use which is evaluated in terms of the physical, chemical and biological composition thereof (DWAF, 1996). It is therefore critical to monitor the water quality continuously to assess the pollution level and to identify trends. Monitoring refers to all systems that collect data and information to manage the water resource

in an integrated manner in agreement with Chapter 14 of the NWA and the WSA. Water quality is variable in both time and space and requires continual monitoring to detect spatial patterns and changes over time. Water quality monitoring can be done for various reasons including: overall water quality status and trends, compliance with resource quality objectives, compliance with water use licence conditions and finding deviations from background levels (Boyd *et al.*, 2017).

The following institutions are involved in water quality monitoring in the study area:

- DWA: Head Office–national monitoring networks;
- DWA: Western Cape Regional Office–WWTW and industrial discharges;
- BGCMA–research related monitoring, WWTW, Breede River water quality monitoring;
- Local municipalities (Water Service Providers);
- Water User Associations; and
- Cape Nature–research related monitoring.

Various water monitoring programmes are conducted by DWS each with a specific purpose. The DWS Head Office is the custodians of the data which are collected by the Regional Offices. The National Chemical Monitoring Programme (NCMP) is relevant to this study and provides data and information on the surface inorganic chemical water quality of South Africa's water resources. The majority of samples are collected at gauging weirs as the surface water quality monitoring network and available from the national dataset of inorganic chemical data of surface waters (DWS, 2021). The National Microbiological Monitoring Programme (NMMP) provide information on the status and trends of the extent of faecal pollution, in terms of the microbial quality of surface water resources (DWS, 2021). The location of NMMP monitoring points is a function of known pollution sources and known downstream users. The DWS monitoring programme information are available from different databases and linked to Geographical Information Systems (GIS) and Google Earth for easy visualisation (DWS, 2021).

Monitoring and assessment of water quality involves measuring physical, chemical and microbiological parameters and comparing monitoring results with regulatory standards. The South African Water Quality Guidelines relate to the intended use of water such as industrial, domestic, recreation as well as agriculture (DWAF, 1996a-f). The South African Water Quality Guidelines is the main source of information for determining the water quality requirements of different water uses (DWAF, 1996a-f).

The South African Water Quality Guidelines Field Guide, Volume 8 of the South African Water Quality Guidelines series, is a summary of all the different Target Water Quality Ranges (TWQR) for all the different water use sectors (DWAF, 1996a-f). The TWQR for a particular constituent

and water use is the range of concentrations at which no known detrimental effects with respect to the fitness of the water for long-term continuous use and the health of aquatic ecosystems are expected (DWAF, 1996a-f).

2.8.4 Background on water quality in the Breede River catchment

Water demand needs to satisfy both the quality and quantity required (WCG, 2011). Several water quality studies in the Breede River were initiated due to declining water quality along the river, mainly related to increased salinity and nutrient enrichment (Murray, Biesenbach and Badenhorst Inc. 1989; Kirchner *et al.*, 1997; Howell, 2016; Cullis *et al.*, 2018). Not only is the water quality along the main Breede River deteriorating downstream, but many of the tributaries were not meeting the Target Water Resource Quality (TWRQ) for agricultural, industrial, domestic and/or environmental use for the main parameters (pH, TDS, SAR, Cl, Na) (DWAF, 2003a-f). Most tributaries dry up during dry summer months and the system is unable to fulfil water demands (New, 2002; BOCMA, 2010). However, when inflows do occur it is reported to be highly saline and of short duration (BOCMA, 2010).

The deterioration of water quality were generally linked to:

- Geology (water rock interaction) and geohydrology of the region;
- Return flows from irrigation;
- Agricultural process water;
- Discharge of water not complying with the standard of WWTWs;
- Runoff from urban settlements without adequate sanitation; and
- Droughts and climate change (WCG, 2011; Kirchner *et al.*, 1997; Cullis *et al.*, 2018).

Where ground water occurs at shallow depths in arid climates such as the BGWMA, evapotranspiration can result in the build-up of salts in the soil from that originally present in the water for irrigation purposes. Irrigation return flows in dry regions may therefore result in the precipitation of some salts in the soil causing salination of soil and potential damage to crops (Murray, Biesenbach and Badenhorst Inc. 1989; DWAF, 2003).

The influences of the factors highlighted here on water quality are discussed in the following section. This discussion provides the foundation for the later discussion on the water quality as well as drivers and risks associated with the decline in water in the Breede River catchment.

2.8.4.1 Influence of geology on water quality

The increased salinity in water for irrigation purposes in the BGWMA was reported as far back as 1938 (Murray, Biesenbach and Badenhorst Inc. 1989). The salinity in surface and ground water in the study area were linked to the geohydrology and underlying geology (water-rock interaction) which is dominated by Later Proterozoic Malmesbury Group rocks as well as sedimentary rocks of the Cape Supergroup (350-450 Ma) and Karoo Supergroup (150-350 Ma). (Kirchner *et al.*, 1997; DWAF, 2003e). The mountains are mostly dominated by sandstone of the Table Mountain Group (TMG) of the Cape Supergroup with the valleys generally underlain by shale and siltstone of the Malmesbury and Bokkeveld Groups and covered by the Quaternary deposits (DWAF, 2003e) (Figure 2-4).

The geohydrology of the Breede River section of the BGWMA is largely controlled by the lowermost unit of the Cape Supergroup, the arenaceous TMG which is the dominant fractured aquifer and occurs in the mountainous areas (DWAF, 2003f). The TMG is known for its high ground water storage potential with the highest ground water potential seen in the Upper Breede River section related to high levels of faulting in the TMG aquifer and higher (although variable) rainfall (DWAF, 2003e,f; Wooldridge, 2005).

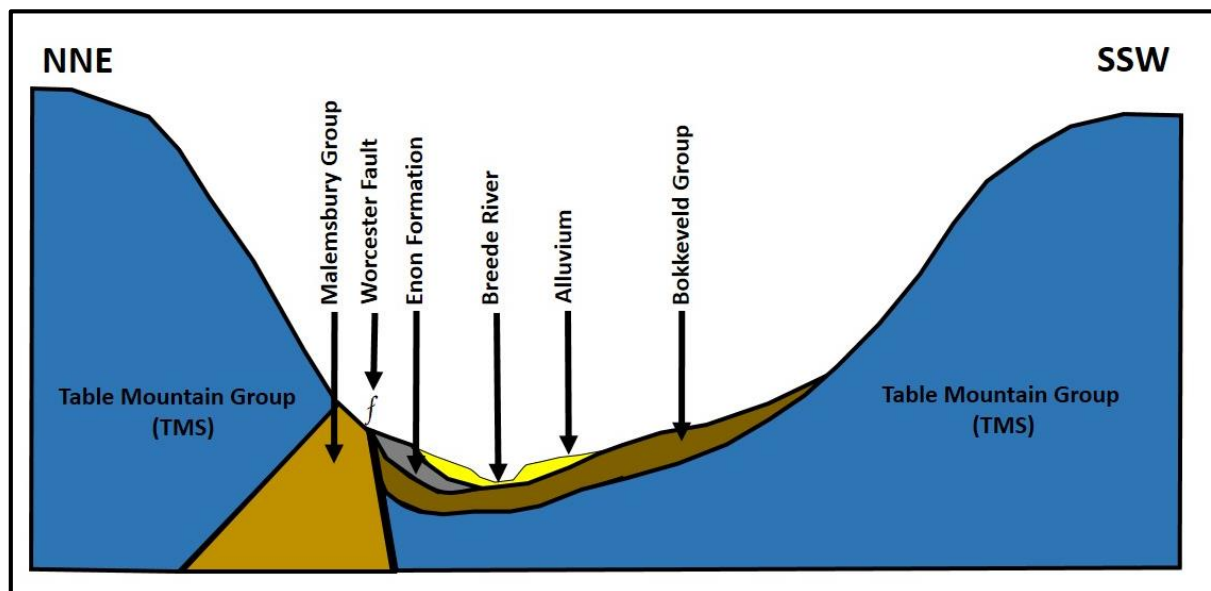


Figure 2-4: Geological cross-section through the Breede River valley (modified after Kirchner *et al.*, 1997).

Water originating from the TMG sandstone is of a high quality with very low salinity (Kirchner *et al.* 1997; DWAF, 2003f). In the mountains the base flow feeds non-perennial tributaries and recharge the alluvial aquifer in the bottom of the valleys. Most of the non-perennial tributaries are associated with short-lived floods during significant rainfall periods and melted snow from the steep mountain catchments (Murray, Biesenbach and Badenhorst Inc. 1989).

The foothills and valleys of the study area are dominated by the Bokkeveld Group (consisting of alternating shales and sandstones), notorious for high salt content and being impermeable (Murray Biesenbach & Badenhorst Ing. 1988). Ground water in these areas are consequently highly saline and mainly not utilised as a water source (Murray Biesenbach & Badenhorst Ing. 1988; DWAF, 2003f). A number of Tertiary and Quaternary deposits occur within the study area consisting mostly of unconsolidated to semi-consolidated calcareous sands of the Bredasdorp and the Enon Formations of the Uitenhage Group. Isolated outliers of the Enon Formation is covered by various Quaternary deposits (gravel terraces, ferricrete and alluvium) which occur adjacent to rivers and streams (Wooldridge 2005) (Figure 2-4). The alluvium deposit (between 20 and 40 m thickness) consisting of clay, sand, pebbles and boulders, which occurs in the valley of the Breede River and its tributaries and scree deposits covering the foothills of the main mountain ranges, represent the youngest transported material.

The study area falls within the Cape Fold Belt (CFB), which is the dominant structural feature in the Southern and Western Cape, which resulted in the formation of the continuous mountain ranges in response to pressure from the south some 250 million years ago (McCarthy & Rubidge, 2005). The main Worcester fault cuts through the Breede River valley and is orientated parallel to the main mountain ranges with a displacement along the southward dipping normal fault which varies from a few meters to 6 000 m along which small patches of Robertson and Greyton granites are located (DAWF, 2003e).

The parent materials from which soils in the study area were derived are mainly the Table Mountain Group sandstones, Malmesbury Group shales, Bokkeveld Group shale and Enon Formation conglomerates and various granites (Wooldridge, 2005). Along the mountains crests soil cover varies from no cover to relatively shallow (Mispha) and covered by tallus. The remainder of the area is covered in mainly red apedal to calcareous soils (foot slopes mainly from Bokkeveld shale and Enon Formation, i.e. Hutton and Sterkspruit soil forms) to yellow-brown apedal soils (from TMG sandstone in flood plain, i.e. Clovelly Fernwood and Westleigh; mid slopes from Dwyka Group, i.e. Swartland, and from Malmesbury and Bokkeveld shale, i.e. Glenrosasoil forms) with minor saline soils with cutanic B horizons (Wooldridge, 2005). The warm climate and well-drained lime-rich soils are ideal for wine grape cultivation (DAWF, 2003e,f).

The contribution of ground water to the irrigation in the Upper Breede River section is estimated at 32%, whereas in the lower portion of the catchment ground water is predominately used for domestic purposes and livestock watering (DWAF, 2003e,f).

Although ground water is not used at the same rate as surface water, the quality thereof is relevant as some areas rely on ground water for irrigation which may contribute to return flows impacting on the surface water quality downstream. Ground water quality differs from excellent (EC <80 mS/m) in the Upper Breede River section to saline as one moves downstream. The highest salinity levels in the ground water occur in the Middle Breede River section, attributed to low recharge rates and lower transmissivity of the argillaceous (shale-rich) host rock (Bokkeveld Group 70-300 mS/m)(DWAF, 2003e). Poorer water quality is also associated with Karoo shales (around Worcester) and alluvial aquifers (DWAF, 2003e,f). The alluvial aquifer has been reported to have elevated salinity (EC 600-1 200 mS/m at Robertson) and high concentrations of nitrate and phosphate as a result of return flows from irrigated vineyards situated on the alluvium in the valleys (DWAF, 2003e,f). However, Kirchner *et al.*, (1997) ruled out ground water as a major contributor to the higher salinity levels of the surface water in the BGWMA.

2.8.4.2 Influence of agriculture on water quality

Although salinisation of rivers in the Western Cape is largely a natural phenomenon associated with specific lithologies, it has accelerated due to agricultural practices (WCG, 2011; Kirchner *et al.*, 1997; Cullis *et al.*, 2018). Agricultural practices expose rocks and soil to leaching, contributing to the salinity problem through return flows carrying the salts into the rivers (WCG, 2011; Kirchner *et al.*, 1997; Cullis *et al.*, 2018). Surface water quality becomes progressively poorer downstream in the Breede River and its tributaries (Murray, Biesenbach and Badenhorst Inc., 1989). The salinity levels are especially high during the summer, when higher volumes of water is used in irrigation leading to higher return flows (Kirchner *et al.*, 1997). Irrigation practices in the Breede River catchment has been linked to high return flows to the Breede River, increasing the salinity levels in the river (Kirchner *et al.*, 1997). The return flow of irrigation water to the natural streams is highly saline (TDS level of 1 189 mg/l) (Murray, Biesenbach and Badenhorst Inc. 1989). The Middle and Lower Breede River sections and tributaries such as the Vink, Kogmanskloof, and Poesjenels Rivers are particularly vulnerable to high salinity concentrations.

These salts need to be flushed out as part of irrigation management to prevent the accumulation of salts in the soil and surface water resources (DWAF, 2003d, e). In response to the increased salinity, water is released from the Brandvlei Dam to dilute the highly saline flow during the summer months (Kirchner *et al.*, 1997).

Waste water generated by wineries are generally of low quality and cannot be disposed of without treatment. Howel *et al.*, (2015), Howell (2016), Van Schoor (2005) and Laurenson *et al.* (2012) also showed that winery waste water may have detrimental effects when used as irrigation water in vineyards. Solid wastes generated by wineries may result in seepage and contamination of soil and water resources that can inhibit vegetative performance (Van Schoor, 2005; Mulidzi *et al.* 2009).

2.8.4.3 Influence of domestic effluent on water quality

Other concerns are related to the contamination of water resources by municipal waste water and urban runoff, contributing to high pathogen and nutrient loads which have an impact on irrigation agriculture and recreational activities along the rivers and estuary (Cullis *et al.*, 2018). Increased nitrogen and phosphorus were linked to the nutrient enrichment which caused algal blooms under low flow conditions in some parts of the Middle Breede River section as well as the clogging of canals by algae and aquatic weeds (DWAF, 2003d, e). These concerns are mainly associated with the efficiency of the 18 WWTWs located in the Breede River catchment and the ability of these WWTWs to accommodate the increasing loads. Many WWTWs in the BGWMA are not functioning optimally and some require upgrades (WCG, 2017; Cullis *et al.*, 2018). The poor quality effluent from WWTW impact on the water quality of the Breede River, the receiving environment, and negatively affects downstream users (WCG, 2017). Cullis *et al.* (2018) indicated that a failure of municipalities to keep up with population growth in urban and peri-urban areas, through managing and upgrading the WWTW, are major risks to water quality in the BGWMA and will have a significant negative impact on the local economy.

Agriculture is the main economic activity in the area and encouraged economic and human population growth in the BGWMA in recent years (Schachtschneider, 2016; Cullis *et al.*, 2018). Agricultural growth stimulates the labour market and subsequently results in population growth in the nearby urban areas, which house the seasonal inflow of job seekers. However, many chose to stay in the area after the harvesting season, resulting in rapid urban growth and pressure on local municipalities to provide basic services, including water and sanitation. Poor quality water, originating from these poorer urban areas, flows back into the catchment along the canals and tributaries that traverse the landscape (Schachtschneider, 2016; Cullis *et al.*, 2018). As is the situation in many local municipalities in South Africa, local governments of the Breede River catchment experience constraints including, financial, institutional and implementation logistical, in the provision of basic services to informal settlements and backyard dwellers. The unpredictable population growth associated with urbanisation and growth in agriculture in the catchment resulted in challenges in the delivery of water and sanitation, as well as bulk services in informal settlements (WCG, 2017).

The aged storm water infrastructure along the Breede River has been identified as a significant risk due to growing settlements in close proximity to the river. Furthermore, threats to the water quality in the Breede River and functioning of wetlands, due to the impact from the informal settlements along parts of the river, have been identified (WCG, 2017). Solid waste which ends up in the river exacerbates the problem as it adds to existing water management problems (WCG, 2017).

2.8.5 Influence of climate change on water quality

Climate change is a natural phenomenon through which global climate change over geological time. However, this change has been exacerbated by anthropogenic activities through greenhouse gas emissions (IPCC, 2014). The net effect of climate change is expected to result in increased temperatures, and changes in regional climate characteristics such as rainfall and extreme weather events (IPCC, 2014; CWDM, 2019). Climate change is therefore expected to further intensify water demand and pose a risk to long term water security and consequently also have a negative impact on food security (IPCC, 2014; Cullis *et al.*, 2018; WWF, 2018). Climate change impacts will also force migration to larger centres, from areas which will become increasingly hostile to human habitation, placing more pressure on the already scarce resources and service delivery in those centres (WCG, 2017).

Climate change projections are essential in any long-term planning as the decrease in water supply and increased demand would exacerbate the current water resource problems in the catchment and negatively affect sustainability and economic development in the area (New, 2002; Steynor *et al.*, 2009). According to the WWF (2018) climate scientists predict that the entire Western Cape Province will become warmer and drier over time. Not only will the rainfall in the province decline by 30% by 2050, but expected temperature increases will result in the escalation of the evaporation rate, leading to decline in surface water availability but also to lower ground water recharge (WWF, 2018). Climate change is predicted to have detrimental impacts on towns in the Western Cape Province as residents will be required to use less water for domestic and other economic purposes as the bulk of the available water will be allocated to support highly productive agricultural activities (WCG, 2017). Associated implications predicted include job losses and economic impacts related to lower exports as a result of lower production (WWF, 2018).

Since the agricultural sector along the Breede River is extremely dependent on water, water scarcity could have a severe impact on the agricultural industry and consequently hinder the economic growth of the region (WC, 2017). The decline in water quantity in the BGWMA due to

climate change is therefore of great concern as was evident from the impact of recent droughts on agriculture and the livelihoods of communities relying on the agricultural and agricultural production sectors (WWF, 2018).

The most recent drought (~2018) had a negative impact on the agricultural sector along the Breede River. As agriculture had to compete with other water users (urban residential and industrial), farmers had to cut water use by 60% resulting in lower output and prioritising higher profit crops (L. Bruwer personal communication, 28 June 2021). WWF (2018) warned that the recent drought should be considered as a warning of scenarios likely in a future under climate change. Agriculture would therefore require implementation of more efficient water use methods to maintain productive yields. The drought highlighted the need for enhanced water efficiency on farm and catchment scale, the control of alien plants, improved land use planning and improved resilience to climate change (WWF, 2018). Many vineyards and fruit trees have for instance been removed due to the water availability concerns in the catchment (WWF, 2018).

The agricultural water requirements and potential impacts of poor water quality on agriculture are discussed in the following section.

2.9 Agricultural water requirements in the study area

The BGWMA is an important producer of table grapes and wine grapes. A decline in the irrigation water quality along the Breede River poses a significant economic risk due to the strict requirements of international export markets (Kirchner *et al.*, 1997). Water is not only used for irrigation but also in other aspects of the wine industry. These include winery activities from pre-harvest to post-harvest where water is used in (alkaline) washing, rinsing of the tanks, floors etc., and also as process water including water used for acidification and cooling during which various contaminants will enter the waste water stream (Howell, 2016). Wineries produce large volumes of low quality waste water, particularly during harvest. Using untreated winery waste water is an integral part of the wine production processes with winery waste water historically disposed of on land through irrigation (Howell, 2016). However, excessive irrigation with waste water may lead to seepage of waste water into ground water resources, as well as salinisation and eutrophication of surface water resources (Howell, 2016). Irrigation with untreated winery waste water may also cause soil sodicity, salinity, contamination with a wide range of chemicals, waterlogging, loss of soil structure and increased susceptibility to erosion (Howell, 2016).

The agricultural sector is under increasing pressure to meet demands and food security. To meet the demand farmers need to increase productivity by increasing the use of pesticides and fertilisers or increase irrigation. These farming practices are unsustainable and often lead to

problems such as degradation of soil and thereby reduced productivity as well as impacts on water resources including pollution (pesticides and fertilizer chemicals in run-off and ground water) and increased water usage (WCG, 2017). Water quality problems in the agricultural sector can have direct negative impacts on:

- Crop yield (quantity and quality);
- Soil's sustainability for irrigation purposes; and
- Performance of the irrigation system (WCG, 2017; ARC, 2018).

Water quality in the agricultural context is associated with the effect it has on soils, and crops, as well as management inputs required to overcome quality related problems (ARC, 2018). Depending on aspects such as soil texture, soil composition, drainage, rainfall and volume of irrigation water, irrigating grapevines with poor quality water can result in the accumulation of elements which can reduce yields of commercial crops or damage irrigation equipment (DWAF, 1996a; ARC, 2018). The threshold levels of elements and other parameters in water for irrigation purposes must therefore be known to enable farmers to apply available water cautiously to avoid negative effects and promote long term sustainable use (ARC, 2018). Water used for the purposes of irrigation is therefore analysed at least twice a year, i.e. at the beginning and in the middle of the grape growing season.

However, it is not only the quality, but also the volume used that affects the water security in any catchment. The expansion of agriculture in terms of increased yield is often associated with increased demand and use of water. However, the more efficient use of available water in the agricultural sector could arguably be the key to growth and development in the agricultural industry rather than increasing the amount of water required (WCG, 2015). In many instances available water has been augmented by introducing grey water into the water mix. However, crop sensitivity and the impact on water quality in the surface water resource needs to be taken into consideration when grey water is applied in agriculture (Murray, Biesenbach and Badenhorst Inc. 1989; Howell, 2016). The volume of water used for cleaning purposes in a winery has been estimated at 600 liters for every ton of grapes processed and seepage losses from irrigation canals and farm dams estimated at around 26% with a further 36% of water used in irrigation estimated to be lost on the farm due to management inefficiencies (Murray, Biesenbach and Badenhorst Inc. 1989).

2.9.1 Cost of pollution to agriculture

The economic risks associated with a failure to maintain water quality standards include a risk to the agricultural activities as maintenance cost for irrigation systems continue to increase as well as impacts on the yield and quality of the products which will have a negative impact on the income earned and therefore the economy of the region (Cullis *et al.*, 2018).

Water quality concerns include not only salinity but also microbiological impacts. Clogging of irrigation systems, particularly drip and micro-sprinkler systems, is caused by poor water quality primarily due to the precipitation of iron and/or manganese oxides, Ca and/or Mg in the pipes and pump parts but also due to fouling from algal blooms as a result of high nutrient levels, which all contribute to substantially reduce flow rates (SABI, 2015; ARC, 2018). Over time water flowing through the drippers or micro-sprinklers become blocked due to the precipitates and fouling, making it very difficult to clean the system. The best practice to prevent the build-up or to dissolve oxides is by injecting acid into the irrigation system (ARC, 2018). The excessive growth, or blooms, of micro-organisms can also cause clogging in irrigation systems. The injection of chlorine gas can clear the irrigation system; however, chlorine gas is hazardous and mostly not used locally (ARC, 2018). Aeration of the irrigation water before it is pumped into the irrigation system may also reduce the risk of clogging due to the oxidation of elements, resulting in oxides precipitating out (ARC, 2018).

Increasing salinity levels are expected to have a negative effect on the economic growth in the area due to the potential negative impact on crop yield caused by the build-up of salts in soil over time (DWAF, 2000). Water quality in some tributaries of the Breede River are already not fit for irrigation purposes and is expected to worsen as irrigation developments continue to escalate.

Moolman (1999) found that the yield of grapevines were highly dependent on the salt concentrations and time of exposure to saline conditions in the soil.

The cumulative effect of irrigation with saline water resulted in increased soil salinity with an EC above 75 mS/m linked to a decrease in yield. Since the build-up of salt in the soil have a negative effect on growth in the following season, additional irrigation water (up to 300 mm) is applied to leach the salts from the soil in order to maintain salinity below 100 mS/m which increases the production cost and leads to increased salinity in the rivers (Moolman, 1999; DWAF, 2000). Not only is the crop yield affected by salinity but also the crop quality. As the salt available to the plant increases the ability of the plant to extract water will diminish and the plant will experience salinity induced water stress, affecting the yield. Crop quality is further affected by chloride. Moolman (1999) also suggested that the salinity and chloride target limits set by the DWS (DWAF, 1996),

in order to control the water quality in the lower part of the Breede River, was not strict enough and suggested a limit for EC of 70 mS/m and chloride level of 140 mg/l. The maintenance of the water salinity levels at a level fit for agricultural purposes (below 70 mS/m) by releasing water from the Greater Brandvlei Dam was $30 \times 10^6 \text{ m}^3$ in 2000 and at the time expected to increase to $45.7 \times 10^6 \text{ m}^3$ (DWAF, 2000).

Furthermore, potential losses due to restrictions from international markets due to poor irrigation water quality could be extremely costly to the agricultural sector (Schachtschneider, 2016; Cullis *et al.*, 2018). The consequences are substantial, given that about half of the deciduous fruit and table grapes cultivated in the Breede River catchment are exported (WCG, 2017; Cullis *et al.*, 2018). The non-compliance to the European water quality standards for irrigation might result in the exclusion from the global agricultural market. The perception of contaminated irrigation water (i.e. negative media coverage), even without validity, could result in a decrease in the value of the crops, for the most part through the loss of the export market (WCG, 2017). The potential economic impact of perceptions was highlighted by du Plessis and Korsten (2015) that showed the impact of a recent foodborne disease outbreak which erroneously implicated Spanish cucumbers and tomatoes resulted in a €225 million per week loss to Spanish farmers. The risk to the agricultural sector losing a market due to perceived or potentially poor water quality, however, goes beyond the farm as it may impact on the labour market and ultimately the economy of the urban areas in the catchment (Schachtschneider, 2016; Cullis *et al.*, 2018).

The potential health, reputational and market impacts, due to pathogen pollution in irrigation water, due to inadequate treatment of waste water discharged into the rivers and run-off from unserved low income urban areas, on the regional economy could be severe (Cullis *et al.*, 2018). The social and economic consequences of continued non-compliance by municipal waste water treatment works could therefore be far-reaching (Cullis *et al.*, 2018). Cullis *et al.* (2018) also warned that the growing tourism industry along the Breede River could be negatively impacted by the declining water quality.

2.10 Conclusion

This chapter presented a survey of relevant literature aimed at addressing the study aim and objectives related to the decline in water quality as well as the key drivers and risks associated with that. The literature highlighted the importance of water quality in achieving sustainable development. Literature showed that developing countries, such as South Africa, are vulnerable to the decline in water quality linked to urbanisation. The link between the agricultural sector and the economy of the study area was shown. The factors (natural and anthropogenic) which

potentially impacts on the water quality of the study area was highlighted. Previous studies showed specific water quality parameters which have been linked to impacts on agriculture (including yield and crop quality) were unpacked.

This chapter provided the foundation for the research methodology including the water quality parameters to focus on as well as guiding the questions included in the questionnaires. This chapter also aided in the discussion of results including the water quality, identification of key drivers and risks associated with the decline in water quality and the impact thereof on the agricultural sector in the Breede River catchment.

CHAPTER 3 METHODOLOGY

3.1 Introduction

This chapter explores the methodology through which the water quality in the Upper, Middle and Lower Breede River sections of the BGWMA were re-evaluated and interpreted from existing water quality data extracted from various databases (Research Objective 1). This chapter furthermore explores the research approach involved in the collection, presentation and interpretation of qualitative and quantitative data in order to identify the key drivers of the decline in water quality of the agricultural sector in the Breede River catchment (Research Objective 2) and to identify and evaluate the risks posed by the declining water quality in the Breede River catchment, related to agricultural activities (Research Objective 3).

3.2 Research design

This study followed a mixed methods research approach, which according to Brannen (2005) is a research strategy utilising more than one research method and may combine quantitative and qualitative methods. This method was selected as a combination of quantitative and qualitative methods and were applied during the execution of Research Objectives 1 to 3, respectively.

Data collection for mixed methods can follow strategies falling on different ends of the mixed methods design spectrum. The first is a relatively simple design in which qualitative and quantitative data are collected concurrently. The second is a sequential mixed methods data collection strategy which involves data collected in one phase contributing to the data collected in the next phase (Driscoll *et al.*, 2007). The sequential strategy was applied in the current study where quantitative data was firstly collected to address Research Objective 1. Background information gathered during the literature review as well as results from quantitative data from Research Objective 1 were used to provide information regarding the water quality to be incorporated in interview questions and also for the purpose of guiding the selection of suitable participants. Secondly, qualitative data were collected by augmenting interview questions. Research Objectives 2 and 3 were conducted through semi-structured one-on-one interviews either in person or via electronic media (i.e. Zoom or telephone).

3.3 Literature review

A survey of literature relevant to the study was conducted. The aim of the literature review was to examine the global and South African perspectives on sustainable development and water

management, the local legislation pertaining to sustainable water management, and institutional arrangements related to water management in the study area, to investigate the local water uses and their impacts on water quality with the focus on agriculture and to find the link between water quality and economic growth in the study area. The literature focused on the existing knowledge which would assist in evaluating the current situation regarding the water quality in the study area and the impact thereof on the agricultural industry (Research Objective 1). The literature review furthermore assisted in the development of the questionnaires as it explored potential drivers of the decline in water quality of the agricultural sector in the Breede River catchment (Research Objective 2) and the risks posed by the declining water quality in the Breede River catchment, to agricultural activities (Research Objective 3). Sources included articles in journals, various government publications including acts and strategies, project files, maps, databases and internet sources.

3.4 Data collection

In this section the sources of quantitative water quality data evaluated during the investigation of the Breede River catchment will be discussed (Research Objective 1). The process of collecting quantitative and qualitative data, during the identification of key drivers of the decline in water quality in the Breede River catchment (Research Objective 2) and the identification and evaluation of the risks posed by the declining water quality in the catchment to agricultural activities (Research Objective 3), will be deliberated.

3.4.1 Quantitative: Water quality data

Water quality data was collected from various databases to verify claims of declining water quality and to identify specific parameters that would most likely affect agriculture in the Breede River catchment. These databases included the national water quality database of the DWS and monitoring data from the BGCMA and other sources (peer reviewed publications and research reports). These databases provided historic and recent time series data which were useful in determining whether there was indeed a decline in the water quality and whether identified parameters showed decline.

To be able to evaluate the water quality in the catchment, spatial trends along the Breede River mainstream and tributaries were essential. The DWS and BGCMA have been monitoring water quality at sampling points in the Breede River catchment, from Ceres in the upper reaches to the Breede River estuary, on a monthly basis since 1970 and 2010, respectively (BOCMA, 2010). For this purpose monitoring stations in the sub-catchments covering the Breede River mainstream

and tributaries were selected for this study. Details of the relevant DWS monitoring stations spread over the Upper- (2), Middle- (6) and Lower (1) Breede River sections as well as the Riviersonderend River section (1) of the BGWMA are presented in

Table 3-1 and Figure 3-1.

Table 3-1: DWS monitoring station description (DWS, 2021).

Sample station ID	Brief locality description of sample station	LAT. DECIMAL DEGR (S)	LON. DECIMAL DEGR (E)
UPPER BREEDE SECTION			
H1H003Q01	Breede River at Ceres, Upstream of Wolesley	33,3811	19,3028
H1H015Q01	Breede River at Nekkie/Brandvlei Dam	33,6842	19,4219
MIDDLE BREEDE SECTION			
H2H010Q01	Hex River at Worcester (Three Rivers Bridge)	33,6697	19,4653
H3H011Q01	Kogmanskloof River at Goudmyn, Robertson-Ashton	33,8708	20,0033
H4H017Q01	Breede River at La Chasseur, Robertson	33,8181	19,6947
H4H020Q01	Nuy River at Doornrivier, Worcester-Robertson	33,7181	19,4822
H5H004Q01	Breede River at Wolvendrift, Downstream Robertson	33,8978	20,0128
H5H005Q01	Bree River at Wagenboomsheuvell/ Drew, Upstream Swellendam	34,0022	20,2133
LOWER BREEDE SECTION			
H7H006Q01	Bree River, downstream of Swellendam	34,0658	20,4042
RIVIERSONDEREND SECTION			
H6H009Q01	Riviersonderend River at Reenen, Swellendam	34,0756	20,1456

Water quality parameters included pH, electrical conductivity (EC), total dissolved solids (TDS), ions (all in mg/l): sodium (Na⁺), potassium (K⁺), calcium (Ca²⁺), magnesium (Mg²⁺), ammonium (NH₄⁺), silica (Si), fluoride (F⁻), orthophosphate (PO₄³⁻), chloride (Cl⁻), sulphate (SO₄²⁻), nitrate and nitrite combined (NO₃⁻ + (NO₂⁻), Faecal Coliforms and E. coli. These chemical species are critically important for the calculation of variables that can be used to test the analysis for accuracy (e.g., charge balance).

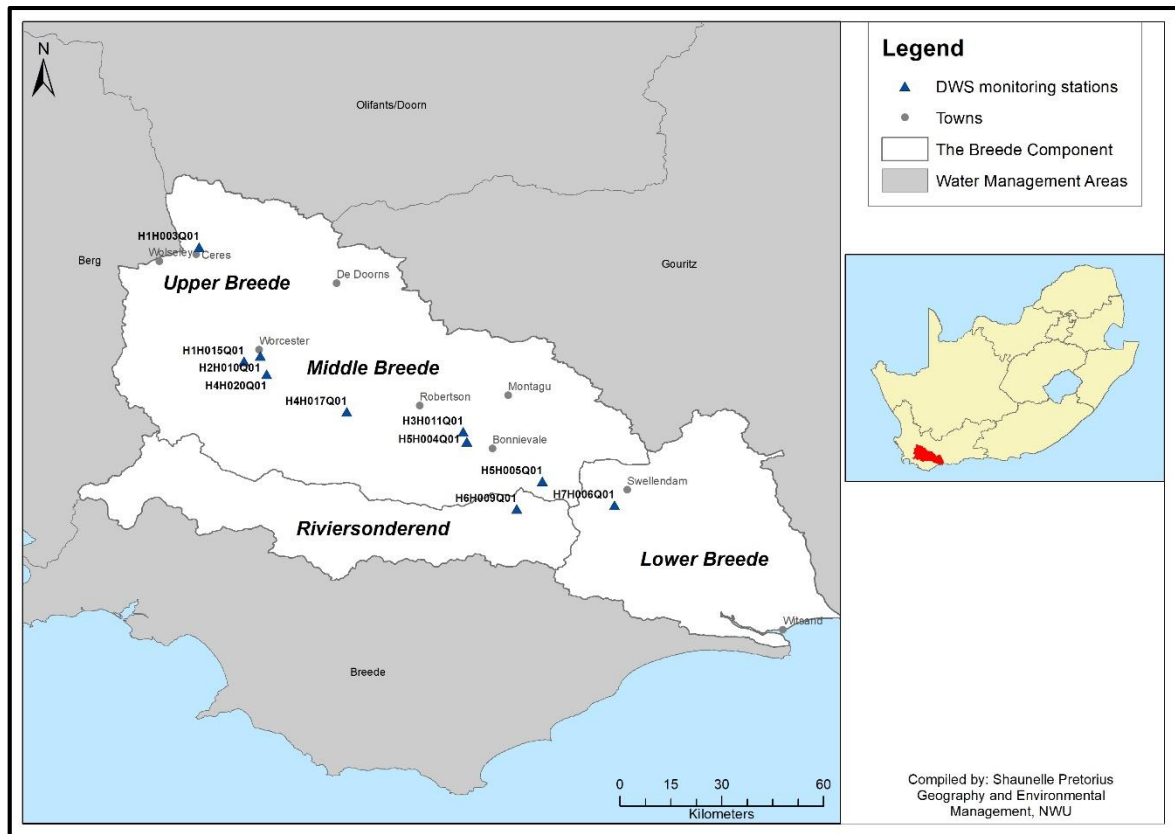


Figure 3-1: Location of DWS monitoring stations for chemical parameters (DWS, 2021).

A chemical analysis is considered to be incomplete (yet not necessarily incorrect) if one of the ions was not analysed. The data was first screened for data quality using the stoichiometric charge balance (SCB) calculation. The SCB is widely used to determine whether a chemical analysis of a water sample is accurate. The SCB can be defined as follows (Huizenga *et al.*, 2013):

$$\text{SCB}(\%) = 100 \times (\sum[\text{cations}] - \sum[\text{anions}]) / (\sum[\text{cations}] + \sum[\text{anions}]) \quad \text{Equation 1}$$

Where $\sum[\text{cations}]$ and $\sum[\text{anions}]$ represent the sum of the charge-corrected cations and anions (meq/l), the chemical analysis is considered accurate when $-5\% < \text{SCB} < +5\%$ (Huizenga *et al.*, 2013). The inaccuracy of analyses are linked to analytical error or due to some ions that were not included in the chemical analysis or presumed to be minor constituents (Huizenga *et al.*, 2013). Data with a SCB which did not fall within the $\pm 5\%$ were discarded.

Both DWAF and BGCMA monitored the microbiological water quality in the BGWMA; however, the DWAF monitoring dataset was particularly incomplete and could therefore not be used. Data from the BGCMA monitoring stations for the Upper and Middle Breede River sections are more

complete for the period 2008 to 2020 and were therefore utilised in the evaluation of the microbiological water quality in the study area.

3.4.2 Qualitative: Interviews

Qualitative data was gathered through semi-structured interviews subsequent to the re-evaluation of water quality data. Interviews are methods used to collect information through oral questionnaires posing a list of pre-planned core questions to selected individuals for guidance to ensure that the same areas are covered with each interviewee (Sandelowski, 2000). An interview is a productive method for data gathering since the interviewer can pursue specific issues of concern that may lead to focused and constructive suggestions and allowing the interviewee the opportunity to elaborate or provide more relevant information if he/she opts to do so (Sandelowski, 2000). All interviews were recorded and transcribed.

The interviews were performed to:

- Identify the key drivers of the decline in water quality of the agricultural sector in the Breede River catchment and was related to Research Objective 2; and
- Identify and evaluate the risks posed by the declining water quality in the Breede River catchment to agricultural activities and was related to Research Objective 3.

The interviews used structured questionnaires consisting of closed- and open-ended questions and followed purposive and snowball sampling techniques (Naderifar *et al.*, 2017). The majority of the interviews were done face to face with all national COVID-19 protocols adhered to. Only three interviews were conducted online (telephone and Zoom), whereas only one participant opted for the completion of the questionnaire online through Google Forms. Data collection took place during June–July 2021 during which a total of 28 interviews were conducted in two groups: Farmers (including farm managers) (15) and Experts (13), making this the final sample size (n=28). The focus was on potentially affected irrigation farmers and farm managers throughout the Upper, Middle and Lower Breede River sections of the BGWMA. A non-irrigation farmer was included to provide a background sample for comparison. The Expert group included individuals who worked in the study area and have intimate knowledge of the water quality aspects of the study area. This group included individuals employed at various provincial, district and local municipal levels, BGCMA, WUAs and environmental consultants.

Two separate questionnaires were used for the Farmers (F) and Experts (E) groups. This was done in order to include relevant information on the local farm conditions which were not relevant to the Experts group. The questions used for the survey data collection for both groups are

included in Annexure A (Annexure A1 for Farmers and Annexure A2 for Experts). The questions were formulated with guidance from literature reviews and the results from the re-evaluation of water quality data (Research Objective 1).

The development of the questions were an important part of the design of the questionnaire and interview process. The questions were developed to accurately measure the opinions and experiences of the average farmer and individuals considered to be experts in water and environmental management in the study area. The questions were pilot tested in order to better understand how participants would comprehend a question and how participants would respond to the overall questionnaire. Where necessary adjustments to the questionnaires were applied before the interview phase were initiated.

Each topic-specific set of structured close-ended questions was followed by at least one open-ended question with an unlimited comment field, which was explicitly linked to the question set immediately preceding it. In most instances, the open-ended question asked the participant to provide additional information to explain their responses or to provide more details on the topic. The questionnaire for the F and E groups followed a similar structure of five sections with only slight differences in the number of questions between the two groups. Questions for the two groups were coded with F (Farmers) and E (Expert) as a prefix for example Question A1 for the Farmers group becomes QA1F. The summarised questions used for the purpose of the survey for both groups are included in Annexure A. The five sections that the questionnaire comprised of and the purpose thereof included:

- *Section A–Participant organisation:* In this section general background questions were asked to enable the researcher to group responses according to focus groups;
- *Section B–Background on irrigation practices:* In this section background information was gathered to assist the researcher in grouping the responses according to specific sections of the catchment, crop segments, irrigation type etc.;
- *Section C–Water quality:* This section focused on the understanding of the water quality in the Breede River catchment. The perception that the water quality has been declining in some sections of the catchment was tested in this section based on evidence of impacts experienced by the agricultural sector. Linked to Research Objective 1;
- *Section D–Key drivers of water quality decline in the Breede River:* In this section the main drivers/ stressors with the most substantial effect on the water quality and quantity in the Breede River catchment were unpacked. Linked to Research Objective 2; and
- *Section E–Key risks posed by the water quality of the Breede River catchment:* In this section the key risks of the perceived decline in water quality in the Breede River catchment, over the past 20 years, were unpacked. Linked to Research Objective 3.

3.5 Data analysis

As discussed previously, this research study employed a mixed methods research approach comprising the combination of quantitative and qualitative research methods. The quantitative and qualitative data generated both required analysis.

3.5.1 Description of water quality data

Trends observed in the data over the period since data was captured and specifically the past 20 years were discussed for the Upper, Middle and Lower Breede River sections of the BGWMA. These findings were compared with findings from previous studies to evaluate the trends observed. A risk assessment for the Upper, Middle and Lower Breede River sections for important parameters were performed linked with potential sources to accomplish the re-evaluation of the water quality in the Breede River catchment intended in Research Objective 1.

The aim of the analysis of the quantitative water quality data was to provide an overview of the current and historic state of the water quality in the Breede River catchment. Water quality evaluations could then provide input in the structuring of interview questions regarding specific water quality parameters and to identify participants for interviews. The descriptive statistical parameters including minimum, maximum and mean concentration of and inferential statistics (correlation matrix, etc.) for physico-chemical parameters and major ion concentrations were determined and tabulated. The water quality data were evaluated against various guidelines (drinking, domestic, irrigation) such as the DWS (DWAf, 1996; Van Schoor, 2005, Van Rensburg *et al.*, 2011) and the World Health Organisation (WHO) (WHO, 2011). Data was presented as tables and graphs including Piper diagrams (Russoniello & Lautz, 2020), Gibbs diagrams (Gibbs, 1970; Day & King, 1995) as well as other relevant diagrams including time series graphs for selected parameters.

Water chemistry is largely controlled and modified by the medium (rock) it is in contact with. Evaluation of water type/ hydrochemical facies are therefore useful in determining water quality and origin. A Piper plot is a way of visualizing the chemistry of water. It is comprised of three sections: (1) a ternary diagram in the lower left representing the cations, (2) a ternary diagram in the lower right representing the anions, and (3) a diamond plot in the centre representing a combination of the two. Water quality data was re-calculated milli-equivalents per litre (meq/l) and normalised for the major cations and anions components in each ternary diagram before it was plotted on the relevant triangle of the Piper diagram. The plotted points in the triangular fields were projected onto a central diamond field, which provided the overall character of the water.

The mechanism controlling water chemistry and the functional sources of dissolved ions can be assessed by plotting the ratio of $\text{Na}^+ / (\text{Na}^+ + \text{Ca}^{2+})$ and $\text{Cl}^- / (\text{Cl}^- + \text{HCO}_3^-)$ as functions of TDS (Gibbs, 1970; Day & King, 1995). The diagram is divided into three different regions, which are the precipitation dominant, the evaporation dominant and the water-rock interaction dominant regions.

The water quality index (WQI) was calculated to measure the degree of contamination from natural and anthropogenic activities based on several key water chemistry parameters. The WQI is used to communicate water quality data to non-technical individuals as it is a systematically structured, summative index which allows for the presentation of water quality data in an easily expressible and understandable format (Brown *et al.*, 1970; Wanda *et al.*, 2016; Krishna-kumar *et al.*, 2015; Banda & Kumarasamy, 2020). The calculation of WQI was performed by following the 'weighted arithmetic index method' by Brown *et al.* (1972) using the following equations:

$$\text{WQI} = \sum Q_n W_n / \sum W_n \quad \text{Equation 2}$$

Where Q_n is the quality rating of n^{th} water quality parameter, W_n is the unit weight of n^{th} water quality parameter. The quality rating Q_n is calculated using the following equation:

$$Q_n = 100[(V_n - V_i)/(V_s - V_i)] \quad \text{Equation 3}$$

Where V_n is the actual value of the parameter observed, V_i represents the ideal value of each parameter. Where $V_i = 0$ except for pH when $V_i = 7$ and V_s is the standard permissible value for each water quality parameter (WHO standard values used) (Table 3-2).

Unit weight (W_n) is calculated using the formula:

$$W_n = K/V_s \quad \text{Equation 4}$$

Where K is the constant of proportionality and it is calculated using the following equation:

$$K = [1/\sum 1/V_s = 1, 2, \dots, n] \quad \text{Equation 5}$$

The WQI classes are shown in Table 3-3.

Table 3-2: WHO standard values used as standard permissible value for each water quality parameter (Vs) (Brown *et al.* 1970).

Parameter	Unit	WHO 2011
EC	mS/m	500
TDS	mg/l	500
pH		8,5
Na	mg/l	200
Mg	mg/l	50
Ca	mg/l	75
K	mg/l	200
Cl	mg/l	250
NO ₃ +NO ₂	mg/l	45
HCO ₃	mg/l	500

Table 3-3: WQI range and status of the water sample (Brown *et al.* 1970).

WQI	Water quality status
0-25	Excellent
26-50	Good
76-100	Very poor
Above 100	Unsuitable

The microbiological water quality was evaluated against the TWQR (Coliforms) and the BGWMA RQO (*E coli*) limits (DWAF, 1996a-f; SA, 2018). The BGWMA monitoring data was used in presenting data as time series plots for each monitoring station.

The incentive-based regulation Green Drop certification programme was developed in 2008 to highlight risks and priority areas. Compliance in terms of effluent quality discharged to the receiving water resource as well as plant design capacity and technical skills were used to identify risks. The compliance are reported as Cumulative Risk Rating (CRR), which is a risk calculated against the Design Capacity of a plant where WWTW with a high CRR value indicating that the plant has reached or is approaching its critical state of operation and therefore requires intervention such as upgrading/ capacity expansion (DWS, 2014). The level of compliance of the municipal WWTW evaluated by previous studies were used to compare with the findings from monitoring data in the Breede River catchment and to evaluate any improvements in compliance of the WWTW since 2010 (CWDM, 2010; WCG, 2017; Cullis *et al.*, 2018).

The suitability of the water in the Breede River catchment for various uses were evaluated based on the compliance of the water quality with guideline limits for these uses. The 10 year averages

for the 1970 to 2018 DWS dataset were used for selected water quality parameters (pH, EC, NO₃+NO₂, PO₄). The robot type coding was used to indicate ideal (blue), acceptable (green), tolerable (yellow) or unacceptable (red) classes for water for irrigation purposes and the aquatic environment (Table 3-4).

Table 3-4: Threshold guideline values for irrigation.

Variable	Ideal	Acceptable	Tolerable	Unacceptable	Guideline used
pH	8	8.4	9	> 9	Irrigation (DWAF, 1996a)
Conductivity (mS/m)	40	90	270	> 270	Irrigation (DWAF, 1996a)
Nitrate & nitrite (mg/L as N)	0.5	1.5	2.5	> 2.5	Aquatic ecosystem (DWAF, 1996f)
Ortho-phosphate (mg/L as P)	0.025	0.075	0.125	> 0.125	Aquatic ecosystem (DWAF, 1996f)
<i>E. coli</i>	1*	500	1000	> 1 000	Irrigation (DWAF, 1996a)

* Threshold value should ideally be 0

3.5.2 Description of interview data

The aim of qualitative data analysis was to discover patterns, concepts, and themes which would assist in identifying the key drivers to the decline of water quality in the agricultural sector in the Breede River catchment and to identify and evaluate the risks posed by the declining water quality to agricultural activities.

The quantitative data from closed-ended questions was analysed using Microsoft Excel which also allowed for the generation of graphs as shown in Chapter 4. In undertaking the qualitative data analysis the responses to the open-ended questions were compiled into tables in which keywords and phrases from responses were grouped into themes highlighting the (a) key drivers of water quality decline in the Breede River (Section D) in order to achieve the intention of Research Objective 2 and (b) key risks posed by the water quality of the Breede River catchment (Section E) in order to achieve the intention of Research Objective 3.

A risk matrix in which the probability or likelihood of the identified impacts of the decline in water quality in the Breede River catchment on agricultural activities and the consequential severity posed by these impacts were captured to define the level of risk posed by each (Table 3-5). Results were presented according to the questionnaire sections (A–Participant organisation, B–Background on irrigation practices, C–Water quality, D–Key drivers of water quality decline in the Breede River, and E–Key risks posed by the water quality of the Breede River catchment, unless

stated otherwise. In this section the linkage of the results from the different sections of the questionnaire were highlighted in order of achieving Research Objective 2 and 3.

Table 3-5: Risk matrix of the risks posed by the decline in water quality in the Breede River catchment.

Likelihood		Highly unlikely to occur or never occur	Unlikely to occur or will occur rarely/ occasionally	Likely to occur or occur often
Consequences	Low Minor adverse impacts	Very low risk 1	Low risk 2	Medium risk 3
	Medium Measurable adverse impacts	Low risk 2	Medium risk 4	High risk 6
	High Significant damage or impact	Medium risk 3	High risk 6	Extremely high risk 9

3.6 Ethical considerations

This research held negligible risk to human participants and generated information through semi-structured interviews, gathering information that was not regarded as sensitive. No children or incapacitated adults were involved in the study.

The NWU Faculty of Natural and Agricultural Sciences Research Ethics Committee (FNAS-REC) accepted and approved the study and provided the study with an ethics clearance number NWU-00451-21-A9. The questionnaires were developed with the ethics considerations in mind (Annexure A). The North-West University (NWU) requirements were adhered to during the study including the identification of potential research study participants.

Participants were encouraged, but not pressured, to take part in the study as a means of contributing to the body of knowledge in the environmental management in the BGWMA. This was communicated prior to the interview as well as included in the cover letters which accompanied the questionnaires. Participants were given the option to consent or withdraw from the interview at any time as well as having the interview recorded in the introductory section of the questionnaires (Annexure A1 and 2).

The ethical considerations during the data analysis stage required anonymity of participants with any reference to responses by a specific participant referred to by a number from 1 to 15 for Farmers (F1-F15) and 1 to 13 for Experts (E1-E13). Participants were also assured that the data obtained from participants would only be used in reaching the objectives of the study and not

divulged to any third-party. All data will be kept in a confidential and secure location by the researcher.

Ethics applied during the reporting of the data included the honest reporting of findings covering both positive and negative findings. Further to the above, the researcher remained objective, not leading the participants in the interview questions and avoided taking the side of Farmers or Experts where negative comments were made by participants.

3.7 Methodological assumptions and limitations

Minor methodological limitations were encountered in undertaking the research. These included:

- (1) The clarity of some interview questions hampered the flow of the interview and required further refinement; and
- (2) The Farmers group were mainly Afrikaans speaking which required the questionnaires for this group to be translated prior to commencement of the interviews. During the interview this was not a problem as the questionnaires were completed (either paper based, directly on Google Forms or filled in digitally), in English.

3.8 Chapter summary

Chapter 3 presented the research methodology followed for this research in which qualitative and quantitative data were collected in a mixed method approach. Water quality was evaluated through Piper, Gibbs and time series plots as well as evaluation of the WQI.

Purposive, random and snowball sampling techniques were used to identify 28 individuals (15 Farmers and 13 Experts) which participated in face to face and online interviews based on structured questionnaires, consisting of closed- and open-ended questions. The questionnaires developed for the Farmers and Experts groups were structured according to 5 sections, based on the background of the participant, background on irrigation practices, water quality, drivers of water quality decline in the Breede River and risks posed by the water quality on agricultural activities. Microsoft Excel was used for the analysis of both quantitative and qualitative data. Key phrases were used in thematic analysis.

Important ethical considerations including the anonymity of participants have been discussed where applicable throughout the research process. Two methodological limitations encountered in the study were also discussed. These were the clarity of some interview questions and

language barriers which were overcome during the interview process and did not hamper the study.

Chapter 4 will present the data analysis and a discussion of the research findings.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Introduction

The previous chapter provided a detailed discussion of the methodology that was followed for this study. The aim of Chapter 4 is to reach Research Objective 1 by re-evaluating the water quality data from the study area (Upper, Middle and Lower Breede River section of BGWMA) through the interpretation of water quality data extracted from existing chemical and microbiological water quality databases, identification of potential contamination source of and evaluation of the suitability of the water for relevant water uses such as irrigation, livestock watering and domestic use on farms. The qualitative and quantitative data collected during the interviews were used to identify and interpret the key drivers of the decline in water quality (Research Objective 2) and the risks posed by the declining water quality (Research Objective 3) to agricultural activities in the study area.

The data presentation and discussion is therefore linked to the research objectives and presented in three main sections: (a) water quality re-evaluation; (b) interview data interpretation; and (c) integration of results in order to link qualitative and quantitative results. The interpretation of the interview data was discussed under the five main sections of the questionnaires: participant organisation (Section A), background on irrigation practices (Section B), water quality (Section C), key drivers (Section D), and risks posed by declining water quality to agricultural activities in the study area (Section E).

4.2 Water quality re-evaluation (Research Objective 1)

Water quality and agricultural soil salinity in the Breede River catchment have been under investigation since the 1980s (Murray, Biesenbach and Badenhorst Inc. 1989; Moolman & De Clercq, 1993; Kirchner *et al.*, 1997; Howell, 2016; Cullis *et al.*, 2018). The DWS (previously Department of Water Affairs and Forestry (DWAF)) had 104 monitoring stations where water samples were collected to characterise the water quality of the Breede River catchment (DWAF, 2003). The data recorded for these stations differed in sampling frequency (weekly to monthly) and continuous length of sampling. The DWS water quality database contains water quality data for nine (9) sub-catchments within the Breede River catchment including data for dams, wetlands, WWTWs and rivers (DWS, 2021) The DWS water quality monitoring data used in this study were limited to the Breede River and larger tributaries (DWS, 2021). The archival DWS data covers a period from 1970's to 2018, when the DWS monitoring in the Breede River catchment ceased. The BGCMA took over water quality monitoring, albeit at a limited number of sites which they

have been monitoring since 2008 (E Rossouw personal communication, 12 June 2021). To be able to draw conclusions about changes in the water quality over time, it was necessary to interrogate long-term datasets for the Breede River catchment. For this reason the DWS dataset was selected for the chemical water quality and the BGCMA dataset for the biological water quality evaluations.

To obtain a representative overview of the catchment-wide water quality trends it was necessary to select a smaller number of stations. To obtain a meaningful overview and trends, it was essential to filter the dataset for the following:

- Length of data record to assess the historical to present water quality status;
- Sampling frequency (weekly or monthly preferred above ad hoc sampling); and
- Distribution of monitoring stations to include the main sub-catchments.

In order to adhere to the above criteria it was necessary to eliminate monitoring stations with short and incomplete data entries. It was therefore necessary to select stations with continuous long term data as far back as possible (in this case 45 years) for the Upper-, Middle- and Lower Breede River sections as well as the Riviersonderend River section of the BGWMA. This was important in that it enabled participants in the research to comment on trends as land use changed over time in the study area as agricultural activities expanded. Not all monitoring stations had complete datasets spanning the 45 years, which required filtering of the available data in order to select the DWS monitoring stations with the longest continuous data record in the relevant sub-catchments. Those stations with the most complete data record were used in the evaluation of the water quality (Figure 3-1).

The re-evaluation of the water quality of the Breede River catchment was mainly based on the physio-chemical parameters included in the DWS database. However, algae and aquatic weeds are also of concern due to their impact on irrigation infrastructure and to the aquatic ecosystem as it reduces habitat diversity and thereby affect biodiversity (DWAF, 2003). In addition the use of pesticides would also have a significant impact on the aquatic ecosystem. However, very limited data were available for these parameters and was therefore not included in detailed discussions. It was therefore only possible to include parameters monitored by DWS on a regular basis.

The long term chemical water quality dataset was used in the evaluation of the water quality in the Upper-, Middle- and Lower Breede River sections as well as the Riviersonderend River section of the BGWMA. Variations between the stations as well as over time were evaluated and where possible correlations between parameters were identified. The long term dataset was also

used to characterise the water in the different parts of the catchment in terms of the hydrogeochemical character, but also the sources for the constituents in the water.

However, before the water quality can be discussed it was necessary to implement quality control of the large dataset. For this reason data entries where discrepancies and blank values were recorded were filtered out and removed from the data sheets before further analysis was done. As an example a total of 1 175 analyses readings between the years 1973 and 2018 were recorded for sample point H1H003Q1 of which 3% (36) were not usable (Table 4-1).

Table 4-1: Remaining critical data set collected for selected sample stations along the Breede River and Riviersonderend sections.

Sample station ID	Period recorded	Samples per station	Un-usable samples per station	Acceptable stations based on charge balance $\pm$ 5%	% Usable
UPPER BREEDE SECTION					
H1H003Q01	1973-2018	1 175	36	1 021	87
H1H015Q01	1972-2017	886	40	632	71
MIDDLE BREEDE SECTION					
H2H010Q01	1981-2018	1 024	18	993	97
H3H011Q01	1973-2018	1 129	19	1 092	98
H4H017Q01	1980-2018	1 140	12	1 028	90
H4H020Q01	1981-2017	953	17	916	96
H5H004Q01	1972-2011	1 215	59	1 109	91
H5H005Q01	1973-2018	1 230	43	1 133	92
LOWER BREEDE SECTION					
H7H006Q01	1973-2011	430	23	391	91
RIVIERSONDEREND SECTION					
H6H009Q01	1973-2018	472	26	399	86

Further evaluation of the quality of the data was based on the charge balance (Equation 1) with an acceptable charge balance in the range of $\pm$ 5%. Histograms showing the frequency of the charge balance results were used to assist in visualising the spread in the charge balance and are presented in Annexure D. For most monitoring stations the histogram showed a normal distribution. Data entries where the charge balance exceeded the $\pm$ 5% were removed from the dataset filtering the data further. Possible causes for errors in the charge balance may include: significant component not measured, failure to measure rapidly changing parameters in the field (pH, alkalinity, etc), improper sample storage, analytical error and/or contamination during sample preparation. As an example: of the original data entries for monitoring station H1H003Q1 (1973 and 2018) only 1021 (87%) had acceptable charge balances (i.e. combining all data points which

fall within the $\pm 5\%$ acceptable range) and a normal distribution on the histogram for filtered data (Figure 4-1). A summary for the number of usable data entries over the 45 year period for the 10 selected monitoring stations are provided in Table 4-1.

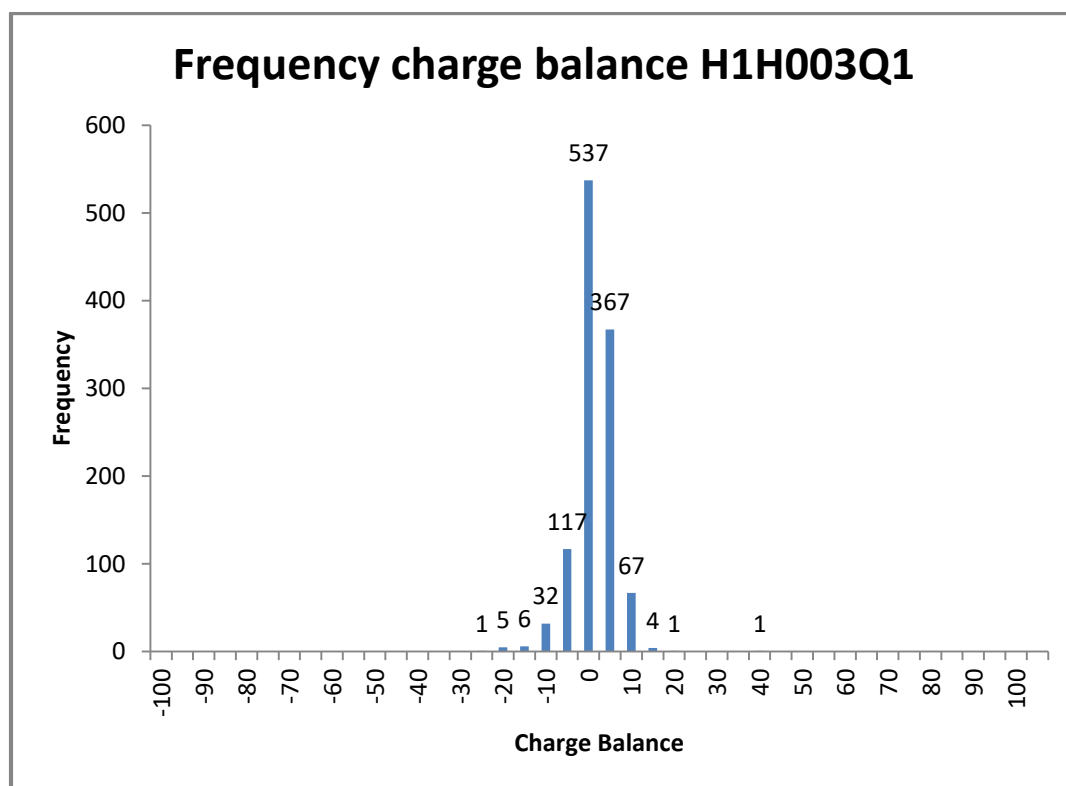


Figure 4-1: Example of a histogram indicating frequency distributions of the charge balance for filtered data for sample point H1H003Q1.

The filtered DWS dataset was used to evaluate the changes in water quality over time. Relevant trends and the possible causes for these are discussed next.

4.2.1 Changes in water quality over time

The DWS dataset (1970's to 2018) was used to provide a time series overview of changes in the water quality along the Breede River and selected main tributaries (DWS, 2021). Time series data for relevant water quality parameters such as the EC, total dissolved solids (TDS), pH, Na, K, Ca, Mg, Cl, NO₂, NO₃, HCO₃, PO₄, SO₄, and F were used.

Statistical analysis was performed on the long term data set for important physico-chemical parameters and major ion concentration to detect the relationships and differences between the water qualities at selected DWS monitoring stations. The Pearsons correlation matrix for the

average values of the simplified dataset for important water quality parameters for the 10 selected sample stations along the Breede River and Riviersonderend sections of the BGWMA for the period 1970-2018 are presented in Table 4-2.

Table 4-2 demonstrates that there is a good correlation between most cations and between the cations and the TDS. Some of the anions, NO_3+NO_2 and PO_4 , did not show any correlations with other parameters, suggesting the sources of these ions differed from that of the other ions.

Due to the vast number of data entries at each DWS monitoring station, the dataset was simplified by using descriptive statistics in the evaluation of the water quality grouped into 10 year intervals: 1970-1979, 1980-1989, 1990-1999, 2000-2009, and 2010-2018. Descriptive statistics for the final filtered dataset used in this study are presented in Annexure E. The average values for each parameter over the 10 year intervals were used to produce simplified time series plots for the period 1970 to 2018 which will be discussed here. However, where applicable, reference will be made to the detailed time series plots for each parameter which are included in Annexure F.

The median pH values for all stations varied between 6.7 and 8.2 (Annexure E). The pH of most raw waters lie within the 6.5 - 8.5 in the DWS TWQR (DWAF, 1996b). The surface waters in South Africa have pH values between 4 and 11 (DWAF, 2003d). Since the solubility and bio-availability of many plant nutrients and potentially toxic constituents are highly dependent on pH the ideal TWQR pH for crop yield and quality for irrigation purposes were set at $6.5 < \text{pH} < 8.4$ and for domestic purposes at $6 < \text{pH} < 9$ (DWAF, 1996a).

Table 4-2: Pearsons correlation matrix for average values for important water quality parameters for selected sample stations along the Breede River and Riviersonderend sections for the period 1970-2018.

	EC	TDS	pH	Na	Mg	Ca	K	NH ₄	F	Cl	NO ₃ +NO ₂	SO ₄	PO ₄	HCO ₃	SAR
EC	1														
TDS	0,998996	1													
pH	0,705999	0,707361	1												
Na	0,998851	0,997123	0,703544	1											
Mg	0,992695	0,995379	0,680226	0,98864	1										
Ca	0,981544	0,987415	0,689207	0,973303	0,99135	1									
K	0,931772	0,938239	0,714809	0,922746	0,939138	0,959838	1								
NH₄	0,087450	-0,08505	-0,20157	-0,09367	-0,07414	-0,05878	-0,07949	1							
F	0,937663	0,944878	0,760349	0,929825	0,938957	0,95224	0,902534	-0,10968	1						
Cl	0,992776	0,989059	0,678547	0,994564	0,98346	0,962534	0,919629	-0,08909	0,908004	1					
NO₃+NO₂	0,300286	0,317450	0,455899	0,2962	0,288462	0,347695	0,41327	-0,01515	0,331279	0,234567	1				
SO₄	0,925722	0,937278	0,646401	0,912512	0,950211	0,967189	0,90397	-0,05773	0,916442	0,8863	0,381418	1			
PO₄	0,267430	0,25720	0,340236	0,273533	0,211636	0,223872	0,322646	-0,00832	0,174334	0,258362	0,679258	0,142472	1		
HCO₃	0,921052	0,92398	0,741905	0,921374	0,895115	0,908788	0,85938	-0,08827	0,929991	0,888146	0,476114	0,851281	0,348705	1	
SAR	0,944940	0,937465	0,74677	0,951525	0,909706	0,885496	0,829669	-0,15198	0,886912	0,938298	0,238885	0,820603	0,27654	0,906026	1

These limits also safeguard the irrigation equipment as corrosion of irrigation equipment are expected at a pH below 6.5 and encrustation of irrigation pipes and clogging of micro-irrigation systems at pH values exceeding 8.4 (DWAF, 1996a). The BGWMA RQO limits were set at $6.5 < \text{pH} < 8$ (Annexure C) (SA, 2018). The majority of the monitoring stations showed pH values within the BGWMA RQO and the TWQR limits as observed on the simplified 10 year interval diagram (Figure 4-2).

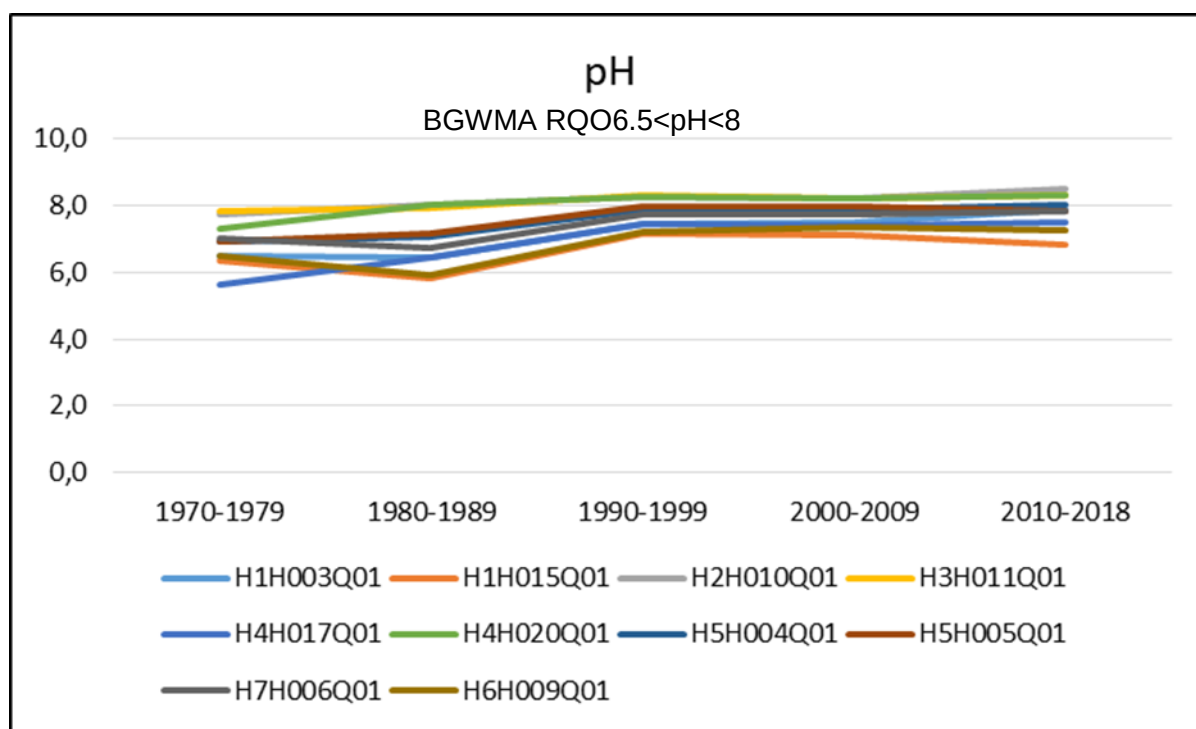


Figure 4-2: pH plot for selected sample stations from average values for the Breede River and Riviersonderend sections for the period 1970-2018.

The detailed time series plots show the particulars of the variations at each station over time (see graphs in Annexure F). The descriptive statistics of the long term dataset (in Annexure E) showed mean pH values for the Upper Breede River section ranging between 6.7 and 8.2 and that of the Middle and Lower Breede and Riviersonderend sections around seven (7). The pH in the Upper Breede River section show a slight increase from the 1970s to 1990, after which the pH remained around seven (7). The highest pH values occurred in the Upper Breede River section regularly exceeding nine (9) (Annexure F). The majority of the monitoring stations in the Middle Breede River section showed pH values closer to the upper guideline limit (8.4) with the H4H017Q01 station, upstream of Robertson, showing a noticeable increase from 1980 to 1990 after which it remained around seven (7). The minimum and maximum pH values observed in the different

sections of the Breede River catchment revealed that there were periods in the past when the TWQR and BGWMA RQO limits were exceeded. Monitoring stations in the Middle Breede River section showed pH values which more regularly exceeded the BGWMA RQO and the DWS TWQR limits compared to other sections (see graphs in Annexure F). At several monitoring stations the lower (acidic) pH limit for both TWQR and BGWMA RQO guideline values were exceeded prior to 1992 (Annexure E and graphs in Annexure F). This occurred mainly in the Upper and Lower Breede River and Riviersonderend sections where the minimum pH values regularly dropped to around four (4), whereas in the tributaries in the Middle Breede River section the minimum pH value rarely dropped below 6.5 prior to 1992 (Annexure E and graphs in Annexure F). The cyclic variation in pH values observed in the majority of the monitoring stations appear to be linked to seasonal changes (see graphs in Annexure F). Although not true in all instances, the general trend observed indicate that a decrease in pH is associated with winter months. Several studies have identified the potential origin of similar seasonal trends as atmospheric solutes, dust and organic materials, sea salt deposition, organic acids, weathering of bedrock and precipitation patterns or complex biogeochemical processes (Hornbeck *et al.* 1976; Chapman *et al.*, 2008; Deyton *et al.*, 2009). Chapman *et al.* (2008) showed that episodic acidification of surface streams occur in areas where the bedrock has limited buffering capacity, resulting in short-term reduction of pH. Deyton *et al.* (2009) argued that episodic acidification occur after long, dry periods and that high-elevation watersheds are particularly susceptible to episodic acidification, where deposition rates of acid anions tend to be higher. Hornbeck *et al.* (1976) also argued that the chemistry of precipitation changes with the seasons due to impacts from dusts and organic materials, which is due to seasonal activities such as farming and snow cover. Furthermore growth activities take place in spring and summer, which affects the organic acids in the soil and ultimately the surface water acidity.

The effect of pH on agriculture is linked to water for irrigation purposes and soil pH which in turn affects the ability to sustain long term cultivation and damage to irrigation equipment (DWAF, 2003a). Since the majority of the monitoring stations rarely showed pH values below 6.5 and above 8.4 since 1992 it is safe to assume that pH did not have a substantial corrosive impact on the irrigation equipment and also did not cause regular encrustation of irrigation pipes and clogging of micro-irrigation systems over the past 30 years. Damage to crops (fruit and other crops) and diminished yield and quality due to direct contact of crop foliage with water with either too high or too low pH is also not expected since the pH values remained relatively constant at $6.5 < \text{pH} < 8.4$. Soil pH is generally buffered, resulting in slow changes in the pH. However, Na and

Cl dominated water have diminished buffering capacity due to the low to absent carbonate or bicarbonate content (DWAF, 2003a).

Since surface water in the catchment is generally used for domestic purposes on farms the TWQR for drinking water purposes were also considered due to potential human health as well as aesthetic (taste) impacts. Water with a pH below six (6) is considered problematic due to its corrosiveness which results in the dissolution of metals (lead, copper and zinc) from the water supply system, leading to metal contamination in drinking water (DWAF, 1996b). Since the descriptive statistics of the long term dataset (Annexure E) showed mean pH values for the Upper Breede River section ranging between 6.7 and 8.2 and that of the Middle and Lower Breede River and Riviersonderend sections around seven (7), no human health impacts are expected.

Midgley and Schafer (1992) showed that acidic stained (tea colour) water in the Western Cape is linked to leaching of water through un-decomposed fynbos and forest plants and are usually an indication of the amount of dissolved organic material (like humic and fulvic acids) in the water. The pH variations seen in the study area, especially the low pH values observed in tributaries in higher mountainous areas in the Upper and Lower Breede as well as the Riviersonderend sections, are therefore generally associated with the naturally acidic nature of water in the Western Cape (DWAF, 2003d). There is no large industries in the study area which could account for changes in the pH since 1992.

The median EC values for all stations varied between 11 and 370 mS/m (Annexure E). The detailed time series plots showed more variations at some stations (see graphs in Annexure D). The BGWMA RQO for EC for the different Breede River sections varied with the limit for the lower Breede River section slightly higher at <270 mS/m (Annexure B). The EC criteria for irrigation water of grapevines in the Breede River were set at 50% of irrigation water volume to not exceed 70 mS/m with 30% of volume allowed to fluctuate between 70 and 120 mS/m and the remainder of the water not to exceed 120 mS/m (DWAF, 2003e).

The spatial variation of the EC along the Breede River is highlighted by the EC time series data which showed two distinct groups, namely those with an EC above 100 mS/m and those below (Figure 4-3). The low EC group (6) included the Lower Breede and Riviersonderend sections, as well as some of the Upper and Middle Breede River section stations. The high EC group is mainly from the Middle Breede River section (4). Figure 4-4 shows spatial variation in the EC between stations for the period 1970-2018, but also the variation in the temporal EC concentration at each station.

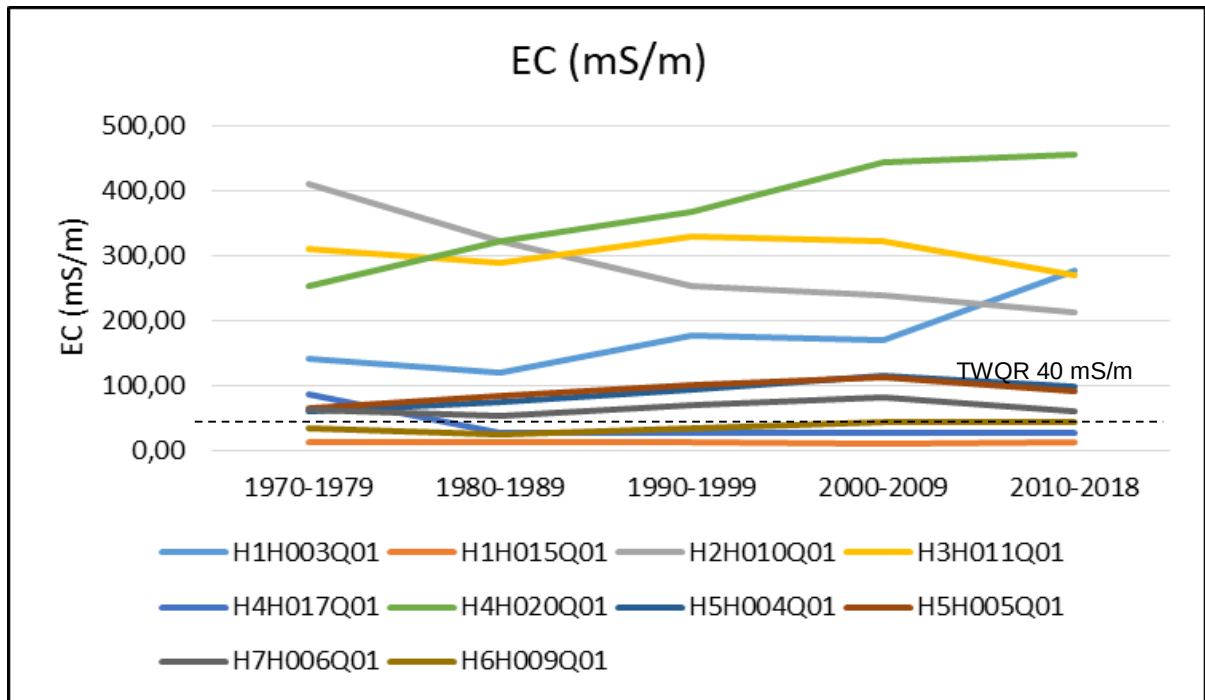


Figure 4-3: EC plot for selected sample stations from average values for the Breede River and Riviersonderend sections for the period 1970-2018.

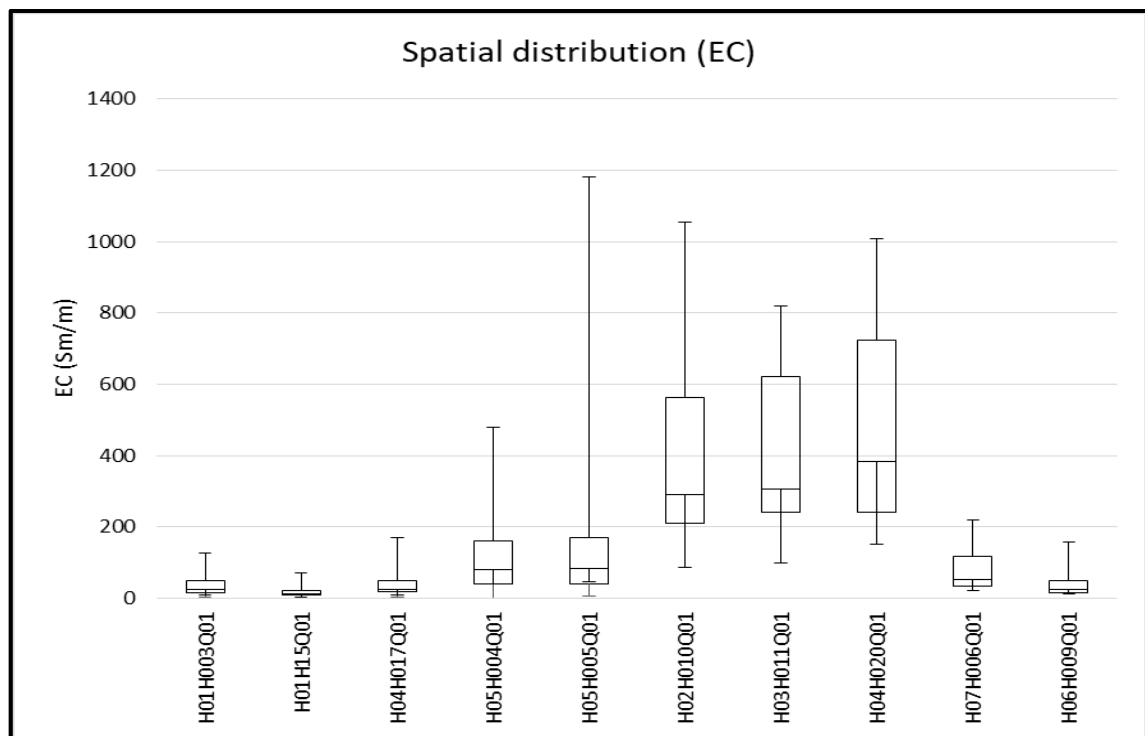


Figure 4-4: Spatial variation of the EC for selected monitoring stations for the Breede River and Riviersonderend sections for the period 1970-2018.

Some stations in tributaries in the Middle Breede River section, including H3H011Q1 (Kogmanskloof River) and H2H010Q1 (Hex River), showed a steady decrease in EC since the 1970s whereas station H4H020Q1 (Nuy River) showed a steady increase since the 1970s (~450 mS/m between 2010 and 2018). The median EC values increase in a downstream direction observed in the main Breede River as well as tributaries (Annexure E and graphs in Annexure F). The EC increase downstream up to the confluence with the Riviersonderend River in the vicinity of Swellendam. The increase at the monitoring station H5H005Q01 between Drew and Swellendam is related to the inflow of the Kogmanskloof River as well as contribution from agricultural return flow. This was also highlighted in previous studies which showed the headwaters of the Breede River and foothill mountain stream areas generally showed lower EC values compared to valley areas (DWAF, 2003d, e). The detailed time series plots showed more variations which generally reflect the poorer water quality during the dry season (October to April) (graphs in Annexure F).

The increased salinity in the Breede River mainstream is closely associated with the inflow of tributaries with higher EC concentrations. This was also highlighted by previous studies which concluded that the tributary inflow was an important factor in the observed salinisation of the Breede River, but the potential of ground water contributing to the lower water quality could not be excluded (Flugel & Howard, 1987; Howard, 1987; DWAF, 2003f). Jolly (1990) and Kirchner (1994) showed that the influence of seepage from ground water was not a major contributor to the salinity in the Breede River with only around 8% originating from aquifers. Greeff (1990) showed that the weathered zone above the Bokkeveld Group sediments contained considerable amounts of salt which may be leached from the soil and end up in agricultural return flow.

Moolman (1999) showed that the yield from grapevines decrease where soil EC was >75 mS/m. This study showed that the cumulative effect of salinity and increased salinity in the soil in one season had a substantial impact on the growth in the following season. Moolman (1999) showed that irrigation with saline water leads to significant accumulation of salts in the root zone during the summer irrigation period and proposed the leaching of saline soils in winter periods to maintain soil salinity levels at 100 mS/m.

Approximately 300 mm of low salinity water for irrigation purposes is required to reduce salinity of topsoil from 300 mS/m to the acceptable limit of 100 mS/m. Based on the limits proposed by Moolman (1999) the water in the lower part of the Middle Breede River, at monitoring stations H5H004Q01 and H5H005Q01, are not acceptable for irrigation purposes based on the EC values and that it would lead to yield loss. The EC of grapevines in the Breede River were set at 50% of

water for irrigation purposes volume to not exceed 70 mS/m with 30% of volume allowed to fluctuate between 70 and 120 mS/m and the remainder of the water not to exceed 120 mS/m (DWAF, 2003a).

The salinity level in the Breede River at the Zanddrift weir near Robertson has been the determining factor in the Breede River since 1977 when the practice of releasing fresh water from the Greater Brandvlei Dam into the Breede River as well as the irrigation canal (Le Chasseur) was initiated to flush out saline water once the EC at the weir approached 70 mS/m, essentially diluting the river water (DWAF, 2003). This dilution practice is reflected in the difference in EC between station H1H003Q1 (average EC ~270 mS/m between 2010 and 2018) located in the Upper Breede River section closer to the town of Ceres and station H1H015Q01 located at Brandvlei Dam (average EC 12 mS/m between 2010 and 2018) (Annexure E).

The median of the total dissolved solids (TDS) values for all stations varied between 62 and 2 337 mg/l (Annexure E). The detailed time series plots showed more variations at some stations (see graphs in Annexure F). The majority of the monitoring stations that had TDS values which exceeded that of water for domestic purposes are 0-450 mg/l and irrigation purposes (< 40 mg/l) required by the DWS TWQR (DWAF, 1996b). Water with a high salinity has an impact on the domestic use of the water seeing that highly saline water may have health impacts such as kidney problems (DWAF, 199b). However, corrosion and scaling of pipes may also occur. Irrigation with high TDS water result in the accumulation of salts in soil which is linked to reduced crop yield (DWAF, 2003c-e).

The spatial variation of the TDS along the Breede River is highlighted by the TDS time series data which again showed two distinct groups similar to the pattern shown by the EC time series, i.e. a high TDS (3) group which showed values exceeding 1 500 mg/l and a low TDS group (7) which falls below this value (Figure 4-5). The lower TDS group included the Lower Breede and Rivieronderend sections, as well as some of the Upper and Middle Breede River section stations. Stations in the Middle Breede tributaries, H3H011Q1 (Kogmanskloof River), H4H020Q1 (Nuy River) and H2H010Q1 (Hex River), showed the highest TDS. However, a steady decrease in TDS since the 1970s were observed in the Kogmanskloof River and Hex River, whereas TDS in the Nuy River continues to increase. It is clear that the TDS concentration in the Middle Breede River section increased severalfold above that of unimpacted streams (Annexure E).

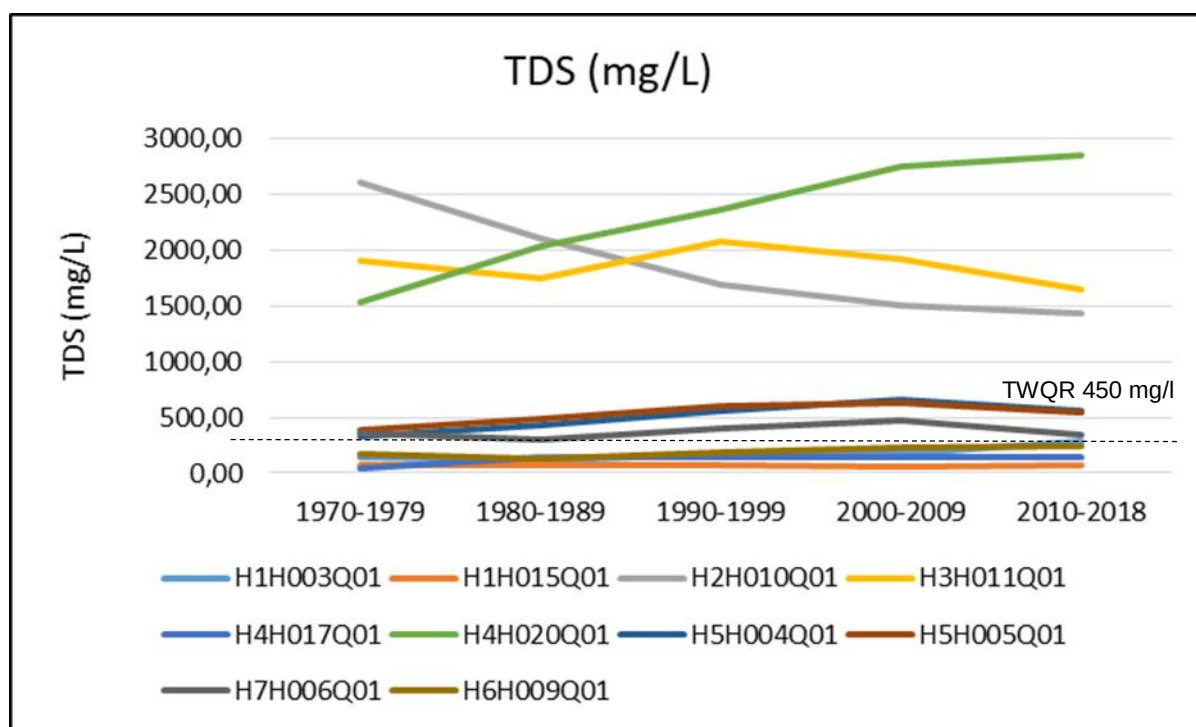


Figure 4-5: TDS plot for selected sample stations from average values for the Breede River and Riviersonderend sections for the period 1970-2018.

The median TDS values in the main Breede River increase in a downstream direction (Annexure E and graphs in Annexure F). This mirrors the findings highlighted for the EC which showed the headwaters of the Breede River and foothill mountain stream areas generally have lower concentrations compared to valley areas (DWAF, 2003e). Kirchner (1994) stated that contribution of ground water seepage to the salinity along the length of the Breede River would be expected to be evenly spread where similar geological structures occur. However, the salinity in the Breede River is not following this pattern; it was therefore concluded that the contribution from aquifers were not the main source of saline water but rather irrigation return flow. Moolman *et al.* (1983) highlighted the fact that the water quality in the Breede River reflected the influences mineral content in irrigation return flow has on the receiving river. Kirchner (1994) proposed that the salinity in the surface water in the Breede River is closely related to the extension of irrigated areas, especially in the tributaries. Greeff (1990) showed that the leaching of salts are especially high in newly developed agricultural areas and that the leached salts are transported to the rivers as irrigation return flow.

Jolly (1990) showed that water in contact with the Table Mountain Sandstone (TMS) which forms the mountain ranges surrounding the Breede River catchment had the lowest contribution to

salinity, with water in contact with the Bokkeveld Group shale as well as the Enon Formation in the valley bottom containing considerable amounts of salt. The shallow ground water, especially in the alluvium, is often influenced by irrigation return flow from nearby irrigated land and/or by evaporation from the near surface-water table (Kirchner, 1994). This was also highlighted by Greeff (1990) which showed that water which leached from the soil associated with the Bokkeveld Group sediments, as agricultural return flow, had an average TDS of 2 966 mg/l. Murray, Biesenbach and Badenhorst Inc (1988) reported that the irrigation return flow may be as much as 11.3%.

Additional water quality parameters of importance in the salinity of water include the Na, sodium adsorption ratio (SAR) and Cl. No BGWMA RQO was set for Na, Cl and SAR. The Na and SAR DWS TWRQ for irrigation are set at 70 mg/l and 0 to 1.5 respectively (Annexure C). The median Na values for all stations varied between 10 and 520 mg/l with monitoring stations in the Upper Breede, upper part of the Middle Breede and Riviersonderend sections not exceeding the TWQR for Na (Annexure E). The main tributaries in the Middle Breede exceeded the TWQR for Na with the stations in the Breede River main stream below the confluence with these tributaries, although still exceeding the DWS TWQR, reflecting the dilution of the high salinity levels once the tributary enters the larger Breede River (Figure 4-6). The median Na concentration increases in a downstream direction. This trend was also reported by previous studies (DWAF, 2003d, e).

The spatial variation of Na along the Breede River is similar to that of EC and Cl showing two distinct groups, those with Na above 300 mg/l and those below (Figure 4-6 and graphs in Annexure F). The tributaries (Hex, Nuy and Kogmanskloof rivers) in the Middle Breede River section fall within the high Na group. Jolly (1990), Greeff (1990) and Kirchner (1994) all showed that water in contact with the Bokkeveld Group shale as well as the Enon Formation in the valley bottom contain elevated concentrations of salts (Na) and that leaching of salts from soils contribute to elevated concentrations in irrigation return flow leading to the cumulative concentration in surface water.

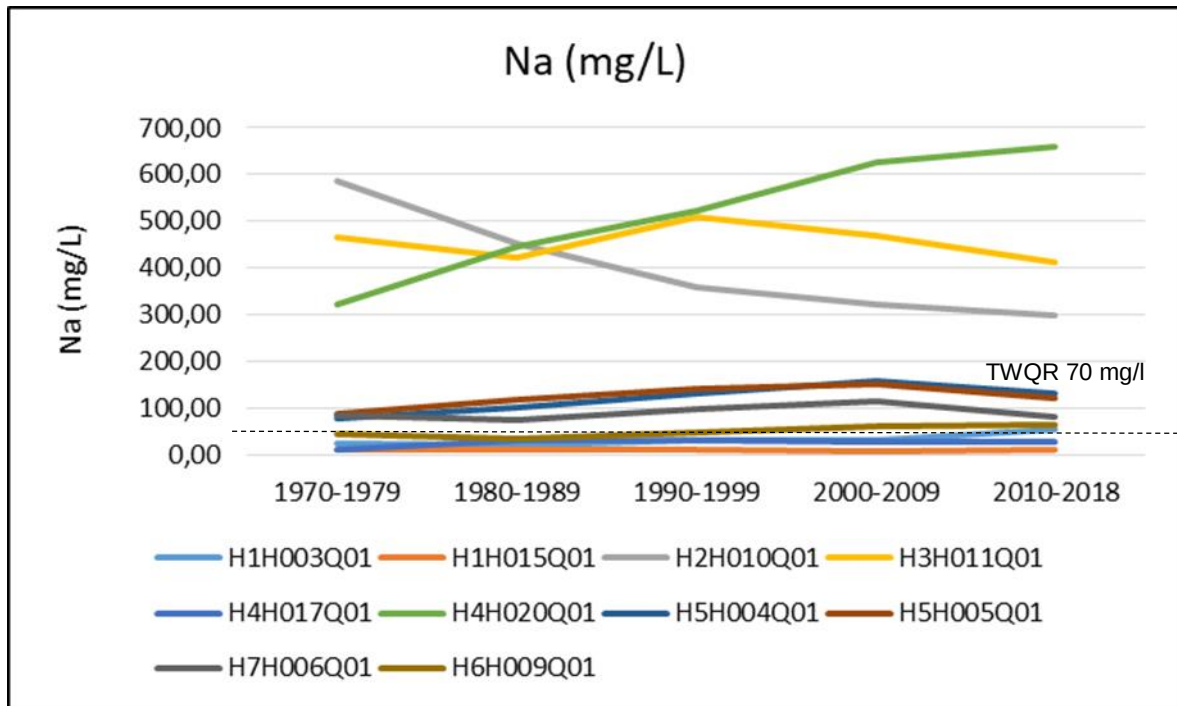


Figure 4-6: Na plot for selected sample stations from average values for the Breede River and Riviersonderend sections for the period 1970-2018.

These tributaries also showed the highest Cl levels and it is therefore safe to assume that Na and Cl originate from the same source. This is supported by the strong correlation between Na and Cl in the Pearsons correlation matrix (Table 4-2). The water in these tributaries is considered to be unsuitable for irrigation purposes. The Na TWRQ concentrations for irrigation purposes are exceeded 50% of the time in the lower part of the Middle Breede River section (Figure 4-6 and graphs in Annexure F). The detailed time series plots show a cyclical pattern highlighting the fact that the water quality is generally poorer during the dry season (October to April) (graphs in Annexure F). This was also shown by previous studies, which suggested that crop yield in the affected sections are compromised (DWAF, 2003). The Na concentrations in the lower part of the Middle Breede River section has deteriorated over time. This is particularly evident in stations H4H020Q1 which showed a steady increase since the 1970s (Figure 4-6 and graphs in Annexure F). The detailed time series plots showed more variations at some stations (see graphs in Annexure F).

Since Na is absorbed by leaves, the quality of crops where the leaves are the marketed product would be compromised at Na levels above 70 mg/l (DWAF, 2003 d, e). The palatability of water where Na concentrations exceed 2 000 mg/l is the main concern in livestock watering. Elevated

Na concentrations affect the physical conditions of soil (reduced permeability and increased hardsetting) and result in reduced yield (DWAF, 2003 d, e). The TWRQ for domestic use are set at 100 mg/l whereas for livestock watering the limit is 2 000 mg/l. The water in the entire Breede River are therefore suitable for livestock watering, but water in the tributaries is not suitable for domestic purposes.

The median SAR values for all stations varied between 0.9 and 6.9 (Figure 4-7) (Annexure E and graphs in Annexure F). The majority of stations therefore exceed the TWQR for irrigation purposes. The spatial variation of SAR along the Breede River is highlighted by the time series data which showed two distinct groups, those with SAR above and those below (Figure 4-7 and graphs in Annexure F).

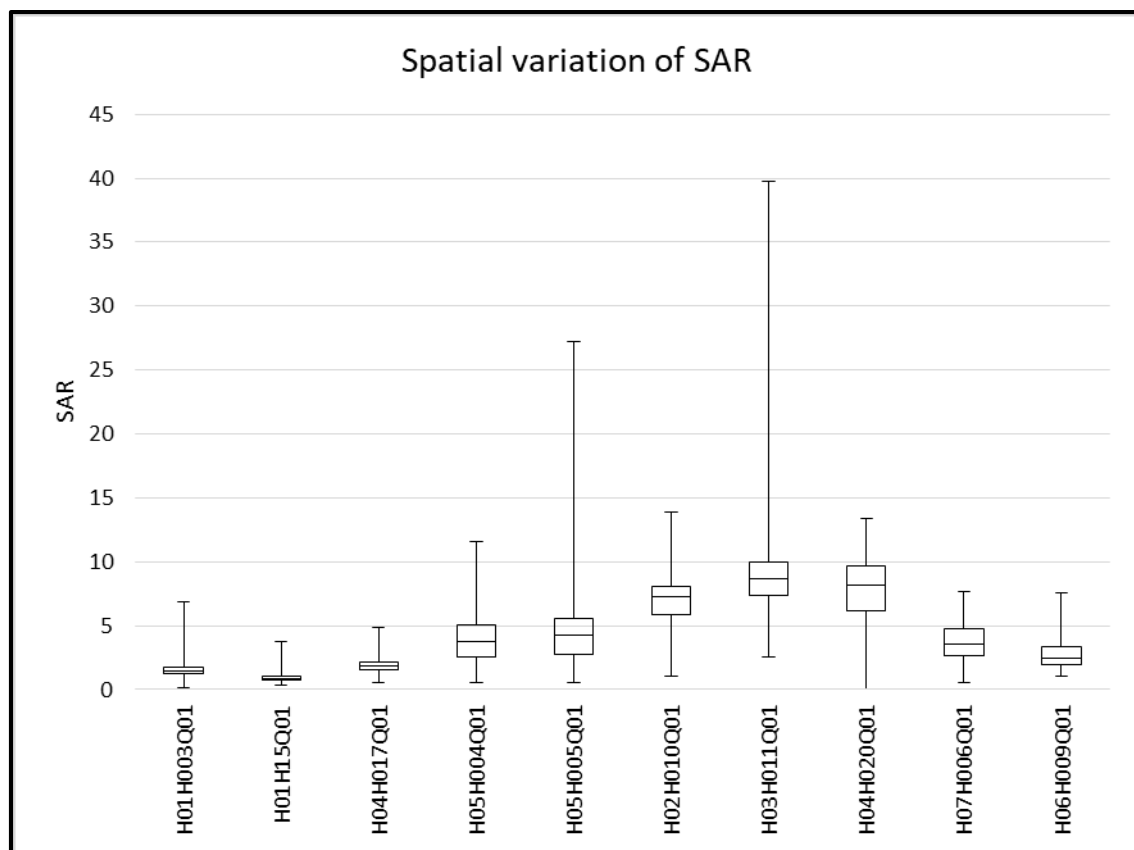


Figure 4-7: SAR plot for selected sample stations from the Breede River and Riviersonderend sections for the period 1970-2018.

The SAR follows a similar trend to that of Na including the elevated levels in the lower part of the Middle Breede River section and main tributaries. The detailed time series plots showed more

variations which generally reflect the poorer water quality during the dry season (October to April) (see graphs in Annexure F). The water in the Upper Breede River section and upper part of the Middle Breede River section up to station H4H017Q01 is therefore suitable for irrigation purposes with respect to SAR, but water in the tributaries including the Riviersonderend and the Lower Breede River sections are not suitable for this purpose.

The DWS TWRQ for Cl for irrigation water are set at 100 mg/l and for livestock watering at 1 500 mg/l (Annexure E). The majority of monitoring stations in the Breede River main stream and tributaries exceeded the TWQR for Cl (Figure 4-8; Annexure E and graphs in Annexure F). However, Moolman (1999) reported a yield reduction of 20% at Cl concentrations as low as 40 mg/l. It was therefore suggested that the TWQR for Cl be lowered and that the Cl concentration rather than the EC be used as the determining factor triggering the release of water from the Brandvlei Dam to protect agricultural yield (DWAF, 2003a, d, e).

The median Cl values for all stations varied between 20 and 898 mg/l with monitoring stations in the Upper Breede and upper part of the Middle Breede as well as Riviersonderend sections not exceeding the TWQR for Cl (Annexure E). The main tributaries in the Middle Breede exceeded the TWQR for Cl with the stations in the Breede River main stream below the confluence with these tributaries. Although the Cl concentrations in the Breede River mainstream still exceed the TWQR after the confluence with these tributaries, the values are substantially lower, reflecting the dilution effect of the larger volume of the slightly better quality water of the Breede River has on the salinity and contributing parameters such as Cl (Figure 4-8; Annexure E and graphs in Annexure F). The trend of increasing median Cl concentration in a downstream direction was also reported by previous studies (DWAF, 2003d, e).

The spatial variation of Cl along the Breede River is similar to that of EC and Na as seen on the time series plot which shows two distinct groups, those with Cl above 400 mg/l and those below (Figure 4-8 and graphs in Annexure D). The tributaries (Hex, Nuy and Kogmanskloof rivers) in the Middle Breede River section fall within the high Cl group. As has been highlighted previously, these tributaries also showed the highest Na levels and it is therefore safe to assume that Na and Cl originate from the same source. The water in these tributaries are considered unsuitable for irrigation purposes as the Cl TWRQ concentrations for irrigation purposes are exceeded more than 50% of the time in the lower part of the Middle Breede River section (Figure 4-8 and graphs in Annexure D). Although the detailed time series plots show a near-cyclical pattern it was not possible to link these to a particular season (see graphs in Annexure F). This trend was also reported by previous studies (DWAF, 2003). The Cl concentrations in the lower part of the Middle

Breede River section has deteriorated over time. This is particularly evident in stations H4H020Q1 which showed a steady increase since the 1970s (Figure 4-8 and graphs in Annexure F). The elevated Cl originate either from the underlying geology (Bokkeveld Group shale) or marine aerosols, elevated concentrations leached from soils contribute to elevated concentrations in irrigation return flow leading to the cumulative concentration in surface water (Jolly, 1990; Greeff, 1990; Kirchner, 1994).

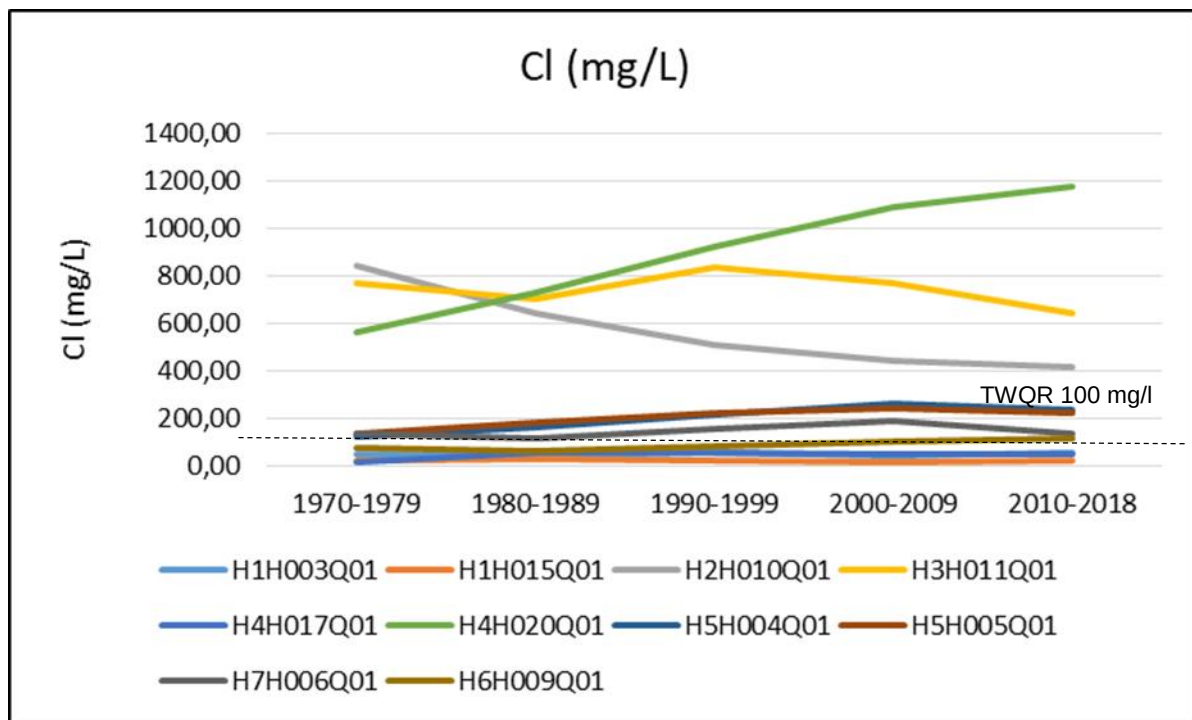


Figure 4-8: Cl plot for selected sample stations from average values for the Breede River and Riviersonderend sections for the period 1970-2018.

Apart from the high EC, TDS, SAR, Na and Cl concentrations other water quality parameters are not considered to be of concern in water for irrigation purposes use. No BGWMA RQO is available for K^+ , Mg^{2+} , Ca^{2+} , HCO_3^- , SO_4^{2-} , F^- , and NO_3^{2-} . These cations and anions, however, reflect the pattern observed for Cl and Na with the lower part of the Middle Breede River section and the tributaries again reflecting poor water quality (Figure 4-9 and Figure 4-10). The anion of chlorine is generally associated with K, Mg and Ca as is reflected in the close correlation between Cl and these cations are shown in the Pearsons correlation matrix (Table 4-2). However, in the K time series station H1H003Q1, in the Upper Breede River section closer to Ceres, an increase was observed from 2000 onwards which is not reflected in the Cl time series.

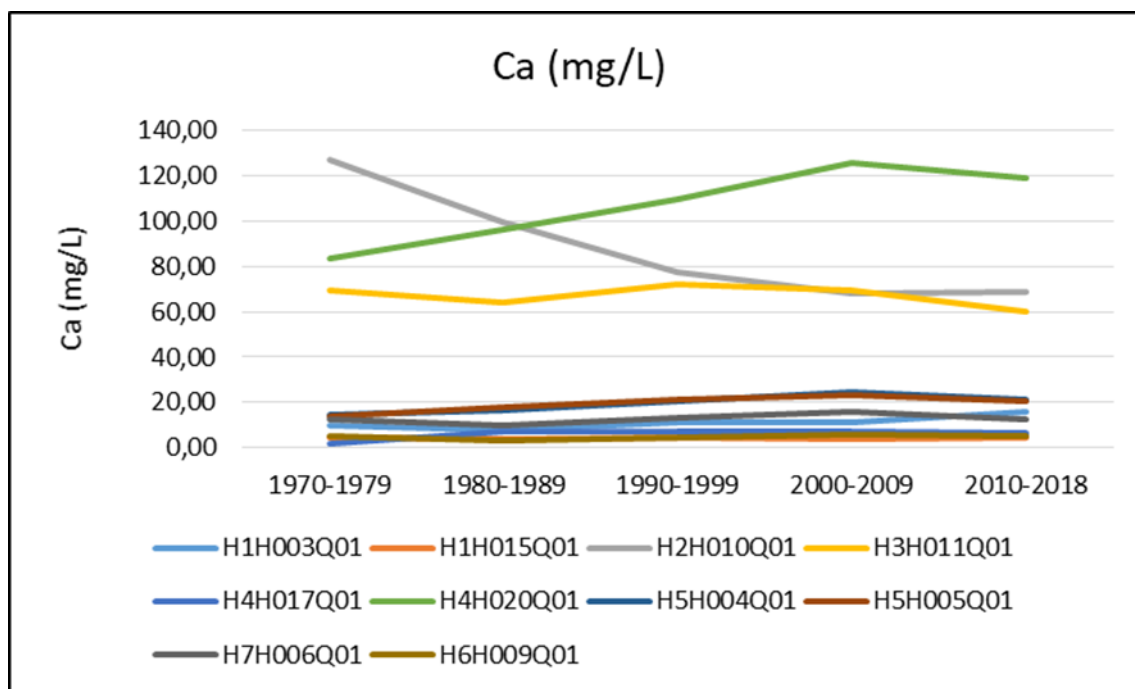


Figure 4-9: Ca plot for selected sample stations from average values for the Breede River and Riviersonderend sections for the period 1970-2018.

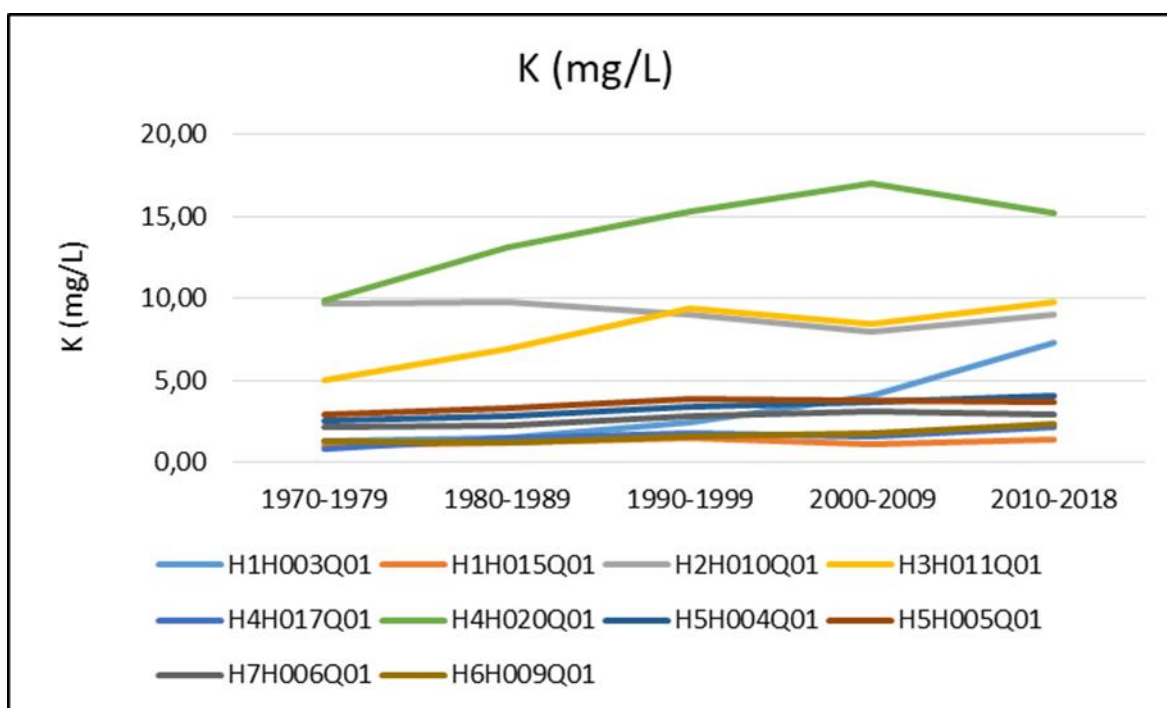


Figure 4-10: K plot for selected sample stations from average values for the Breede River and Riviersonderend sections for the period 1970-2018.

No BGWMA RQO and TWQR were set for SO_4 and HCO_3 for irrigation purposes, whereas the TWRQ for SO_4 for domestic and livestock watering purposes were set at 200 mg/l and 1 000 mg/l respectively. The time series data for SO_4 and HCO_3 revealed a pattern similar to that mentioned above for other parameters concerning tributaries of the Middle Breede River section (stations H3H011Q1, H2H010Q1 and H4H020Q1), displaying elevated concentrations with the remainder of the stations all reflecting values below 100 mg/l (Figure 4-11 and Figure 4-12).

The median SO_4 values for all stations varied between 8 and 423 mg/l (Figure 4-11 and Annexure E). Station H2H010Q1 (Hex River) showed a continuous decrease in SO_4 since the 1970s. High sulphate levels in drinking water renders the water unpalatable (bitter or salty taste); another factor is that the consumption of excessive amounts of sulphate in drinking water generally result in diarrhoea (DWAF, 1996b). The dissolution of minerals containing sulphur (often gypsum, pyrite) in soil and rock is a natural source of sulphate; additionally, anthropogenic sources including tanneries, textile processing, as well as atmospheric discharge from industries and combustion of fossil fuels result in the return of sulphate to surface waters (DWAF, 1996b).

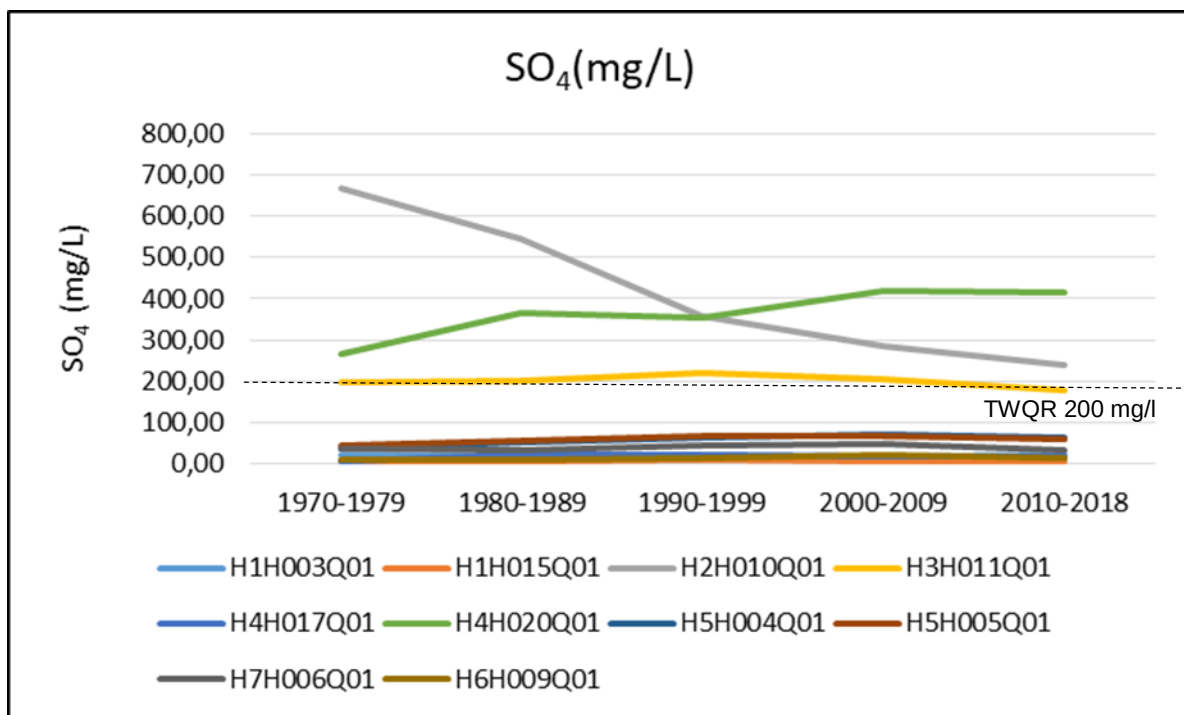


Figure 4-11: SO_4 plot for selected sample stations from average values for the Breede River and Riviersonderend sections for the period 1970-2018.

However, none of these anthropogenic sources occur in the catchment. Sulphuric acid is, however, used in the winemaking process to acidify and stabilise wine and SO_2 used as an antimicrobial additive (Howell & Myburgh, 2018). Howell (2016) showed that the SO_4^{2-} content in winery waste water is generally below 250 mg/l and commonly spikes following the harvest period.

Stations H2H010Q1 (Hex River) and H1H003Q1 (Upper Breede River section) were the only two stations which showed an increase in HCO_3^- since 2000 (Figure 4-12 and Annexure E). HCO_3^- , the bicarbonate ion, is the main alkaline factor in almost all water and is generally inversely proportional to the pH. Of the three carbonate species (H_2CO_3 , HCO_3^- and CO_3^{2-}) which contribute to total alkalinity, HCO_3^- is dominant at neutral pH. Bicarbonates become an increasing concern as the water increases from a pH of 7.4 to 9.3 (Spectrum Analytic Inc., 2021).

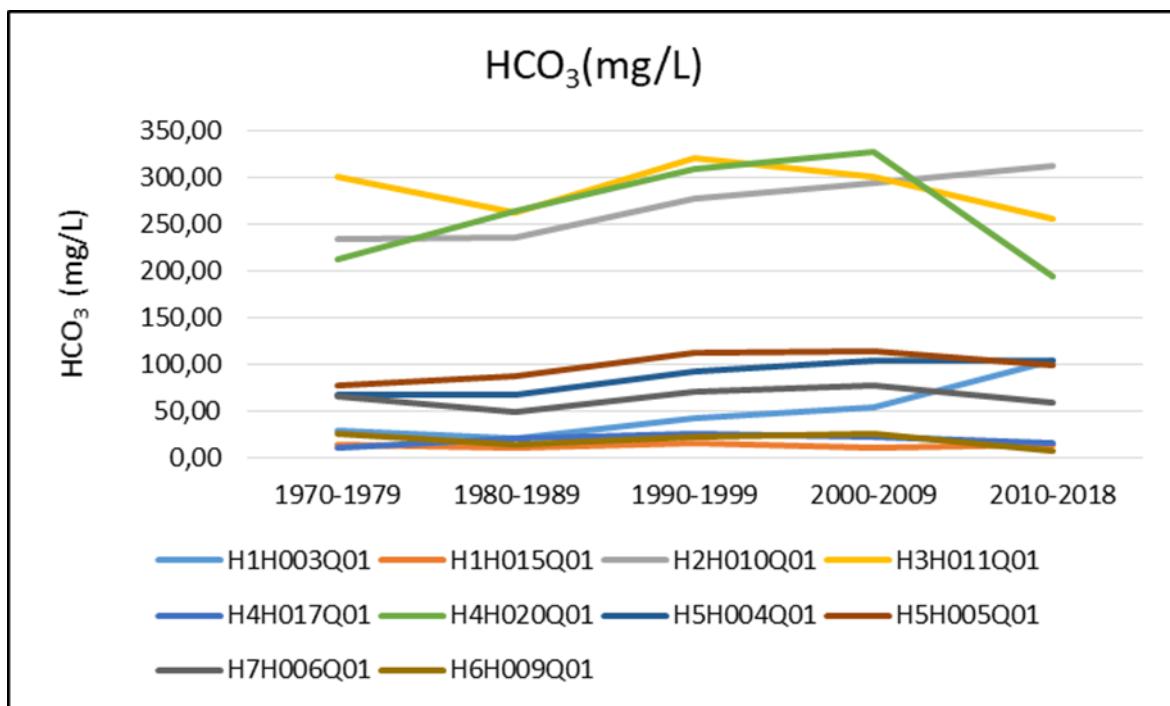


Figure 4-12: HCO_3^- plot for selected sample stations from average values for the Breede River and Riviersonderend sections for the period 1970-2018.

Alkalinity in most natural surface waters is derived from the dissolution of carbonate minerals, CO_2 in the atmosphere and soil (Day & King, 1995). Rock types which contribute to alkalinity include sedimentary rocks of marine origin including limestone. Water from deep aquifers also often contains high levels of bicarbonates. Anthropogenic sources include limestone (lime) applied to agricultural land to increase the pH of the soil and the effluent from WWTW (Spectrum

Analytic Inc., 2021). Stream water with high HCO_3 has a greater ability to buffer the changes in the pH related to impacts from pollution.

High alkalinity levels in water will tend to increase the pH of the soil and can be detrimental to plant growth as it removes calcium by forming CaCO_3 , effectively reducing the presence of calcium in soil for uptake by plants. Bicarbonate levels above 200 mg/l will cause lime (calcium and magnesium carbonate) to be deposited on leaves and roots. Low bicarbonate reduces nutrient absorption by roots. High alkalinity also affects the sodium levels in the soil which could damage the soil structure as well as negatively influence plant growth (Spectrum Analytic Inc., 2021). On the other hand low alkalinity in water for irrigation purposes could cause soil becoming too acidic for plant growth as the application of acid-forming fertilizers could be accelerated when the pH of the water is not buffered. Bicarbonate levels in water for irrigation purposes are: 0-100 mg/l (low), 100-180 mg/l (moderate), and 180-600 mg/l (severe) (Spectrum Analytic Inc., 2021). Water in the tributaries in the Middle Breede River section falls in the severe category with the remainder of the Breede River not considered to be adversely affected by water used for irrigation in terms of the HCO_3 levels.

Apart from the increasing salinity in the Breede River other concerns identified by previous studies included (DWAF, 2003):

- Occurrence of algal blooms under low flow conditions at some locations along the Breede River; and
- Clogging of canals by algae and aquatic weeds.

These concerns are related to nutrient enrichment in the water body and most are likely linked to inorganic nitrogen and phosphorous (DWAF, 2003). Excessive plant growth in response to nutrient enrichment leads to eutrophication of the water resource. The nutrients responsible for eutrophication are phosphorus as phosphate ions (PO_4^{3-}) and nitrogen as nitrate (NO_3^-), nitrite (NO_2^-) and ammonium (NH_4^+) (De Villiers, 2007). The increased nutrient levels in South African water resources are linked to a significant increase in urban runoff and progressively more so from overloaded and/or dysfunctional municipal water treatment plants and un-serviced informal settlements (De Villiers, 2007; Cullis *et al.*, 2018). The guidelines for the relevant parameters for trophic classification of freshwater ecosystems are summarised in Table 4-3 (De Villiers, 2007).

Table 4-3: Trophic status classification of freshwater ecosystems (DWAF, 1996b; De Villiers, 2007)

Parameter	Oligotrophic	Mesotrophic	Eutrophic	Hypertrophic
Inorganic Nitrogen ($\mu\text{g N/l}$) – SAWQ guidelines for Aquatic Ecosystems	<500	500-2 500	2 500- 10 000	>10 000
Inorganic Phosphorus ($\mu\text{g P/l}$) – SAWQ guidelines for Aquatic Ecosystems	<5	5-25	25-250	>250

Nitrogen is one of the macro plant nutrients with inorganic nitrogen occurring in the reduced form of ammonium (NH_4) as well as oxidised forms of nitrite (NO_2^-) and more dominant nitrate (NO_3^-) in water for irrigation purposes. The TWQR for nitrate/nitrite ($\text{NO}_2\text{-NO}_3$) is set at <5 mg/l to protect sensitive crops such as grapes and fruit trees and <0.5 mg/l for the protection of irrigation equipment. Furthermore, inorganic nitrogen (and phosphorus) concentrations should not be changed by more than 15% from that of the water body under local un-impacted conditions at any time of the year (DWAF, 1996a).

NO_3^- is applied as fertilizer but can also originate from the decay of organic matter. Nitrogen in water used for irrigation stimulates the growth of algae and aquatic weeds in irrigation infrastructure (canals, storage dams). The algae growth also interferes with the distribution of irrigation water (clogging of sprinklers) (DWAF, 1996a). The nitrogen TWQR limit of 0.5 mg/l is set for the protection of irrigation equipment by limiting the degree of eutrophication and growth of algae as well as other aquatic weeds. The median $\text{NO}_2\text{-NO}_3$ values for all stations varied between 0.2 and 1.0 mg/l with the median for stations in the Middle Breede River section slightly higher than the rest (Annexure F). Mesotrophic conditions where occasional growth of algae and plants will cause problems occur at nitrogen levels of 0.5 to 2.5 mg/l and eutrophic conditions of more frequent plant and algal growth at nitrogen levels between 2.5 and 10 mg/l (DWAF, 1996a).

The spatial variation in the nitrogen concentration along the Breede River main stream and tributaries for the simplified data relating to all stations over the 1970-2018 time period showed that no monitoring station had a $\text{NO}_3 + \text{NO}_2$ concentration exceeding the 5 mg/l TWQR for irrigation purposed water, suggesting that the nitrogen concentration would not affect crop yield (Figure 4-13 and Annexure E). The potential for stimulation of algal growth and mesotrophic conditions are, however, relatively high for stations in the Upper (H01H003Q01 and H01H015Q01)

and Middle (H02H010Q01 and H03H011Q01) Breede River sections and where the 0.5 mg/l limit is exceeded. Although the time series for $\text{NO}_3 + \text{NO}_2$ for most monitoring stations showed either a constant or decrease in $\text{NO}_3 + \text{NO}_2$ concentrations since 2000, station H1H003Q1 in the Upper Breede River section closer to Ceres showed a sharp increase (Figure 4-13). Nitrogen concentrations appear to decrease downstream of Worcester/ Brandvlei Dam but spike again in the Middle Breede River at Robertson. This trend was also described by Cullis *et al.* (2018) who linked it to return flows from the Worcester and Robertson WWTW and non-point source pollution from un-serviced peri-urban informal settlements. The improvement in the $\text{NO}_3 + \text{NO}_2$ in the Lower Breede River section can be linked to natural processes which remove nitrogen (Cullis *et al.*, 2018). The link between nitrogen levels and increased farming activities which could result in elevated $\text{NO}_3 + \text{NO}_2$ in irrigation return flow should, however, not be disregarded. Ammonium levels were relatively constant throughout the catchment and represent a minor component of the nitrogen composition, indicating a well-aerated system. This trend was also observed in the Berg River, which has similar land use as well as impacts to the Breede River. De Villiers (2007) showed that a combination of droughts, population growth and a fast growing local economy has put severe pressure on water resources within the Berg River.

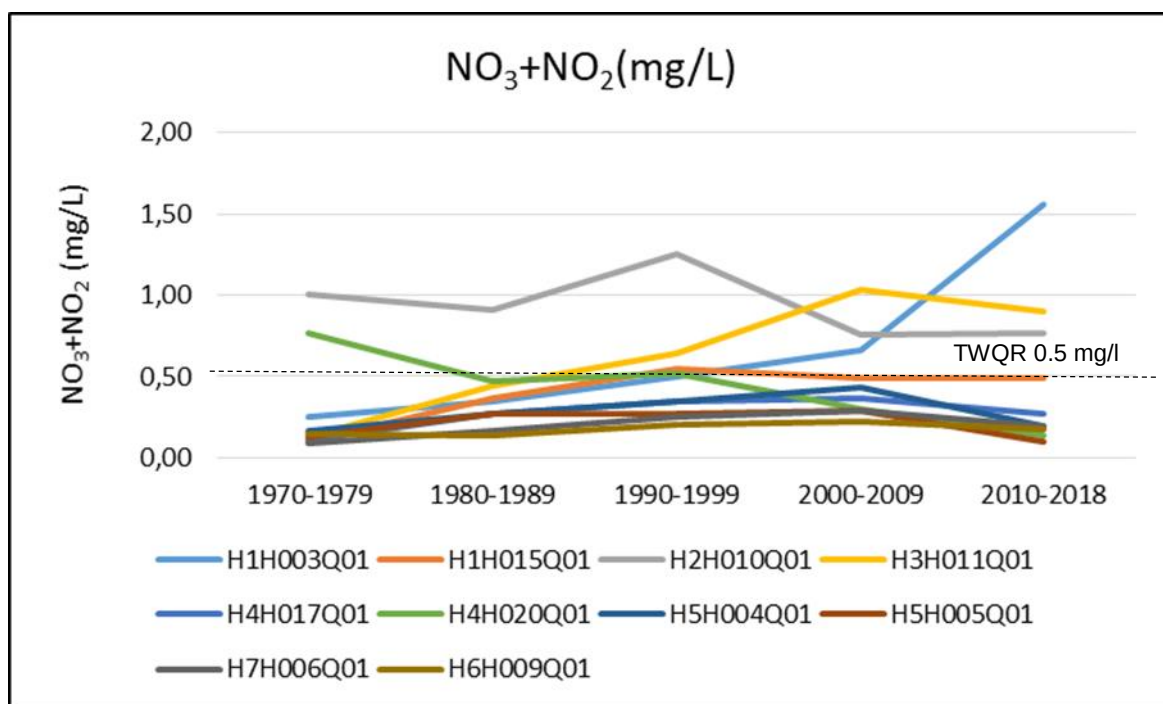


Figure 4-13: $\text{NO}_3 + \text{NO}_2$ plot for selected sample stations from average values for the Breede River and Riviersonderend sections for the period 1970-2018.

Phosphorus is a plant nutrient and originates naturally from weathering of rock and in soils due to decomposition of organic matter. Non-point source of PO_4^{2-} include precipitation, urban run-off and fertilizer in irrigation return flow (DWAF, 2003). The PO_4^{2-} limit of 5 $\mu\text{g/l}$ is set to limit the degree of eutrophication and growth of algae and other aquatic weeds (Table 4-3). The BGWMA RQO was set at <0.075 mg/l to maintain the river at a mesotrophic or better condition (SA, 2018). The median PO_4^{2-} values for all stations varied between 0.02 and 0.07 mg/l with the median for stations in the Middle Breede River section slightly higher than the rest. The time series data showed that the BGWMA RQO PO_4^{2-} limit is exceeded during summer months, suggesting that mesotrophic conditions occur during the dry season (Figure 4-14 and in Annexure F).

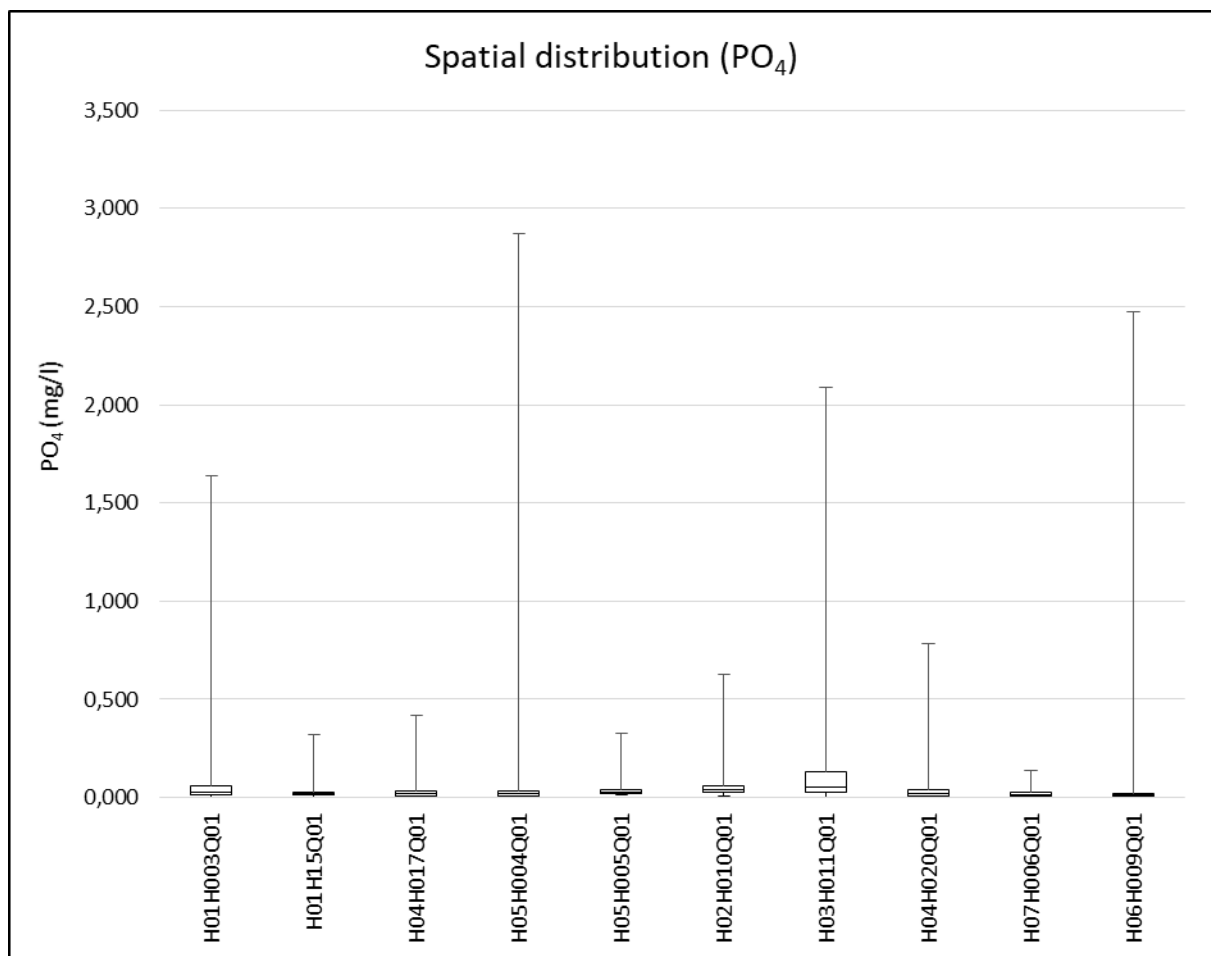


Figure 4-14: PO_4 plot for selected sample stations in the Breede River and Riviersonderend sections for the period 1970-2018.

Cullis *et al.* (2018) also highlighted the high levels of PO_4^{2-} along the full length of the river. This study showed that there is an association between high PO_4^{2-} and high levels of chemical oxygen

demand (COD) which was linked to return flows from WWTW and non-point sources of pollution from peri-urban and informal developments close to the water resource. De Villiers (2007), showed a similar trend for the Berg River with a 10 fold downstream increase in nutrient levels which were linked to the consumption of nutrients by algal and macrophyte productivity.

Eutrophication leads to a decline in water quality which reduces its suitability for different uses (DWAF, 1986a-f). It is not only a major risk to the provision of raw potable water but also to water used for irrigation purposes (DWS, 2020). Poor water quality not only has a negative impact on crop yields but it also constitutes a threat to international markets due to import restrictions from countries with strict quality standards (Cullis *et al.*, 2018; DWS, 2020). Cullis *et al.* (2018) highlighted the potential risk that the loss of international markets pose to the Western Cape.

Human activities and natural factors determine the hydrogeochemical characteristics of water resources. The water quality observed at each of the selected DWS monitoring stations can be used to assess the hydrogeochemical characteristics of the surface water in the study area.

4.2.2 Evaluation of hydrogeochemical characteristics

Water chemistry is largely controlled and modified by the medium (rock) it is in contact with (Gibbs, 1970; Day & King, 1995). Evaluation of water type/ hydrochemical facies are therefore useful in determining water quality and origin. Water samples shown on the Piper diagram can be grouped in hydrochemical facies. The Piper diagram for the yearly averages for all monitoring sites were used to visualise the entire dataset (Figure 4-15). The Piper diagrams for individual monitoring stations are included in Annexure G. These diagrams did not reveal any significant deviation from the summary Piper diagram (Figure 4-15 and Annexure G).

Piper diagrams for individual sites and the summary diagram show that the water types are confined to the fields of chloride type, sodium and potassium type, NaCl and mixed Ca-Mg-Cl types of water, respectively. From the plot it can be observed that strong acids exceed weak acids; alkalis (Na^+ and K^+) exceed the alkaline earths (Ca^{2+} and Mg^{2+}); and Cl-exceeds the other anions.

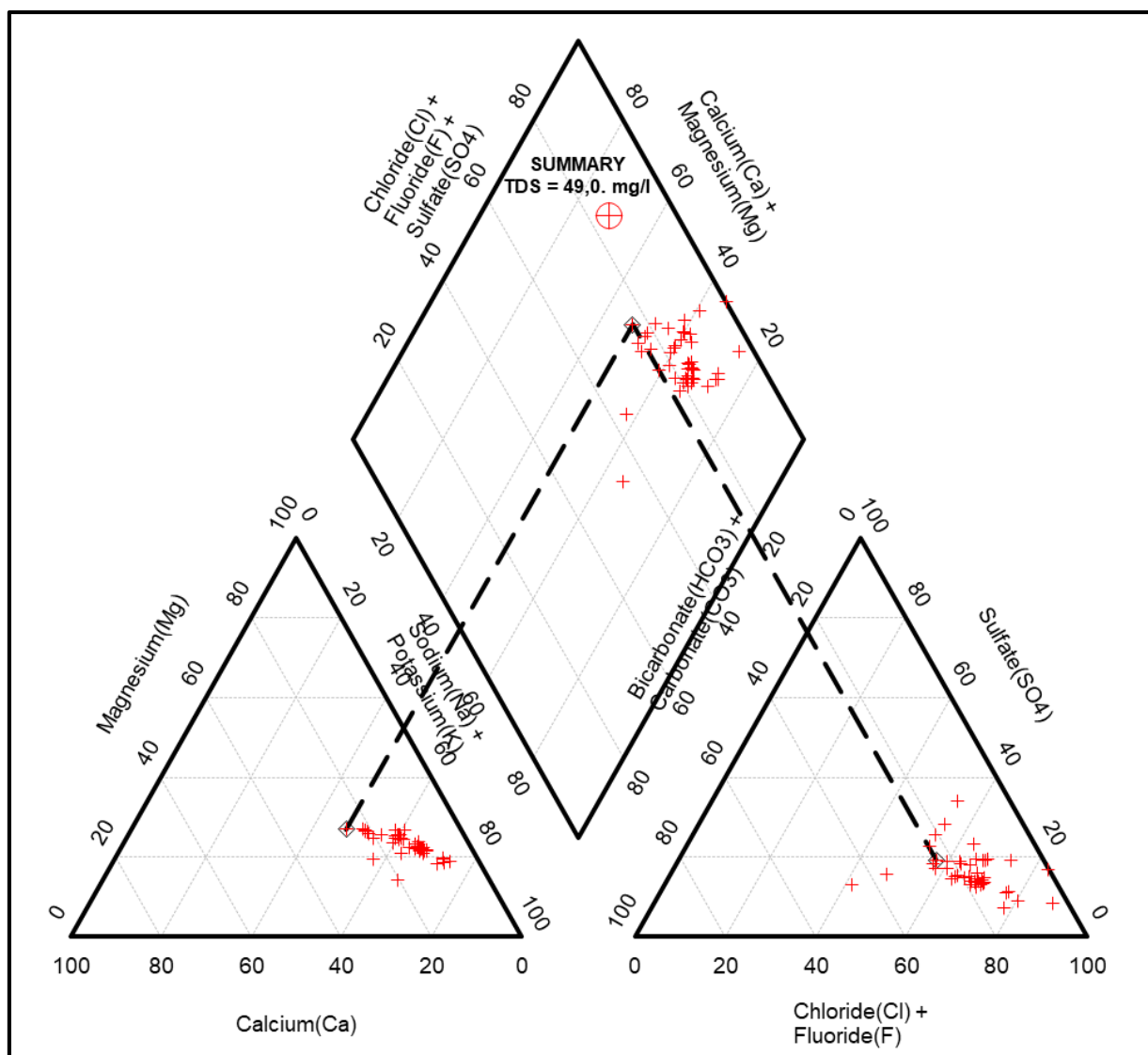


Figure 4-15: Piper diagram for yearly averages for all sample sites from the Breede River and Riviersonderend sections for the period 1970-2018.

The lithological, precipitation and evaporation characteristics are important in water composition studies. The following section will provide insights into the relationship of water composition to each of these natural inputs.

4.2.3 Evaluation of water chemistry

The mechanism controlling water chemistry and the functional sources of dissolved ions can be assessed by plotting the ratio of $\text{Na}^+ / \text{Na}^+ + \text{Ca}^{2+}$ and $\text{Cl}^- / \text{Cl}^- + \text{HCO}_3^-$ as functions of TDS (Gibbs, 1970; Day & King, 1995). The Gibbs diagram (Figure 4-16) is divided into three different regions,

which are the precipitation dominant, the evaporation dominant and the water-rock interaction dominant regions. Water chemistry data are visualized on a Gibbs diagram for each sample station included in Annexure H.

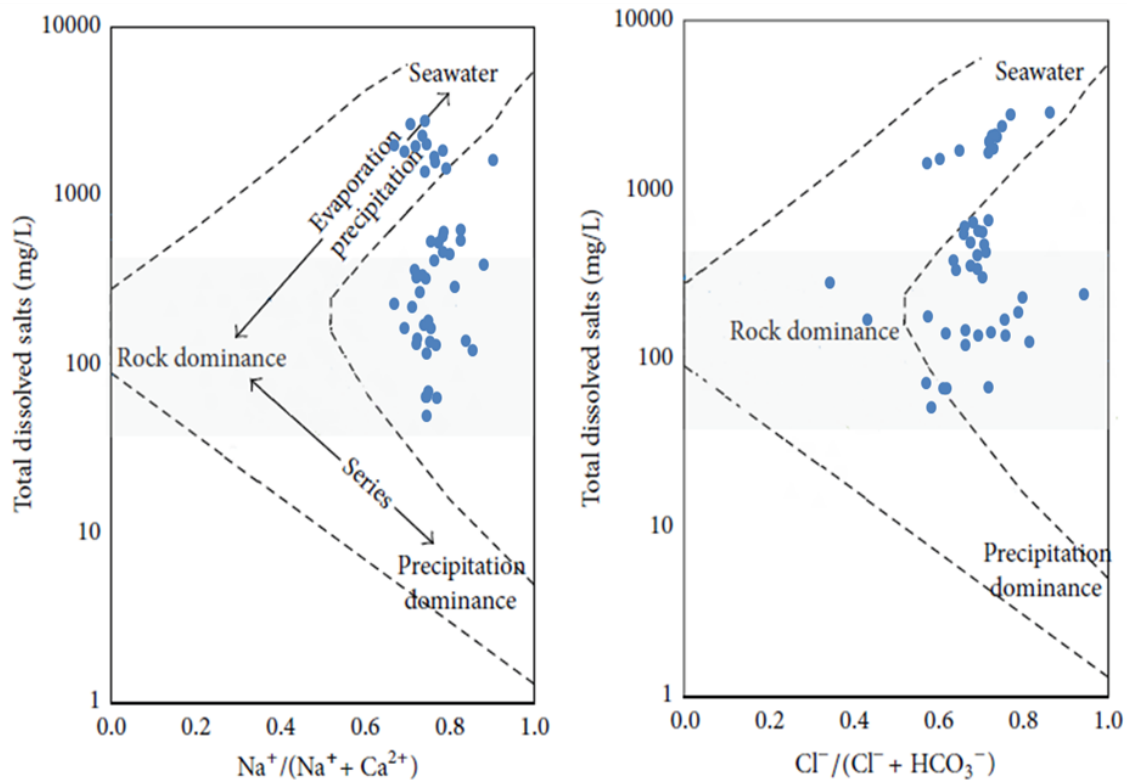


Figure 4-16: Gibbs diagram for yearly averages for all sample sites.

The Gibbs diagram for the yearly averages for all sample sites indicate a continuum between rock dominated and evaporation dominance fields. Na and Cl dominate, indicating a mixture between rock weathering and evaporation, and possibly marine aerosols (Figure 4-16). Original rock weathering ions are concentrated due to evaporation. In the Upper Breede River section the Gibbs diagrams showed a rock dominated pattern with a minor shift towards the precipitation dominance field. Na and Cl dominate at moderate TDS, indicating the original rock weathering ions concentration, possibly diluted by precipitation. In the Middle Breede River section the Gibbs diagrams showed an evaporation dominated pattern with some rock weathering dominance displayed by a minor number of data points. Na and Cl dominate at high TDS indicating the original rock weathering ions concentrated possibly due to evaporation. In the Lower Breede River section the Gibbs diagrams showed a rock dominated pattern with a minor shift towards the evaporation dominance field. In this instance Na and Cl dominate at moderate to slightly elevated TDS again alluding to rock weathering ions being concentrated through evaporation, but the

possible influence of marine aerosols cannot be ruled out. In the Riviersonderend section the Gibbs diagrams showed a rock dominated pattern with a minor shift towards the evaporation dominance field. Na and Cl dominate at moderate TDS, indicating rock weathering undiluted by precipitation.

Evaluation of the water quality using Piper plot and the Gibbs diagrams suggests that there is a clear indication of the influence of the weathering of underlying rocks on the water quality. The evaporation influence in the Middle Breede River section points to high evaporation and lower precipitation in this region, whereas the higher precipitation in the Upper Breede River section, acts as a dilution to the salt load originating from the weathering of the underlying rocks.

The contribution to the Na and Cl in the water in the Lower Breede River and Riviersonderend sections can also be linked to a possible marine influence due to the proximity to the ocean (Day & King, 1995). Day and King (1995) showed that rivers in the coastal regions of the south-western Cape and more arid neighbouring inland regions (100 km from coast) are dominated by Na⁺ and Cl⁻ ions.

The Berg River has been plagued by similar water quality challenges to that of the Breede River (De Clercq *et al.*, 2009). The salinity in the Berg River was linked to several potential causes including soils and geology, with salts occurring at the interface of the deeply weathered recharge zone overlying kaolinized Malmesbury shales with very low hydraulic conductivity, as well as marine aerosols and rain combined with climatic conditions whereby salinity is increased through evaporation (De Clercq *et al.*, 2009).

The fact that the salt load in the Breede River increases downstream has been highlighted by previous studies which related the increase to irrigation practices (Murray, Biesenbach and Badenhorst Inc. 1989; Cullis *et al.*, 2018).

4.2.4 Evaluation of microbiological characteristics

Faecal coliform is generally used to evaluate the presence of bacterial pathogens transmitted in faecal matter. Faecal Coliform range (counts per 100 ml) should ideally be 0 but 1 is generally accepted as tolerable. Counts up to 10 present risks of microbial infections with continued exposure with counts up to 20 posing a risk of transmission of infectious diseases (DWAF, 2003). The TWQR for microbiological (Faecal Coliforms) measured in counts per 100 ml for irrigation purposes is <1 c/100 ml, livestock watering is less stringent at 200 c/100 ml whereas for domestic

drinking purposes it is set at 0 c/100 ml (DWAF, 1996a-f). The BGWMA RQO use *E. coli* as measure of pathogens and is set at 165 c/100 ml (SA, 2018).

Both DWAF and BGCMA monitored the microbiological water quality in the BGWMA; however, the DWAF monitoring dataset was particularly incomplete and could therefore not be used. Data from the BGCMA monitoring stations for the Upper and part of Middle Breede River sections are more complete for the period 2008 to 2020 and were therefore utilised in the evaluation of the microbiological water quality in the study area (Table 4-4 and Figure 4-17). The biological monitoring data for each monitoring station is presented in Annexure I and time series data plots in Annexure J.

Table 4-4: BGCMA microbiological water quality monitoring sites (CWDM, 2010; BGCMA, 2021).

Sample station ID	Brief locality description of sample station	LAT. DECIMAL DEGR (S)	LON. DECIMAL DEGR (E)
CER 1	Ceres (Oewersig)	33.3604	19.3008
CER 2	Ceres- Dwarsrivier (Eilandplaas)	33.3745	19.3182
CER 3	Ceres (sewerage farm bridge)	33.3826	19.3121
CER 4	Ceres-Wolesley (Witbrug)	33.4217	19.2671
CER 5	Ceres (La Plasante bridge)	33.4480	19.2061
CER 6	Ceres (Bainskloof bridge)	33.5198	19.1858
WOR1	Worcester-Rawsonville Edelweis bridge	33.6517	19.3344
WOR2	Worcester-Rawsonville Nekkie bridge	33.6849	19.4209
WOR3	Worcester east pumping station	33.6979	19.4578
WOR4	Worcester Climor bridge	33.7368	19.4871
WOR5	Worcester Eilandia River camp	33.7695	19.6131

Variations between the stations as well as over time was evaluated and where possible correlations between parameters were identified. Based on the Coliform and *E. coli* TWQR for irrigation and BGWMA RQO limits the majority of the stations exceeded these limits at regular intervals with Faecal Coliform counts as high as 240 000 c/100 ml and *E. coli* counts of up to 110 000 c/ 100 ml recorded at stations higher-up in the Upper Breede River section (Figure 4-18 and graphs in Annexure J). The stations between Ceres and Worcester recorded the highest Faecal Coliform and *E. coli* counts mainly in 2011, 2014 and again in 2019.

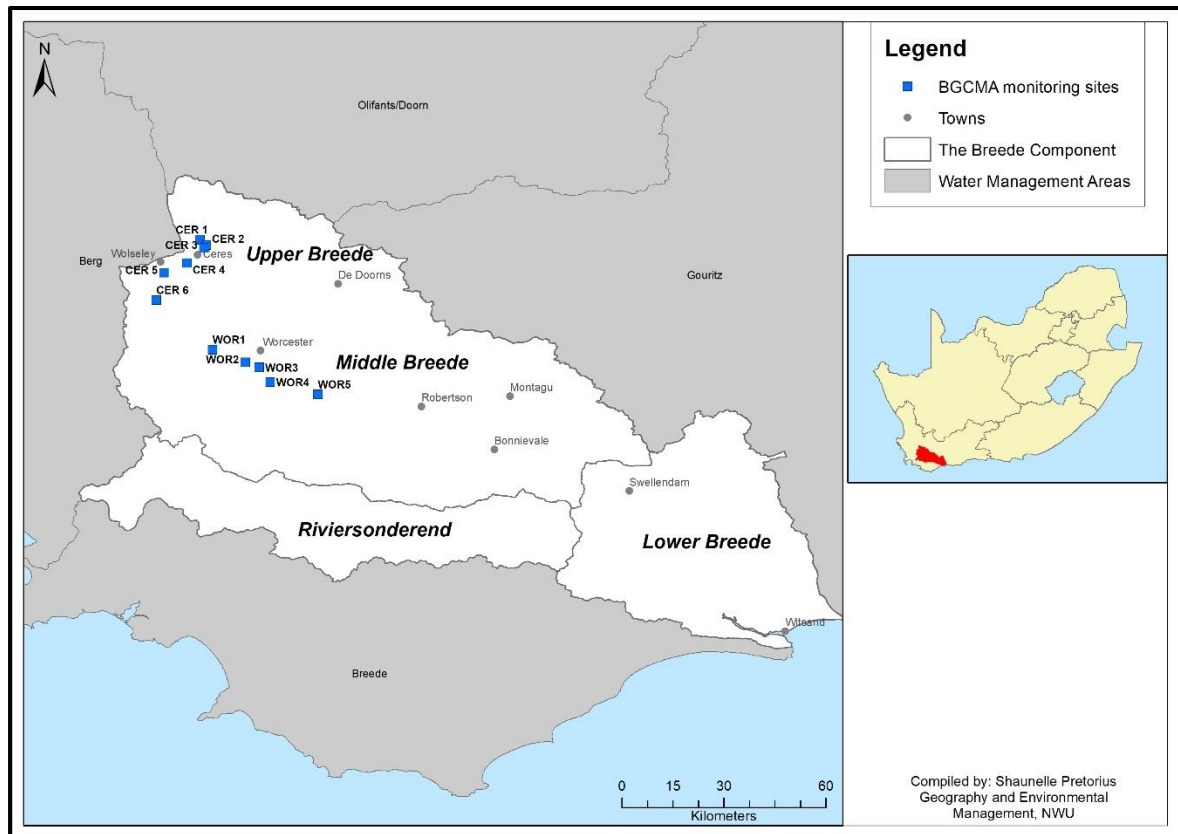


Figure 4-17: Location of BGCMA monitoring stations for microbiological parameters (modified from BGCMA, 2021).

The monitoring stations between Worcester and Robertson (Middle Breede River section) showed a similar trend although the levels rarely exceeded 1 000 counts/ 100 ml with the monitoring station downstream of Rawsonville (Wor1) more regularly exceeding the limits prior to 2015. An alarming trend is the elevated levels for *E coli* (up to 6 000 c/100 ml) recorded more recently (2019-2020) at stations (Wor 2 and Wor 3) downstream from Worcester (Figure 4-18 and Annexure J). The elevated *E coli* levels observed at these stations downstream of Worcester either suggest that the WWTW is not operating optimally which is contrary to the compliance findings by WCG (2017) and Cullis *et al.* (2018), or indicates the contribution from the un-serviced informal settlement have increased.

The highest levels were generally recorded in late summer/ early autumn when the flow in the streams were low with lower values generally coinciding with winter rainfall periods (and Annexure J). The *E. coli* lower levels during winter months suggests that the majority of the *E. coli* is removed from the system when the system is flushed during floods.

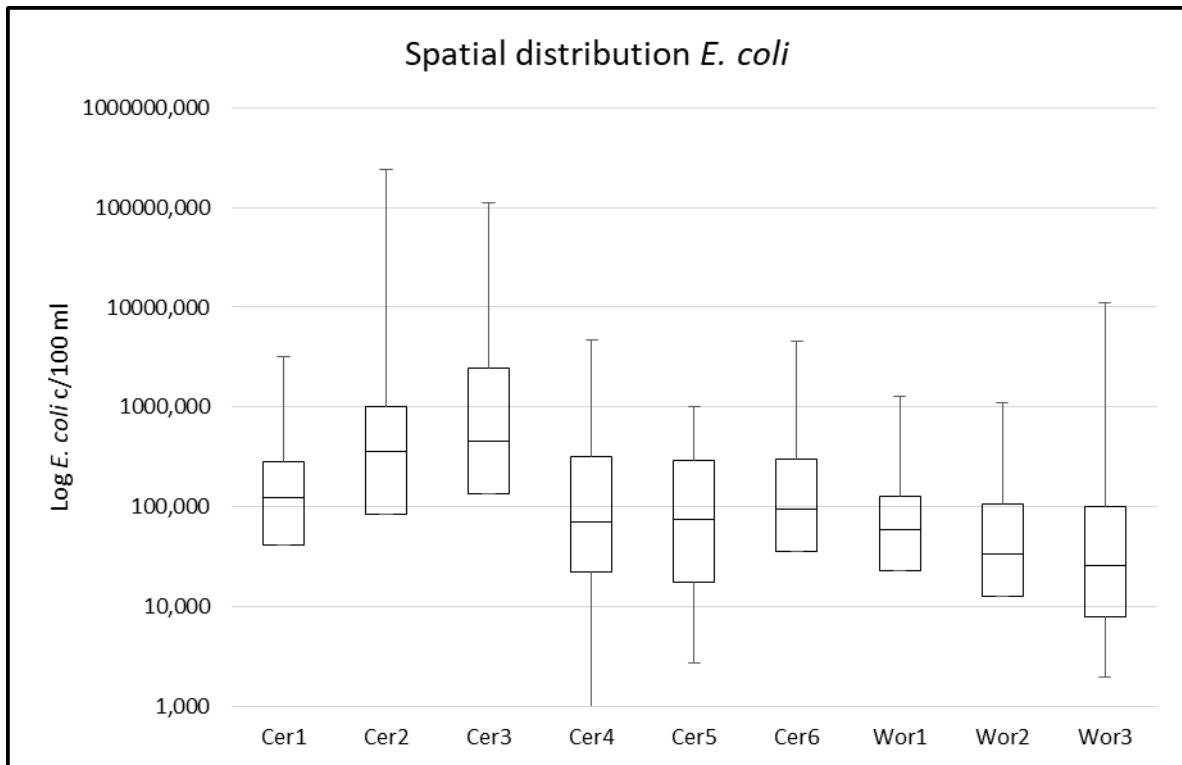


Figure 4-18: Spatial variation in the microbiological (*E. coli*) water quality for selected BGCMA monitoring stations for the Breede River.

There are 82 WWTWs within the BGWMA, of which 21 are municipal WWTW ranging in size from 30 Ml/d for Worcester to less than 1 Ml/d in the smaller towns (BGCMA, 2017b WCG, 2017). The majority of the WWTW (70%) are small, treating less than two (2) Ml/d (BGCMA, 2017b). Of these WWTW 41% are oxidation ponds, 6 % are biofilters and the remaining 53% are activated sludge plants. Not all WWTW are fully compliant with legal requirements including authorisation (BGCMA, 2017b). The BGCMA (2017b) study showed that 28% of the 82 WWTW did not have any authorisation, 27% are authorised under General Authorisation, and the remainder either have existing permits or a Water Use Licence.

The level of compliance of the municipal WWTW was evaluated by several studies based on compliance with microbiological and chemical requirements (CWDM, 2010; WCG, 2017; Cullis *et al.*, 2018). A summary of the findings from these studies for relevant municipal WWTW are presented in Annexure J. Based on the Green Drop System, the CRR risk rating indicates that the majority of the plants in the study area are rated as either high or medium risk plants.

The incentive-based regulation Green Drop certification programme was developed in 2008 to highlight risks and priority areas. Compliance in terms of effluent quality discharged to the receiving water resource as well as plant design capacity and technical skills were used to identify risks. Compliance is reported as Cumulative Risk Rating (CRR), which is a risk calculated against the Design Capacity of plant where WWTW with a high CRR value indicating that the plant has reached or is approaching its critical state of operation and therefore requires intervention such as upgrading/ capacity expansion (DWS, 2014).

By comparing the results from previous studies the impression is that the level of microbiological compliance of most WWTW improved between 2010 and 2018, the only exception being Montague (Annexure J) (CWDM, 2010; WCG, 2017; Cullis *et al.*, 2018). Worcester, Ceres and Wolseley generally have the best compliance levels with Ceres showing the best improvement since 2010. However, the *E coli* levels since 2018 do not reflect this improvement with microbiological water quality at most stations downstream of Ceres, showing elevated levels, with up to 45 000 c/ 100 ml recorded (Cer 3 downstream of outflow of Ceres WWTW) (Annexure J). Compliance improvements were reported for Worcester and Rawsonville which reflects the upgrading of the WWTW, although some incidents where the *E coli* standards were exceeded at stations downstream of Worcester were recorded since 2019 (Figure 4-18 and Annexure J). Discharges of treated waste water from the WWTW at Rawsonville and Worcester have a negative impact on water quality in this segment (and downstream areas). Of concern are the low levels of compliance to the microbiological standards reported for Robertson (CWDM, 2010; Cullis *et al.*, 2018).

4.2.5 Water quality index

The water quality index (WQI) was calculated from the DWAF dataset (1970-2018) for chemical parameters to measure the degree of contamination from natural and anthropogenic activities based on several key water chemistry parameters. The WQI indicates the sustainability of a water resource for various purposes by using a water quality rating system based on the composite influence of all individual water quality parameters on the overall water quality (Brown *et al.*, 1970). The WQI in the study area was calculated by using the equations provided in section 4.2.5 and classified according to the WQI ranges presented in Table 3-3.

The WQI was calculated for each of the 10 year intervals at each of the monitoring stations and is presented in Annexure K. The average WQI for each monitoring station over the period 1970 to 2018 is presented in Table 4-5. Among these, 60% of the monitoring stations classified as good

quality water, and 30% classified as unsuitable for drinking purposes based on the WHO standards. The monitoring stations in the Upper and Lower Breede River section as well as Riviersonderend section classified as good to excellent (Table 4-5.). The water quality in the upper part of the Middle Breede River section classified as good with the tributaries classifying as unsuitable.

The water quality compliance for selected water quality parameters (pH, EC, NO_3+NO_2 , PO_4) for the DWS long term dataset (1970 and 2018) were used to evaluate the suitability of the water in the Breede River catchment for irrigation purposes. The averages for each parameter for 10 year intervals were compared to standards for each parameter as presented in Table 3-4 in section 3.4.1.

Table 4-5: Average water quality index (WQI) and classification for DWS monitoring stations

DWS Station	WQI values	Water quality classification
H1H003Q01	30.68	Good
H1H015Q01	20.69	Excellent
H2H010Q01	135.33	Unsuitable
H3H011Q01	135.27	Unsuitable
H4H017Q01	34.44	Good
H4H020Q01	156.61	Unsuitable
H5H004Q01	48.34	Good
H5H005Q01	49.15	Good
H7H006Q01	38.44	Good
H6H009Q01	27.81	Good

The robot type coding was used to indicate the suitability of the water in the Breede River catchment over time (ideal (blue), acceptable (green), tolerable (yellow) or unacceptable (red)). The classes for all DWS monitoring stations based on irrigation water quality limits are presented in Annexure L. From this classification it was clear that the majority of parameters for the monitoring stations in the Upper Breede River section had ideal water quality over the 1970-2018 period with only minor deviations from that seen for NO_3+NO_2 , PO_4 on one occasion each since 2000. The tributaries of the Middle Breede River section have the most unsuitable water quality

with most parameters not falling in the ideal water quality class. The water quality in these tributaries were worst in the 1970-1979 period when it was classified as tolerable to unacceptable. This supports the WQI findings which showed that the water quality in the tributaries were unsuitable. The lower part of the mainstream in the Middle Breede River section improved over time from tolerable to acceptable or ideal. The Lower Breede River section (and Riviersonderend section) had the best suitable water quality with most parameters classed as ideal. EC and PO₄ were the parameters which were most often not classed as ideal. This is also true for all stations since 2000 (Annexure L).

4.3 Results from questionnaire (quantitative and qualitative) analysis

The analysis of the qualitative data is divided into five (5) sections corresponding to the subdivisions in the questionnaires, i.e. participant organisation (A), background on irrigation practices (B), water quality (C), key drivers of water quality decline (D), and key risks posed by the water quality (E), each with a particular focus in collecting information relevant to Research Objective 2 and Research Objective 3 of the study. Details on the selection of participants and structure of the questionnaires were discussed in section 3.3.2.

As indicated in section 3.3.2 a prefix (F for Farmers and E for Expert) will be used in the discussion, for example Question A1 for the Farmers group becomes QA1F, to highlight the differences in the responses from the two interview questionnaires. The total number of open-and close-ended questions for the Experts and Farmers group were 39 and 52 respectively (see Annexure A). The semi-structured interview questions therefore differed slightly between the two groups, specifically for section A to C. In most instances the close-ended question was followed by an associated open-ended question to provide the participants the opportunity to elaborate on the answer of the preceding open-ended question. The discussion will incorporate these replies where applicable. The open-ended questions were important in the identification of important themes such as key drivers of water quality decline (Section D) and key risks posed by the water quality in the Breede River catchment (Section E).

4.3.1 Section A: Participant organisation

This section was structured according to section A of the questionnaires which consisted of four questions (see Annexure A). The background information on the participants contributed towards providing an overview of the participants in both the Farmers and Experts groups and further added towards aspects such as knowledge and proficiency as well as the relevance of including

a particular participant in the study. This in turn contributed towards demonstrating the credibility of this research study. The discussion of the background information on participants applicable to this study are divided into the following sub-sections: highest level of qualification, relevant occupation field, and years of working experience in the selected field.

4.3.1.1 Highest level of qualification (QA1E/QA1F)

In the first question of this section (A1) participants were asked to state their highest level of qualification. The findings revealed that in the Farmers group a Matric certificate was the highest qualification for 20% (3 out of 15) of participants compared to 8% (1 out of 13) in the Experts group (Figure 4-19a and b). The majority of participants therefore hold some form of tertiary qualification. The majority of the Farmers group hold a Bachelor of Science in Agriculture (BSc Agric) degree or a Diploma in Agriculture (BTech Agric) (80%), with only one (7%) which holds a Masters (MSc) degree in Agriculture and one (7%) a BCom Economy background (Figure 4-19a). In the Experts group the majority of participants (85%) hold a tertiary qualification in a science and engineering discipline including a Diploma in Public Health (8%) and Civil Engineering (8%). Of the Expert group only a limited number indicated that they held a BSc Honours degree (27%) or a Master's degree (27%) as their highest qualification (Figure 4-19b). It was therefore concluded that the participants had sufficient knowledge on the water quality and local agricultural practices to take their responses into consideration.

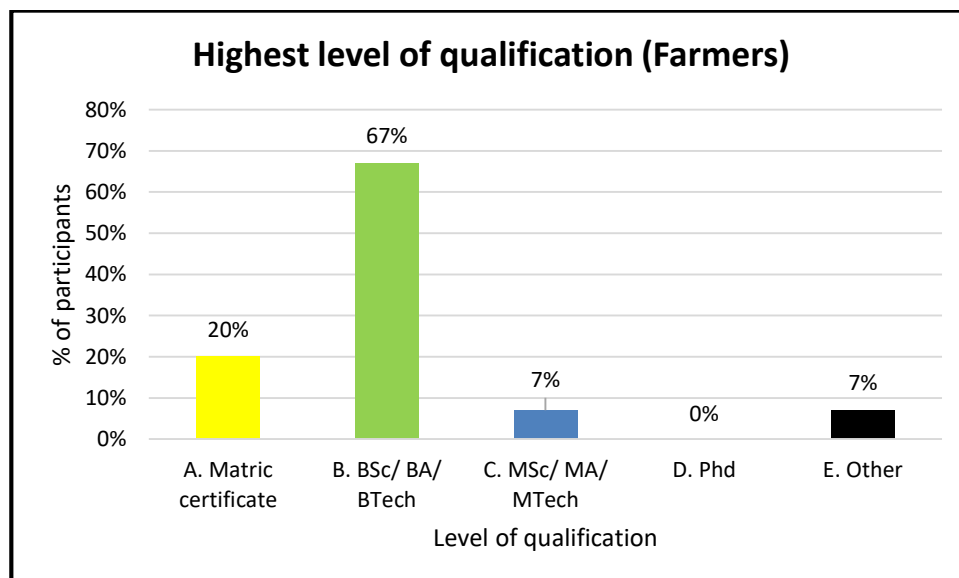


Figure 4-19a: Highest level of qualifications for the Farmers group (QA1F).

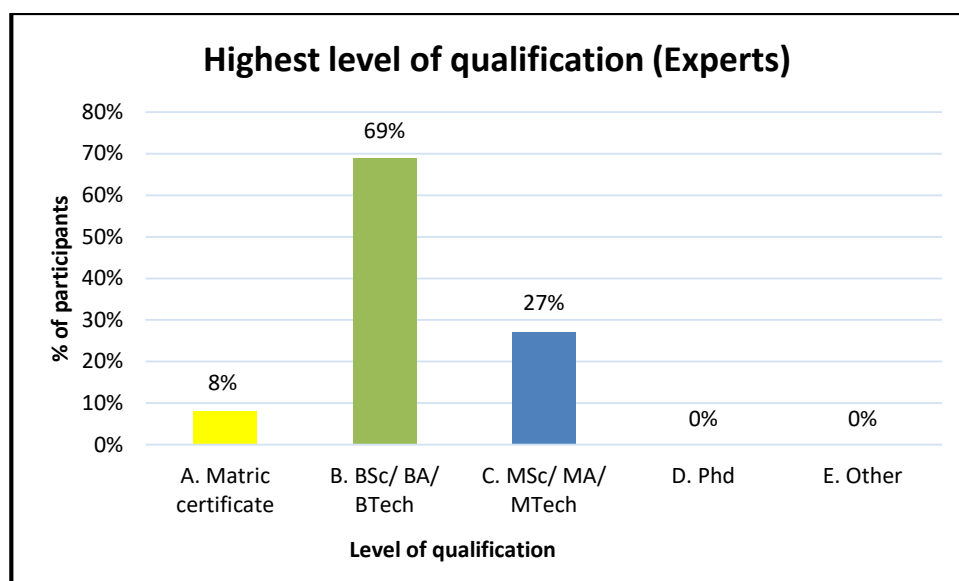


Figure 4-19b: Highest level of qualifications for the Expert group (QA1E).

From the findings on qualifications it was evident that the majority of the participants have a tertiary educational background in agricultural and/or environmental fields and would therefore be able to contribute to the study by providing relevant and informed opinions.

4.3.1.2 Occupational field and working experience (QA2E/QA2F and QA3E/QA3F)

The majority of participants in the Farmers group indicated that they are either the Farmer or farm manager (93%) with only one (1) participant falling in the processing of agricultural products (7%) (Figure 4-20a) (QA2F). The results showed the occupational field in which the Experts group fall include (QA2E): Local Municipality- Environmental services (A) (8%), Environmental Expert/ EAP (D) (8%), Environmental: Water management (E) (15%), Agricultural: Water distribution (F) (31%) (including various water user association and Breede-Gouritz catchment Management Agency), Agriculture: Agro-chemicals (G) (8%), and Other (H) including wine cellar manager (15%), Department of Agriculture (8%), Western Cape Provincial Department of Environmental Affairs and Development Planning (8%) (Figure 4-20b).

In response to QA3E/QA3F concerning the number of years of working experience in a field relevant to the study 100% of the Farmers group indicated that they have more than 16 years of experience in the agricultural field (Farmer, farm manager, process manager) with 69% of the Experts group indicating that they have more than 16 years' experience in the environmental and/or agriculture field. It can therefore be concluded that the participants have sufficient working

knowledge in their respective fields with an adequate period of experience spent/gained in the Breede River catchment to provide a constructive contribution to the study. Further to the above, the importance of experience and how this shapes perceptions towards the impact of water quality on agriculture is discussed under section 4.3.4.

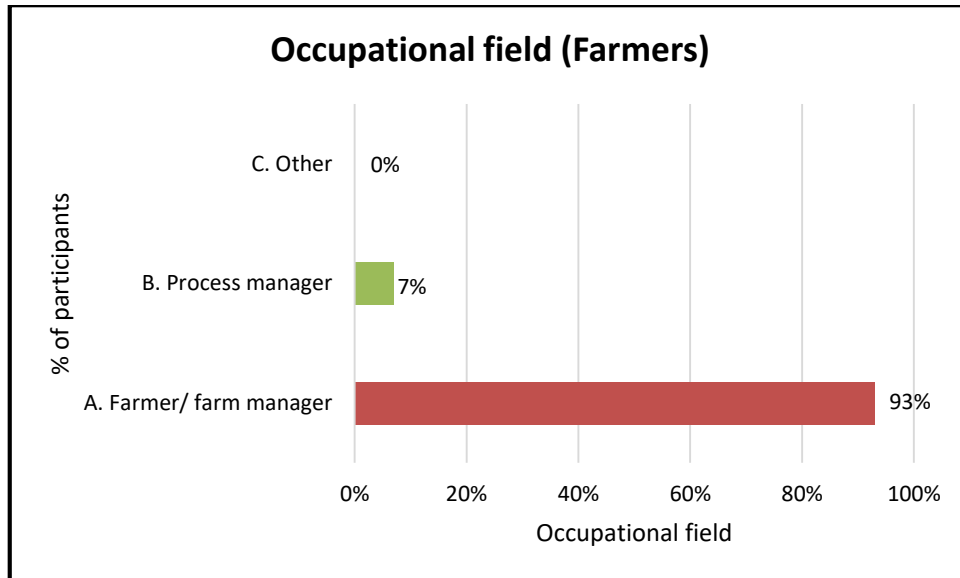


Figure 4-20a: Distribution of working experience in a field relevant to the study for the Farmers group (QA2F).

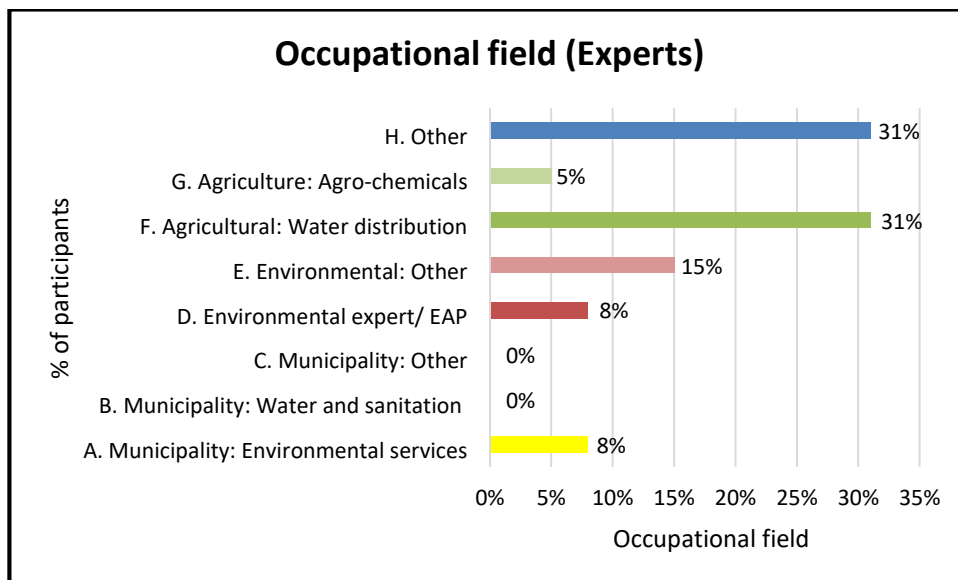


Figure 4-20b: Distribution of working experience in a field relevant to the study the Expert group (QA2E).

4.3.1.3 Agricultural sector(s) (QA4F)

Participants in the Farmers group were asked to indicate in which agricultural sector(s) they fall (QA4F). The responses indicated that the dominant crop type (73%) was grapes (table and wine grapes) with fruit (citrus, apples, peaches etc.) and grain (including animal feed and canola) each 7% with mixed farming selected by 20% of participants. Mixed farming included dairies and other minor crops.

4.3.2 Section B: Background on irrigation practices

This section was structured according to section B of the questionnaire which focused on the background information gathered related to the irrigation practices in the study area. Information gathered will assist in aligning responses according to sub-catchments, crop type etc. In order to assist in highlighting important trends. More attention was paid to the Farmers group in this section with 17 questions in the Farmers questionnaire compared to 5 in the Experts questionnaire. To assist in streamlining the discussion several questions were combined under an appropriate overarching heading. The relevant questionnaire questions were indicated for easy orientation to the questionnaires (Annexure A).

4.3.2.1 Water for irrigation purposes

Under this section questions related to the relevant section of the BGWMA (QB1E/QB1F), water source (QB2E/QB2F), and irrigation source/ infrastructure (QB3E/QB4F) were included. Farmers were asked to indicate in which part of the BGWMA their farm/ operation falls (QB1E/QB1F). This distribution was relevant in discussions in the succeeding sections. The distribution of Farmers across the relevant BGWMA were as follows: A. Upper Breede River section (26%), B. Middle Breede River section (47%) and C. Lower Breede River section (26%) (Figure 4-21a). The same question was put to the Experts group, although many of them work across the entire catchment; participants indicated that their main focus were in A. Upper Breede River section (39%), and B. Middle Breede River section (62%) (Figure 4-21b).

The results indicate that sufficient Expertise was distributed across the different sections of the BGWMA relevant to the study. This suggests that Farmers and Experts have sufficient experience in the complexities of the agricultural activities and agricultural water distribution across the three relevant BGWMA sections. The distribution of the farms/ operations along the Upper and Middle

Breede River sections was important as these sections were highlighted as areas of concern regarding water quality as highlighted earlier in section 4.2.

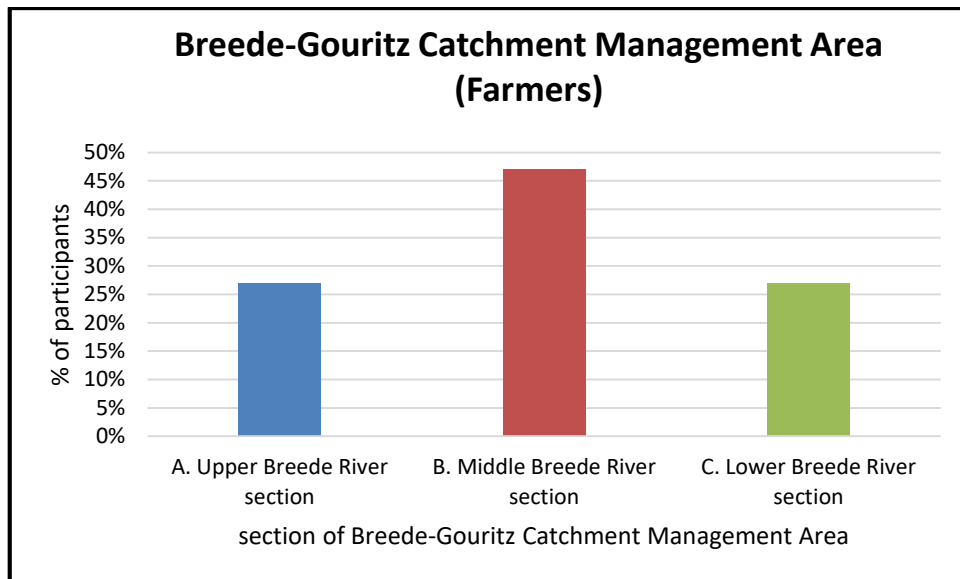


Figure 4-21a: Distribution of participants of the Farmers group throughout the BGWMA relevant to the study (QB1F).

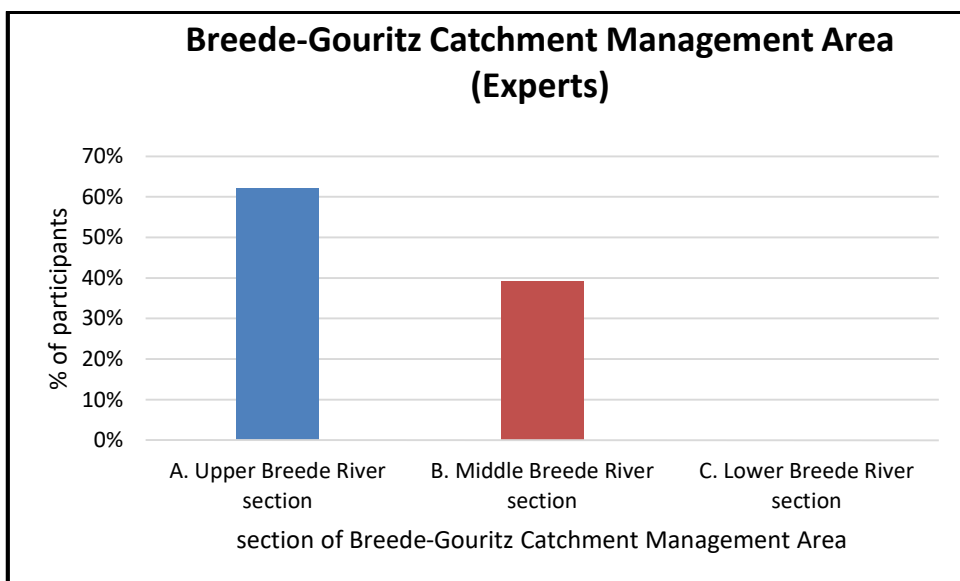


Figure 4-21b: Distribution of participants of the Expert group throughout the BGWMA relevant to the study (QB1E).

Farmers were asked if they make use of any form of irrigation on the farm (QB3F) to be able to screen out those where no irrigation from the surface water in the BGWMA occurred. Of the 15

Farmers interviewed only one (1) did not make use of irrigation but mainly relies on rainfall with augmentation from ground water as emergency supply during extended droughts. It was important to also include the views of this Farmer as a control in the sample of irrigation Farmers. Farmers and Experts were asked to indicate the main source of water for irrigation purposes (QB2E/QB2F). The majority of Farmers (14) (93%) indicated that they make use of surface water as main source of water with rainfall identified as the main secondary source of water (9) (60%) with only (5) 33% of Farmers indicating that they make use of ground water as a secondary source of water (Figure 4-22). The Experts group, however, identified ground water (8) (62%) and rainfall (5) (39%) as the most dominant secondary sources. Ground water is more often utilised in the Upper Breede River section as a secondary source of water (75%) compared to the Middle Breede River section (29%) and Lower Breede River section (0%) (Figure 4-23).

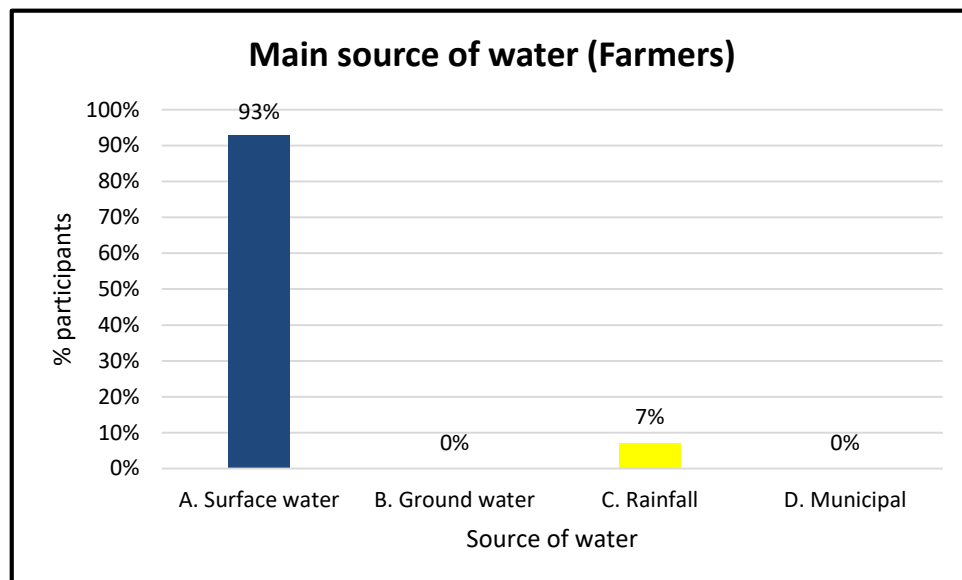


Figure 4-22: The distribution of the main and secondary water sources identified by Farmers (QB2F).

This corresponds to findings by previous studies which showed that ground water originating from the TMG fractured aquifer in the mountainous areas (Upper Breede River section) were good quality, low salinity water whereas the ground water in the valley bottoms (Upper and Middle Breede River sections) had the highest salinity, attributed to the argillaceous (shale-rich) host rock of the Bokkeveld Group (Murray, Biesenbach and Badenhorst Inc. 1989; Kirchner *et al.* 1997; DWAF, 2003).

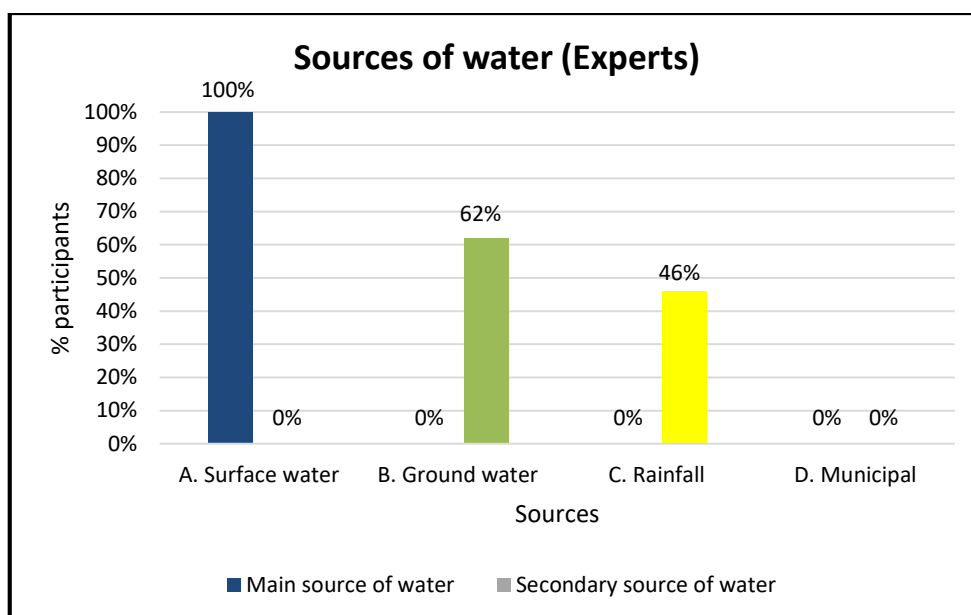


Figure 4-23: The distribution of the main and secondary water sources identified by Experts (QB2E).

These studies also confirm that, based on the high salinity levels, ground water was not an important source of water for irrigation purposes in the BGWMA. Farmers were asked to select the main irrigation water distribution infrastructure from which they receive water (QB3E/QB4F). The majority of Farmers indicated that they received water from the Breede River (40%) or the tributaries thereof (13%) compared to 27% of Farmers indicating that they receive water for irrigation mainly from the irrigation canals as the primary source (Figure 4-24).

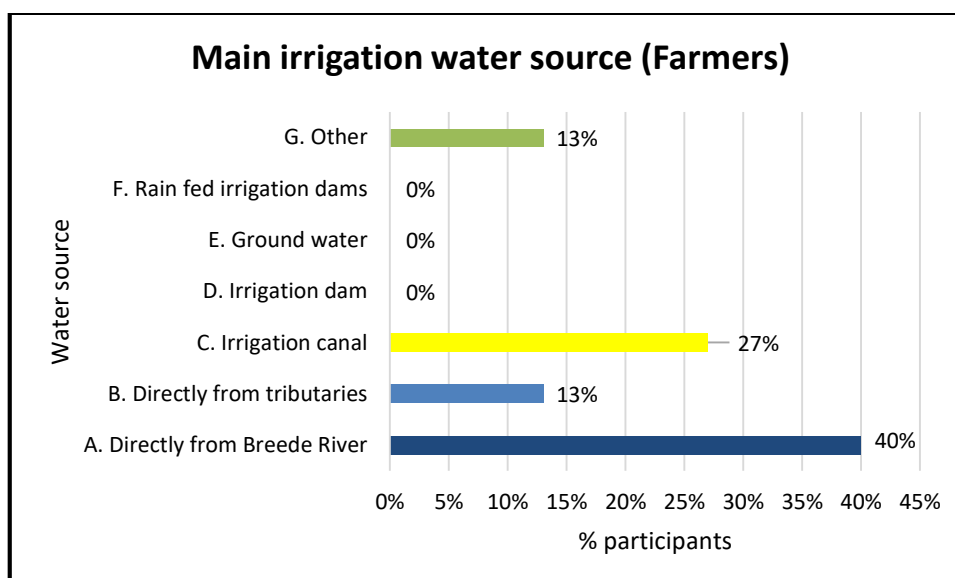
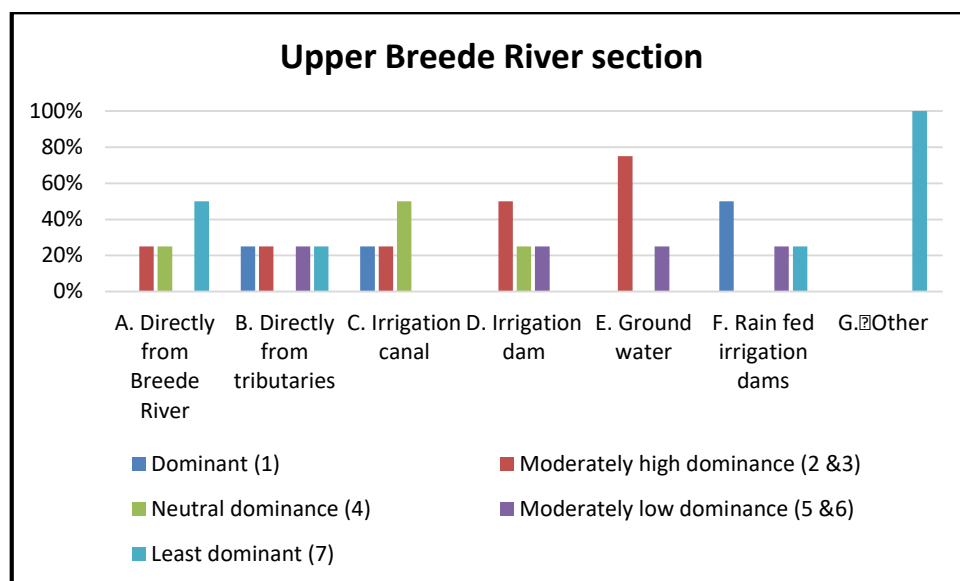


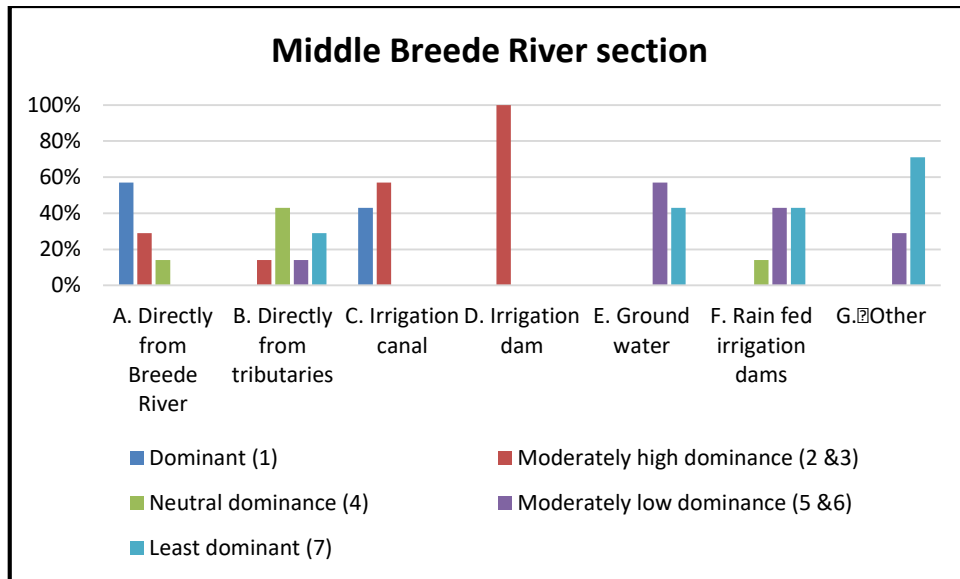
Figure 4-24: Distribution of main water source used in irrigation indicated by Farmers (QB4F).

The second most dominant source of irrigation water were indicated as either irrigation canals or irrigation dams with only 14% of Farmers indicating that the second most dominant source were ground water. Experts agreed with these findings that indicate irrigation directly from the Breede River (69%) is the main source of irrigation water distribution with the tributaries the second most dominant source of irrigation purposed water (62%).

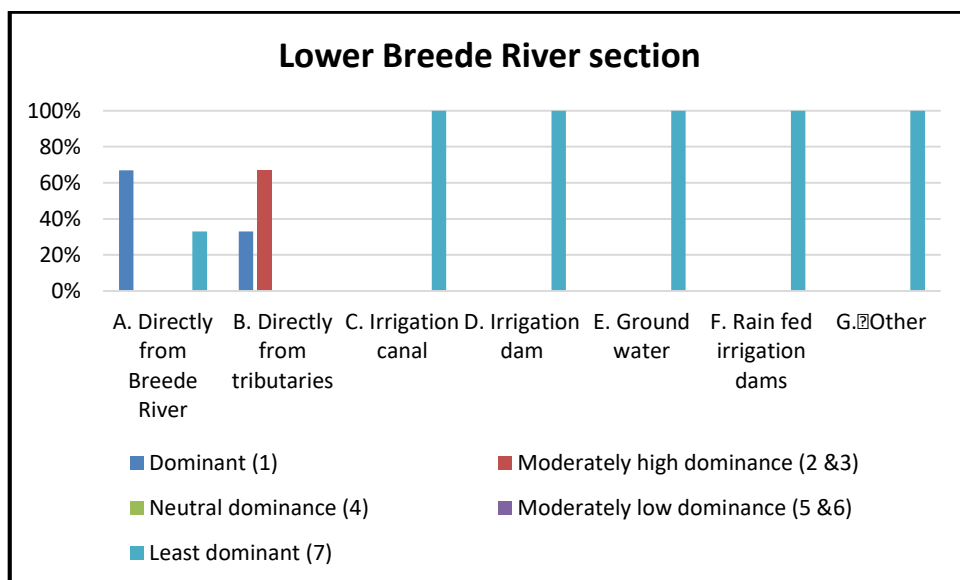
The main irrigation source changes as one moves from the Upper to the Lower Breede River as indicated in Figure 4-25. In the Upper Breede River section the main source is spread evenly between the surface streams (Breede River and tributaries) and irrigation canals. The majority of Farmers (57%) in the Middle Breede River section selected irrigation directly from Breede River and irrigation canals (43%) as the main irrigation sources and 57% as the second most dominant source (Figure 4-25). The Breede River is again indicated as the main source (67%) in the Lower Breede River section. These findings are in agreement with previous studies which showed that the Middle Breede River section has a larger network of the irrigation infrastructure compared to the other section (DWAF, 2003a).



(a)



(b)



(c)

Figure 4-25: Distribution of main irrigation source across categories per Breede River section (QB3E/QB4F).

The intention behind the inclusion of this detail was to determine from which source the irrigation water was received to be able to determine which irrigation water distribution infrastructure was the main conveyor of the potentially contaminated water identified earlier in section 4.2; to be linked with section 4.3.4 and 4.3.5. The level of knowledge of the Farmers and Experts related to the water quality in the different sections of the BGWMA will also be important in the evaluation

of key drivers of and risks posed by the water quality and will be important in the discussions in sections 4.3.4 and 4.3.5.

4.3.2.2 Crops under irrigation

Under this section questions related to the crops under irrigation (QB4E/ QB5F), land area under irrigation (QB6F and QB7F), quantity of irrigation water (QB8F), irrigation water restrictions (QB5E/QB13F), expenditure on water for irrigation purposes - (QB9F and QB10F) and irrigation pumping/ electricity costs (QB12F), quantity of fertilizer (QB14F), and quantity of herbicides and pesticides (QB15F) were included.

Farmers were asked to select the main crop under irrigation (QB4E/ QB5F). Results indicate that the dominant crop type changes from the Upper to the Lower Breede River section as indicated in Figure 4-26. The dominant irrigated crops in the Upper and Middle Breede River section were identified as grapes (wine and table grape) (71%) with fruit (citrus, stone fruit) the second most dominant (79%) crop. In the Lower Breede River section the most dominant crop was grain (wheat), canola and pastures (lucerne etc.) with minor fruit and grape producers. The Lower Breede River section is dominated by mixed agriculture which includes crops as well as poultry (sheep) and dairies. The mixed and other categories generally include pastures, poultry and dairies (67%). Other mixed crops listed across the catchment included: olive, almond, blueberries, watermelon and vegetables.

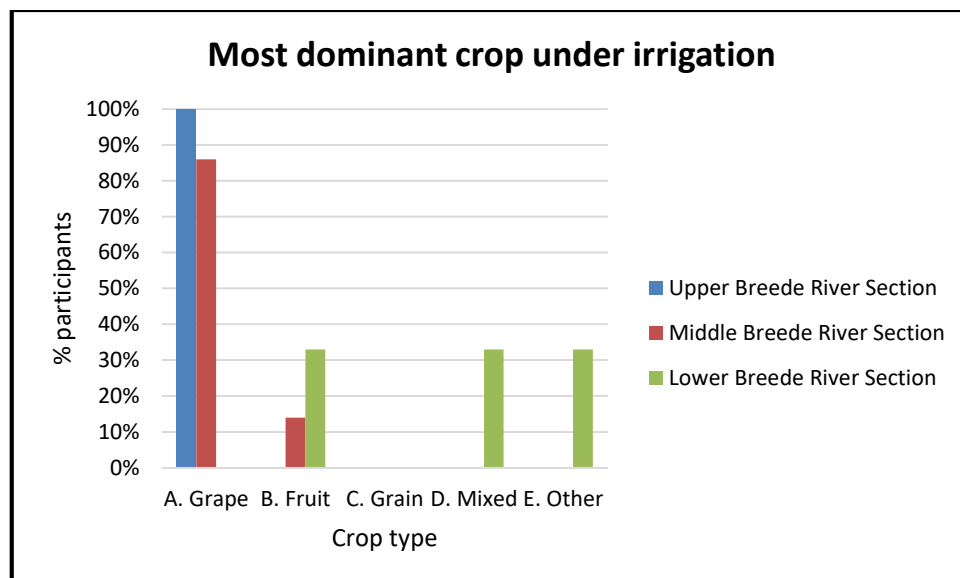


Figure 4-26: Distribution of the dominant crop type under irrigation across different sections of the Breede River (QB4E/ QB5F).

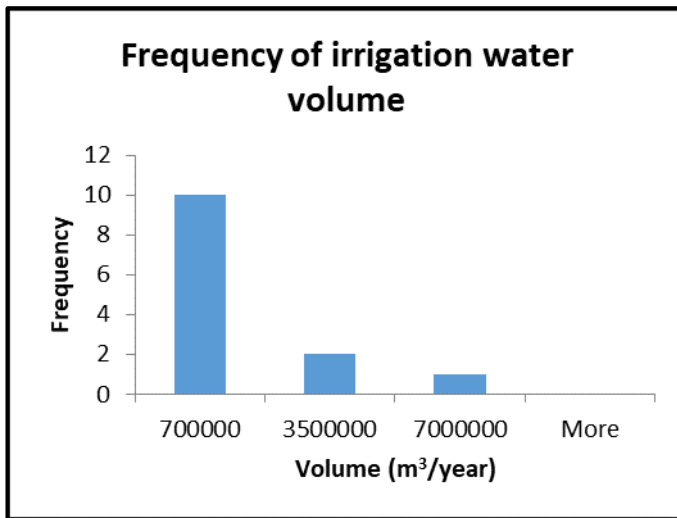
Farmers were asked to elaborate on the land area under irrigation in each of the crop categories for the year 2000 and 2020 (QB6F and QB7F). The intention behind the inclusion of this detail was to determine whether there was any significant change in crop type over the past 20 years. The size of the average land area where grapes were cultivated per farm were 100 ha with the maximum size being 1 000 ha for a mega-farm where several smaller farms were amalgamated. The average land area where fruit were cultivated was below 100 ha. The land size where mixed farming (pastures and diaries) dominate, ranged between 100 ha and 500 ha. There was no significant change reported in the distribution of crop type on the available land area over the past 20 years. The main change was where additional land was purchased or land not previously utilised was added to the total land area cultivated. This was generally considered to be due to the fact that the area investigated was an already established farming area with most available fertile/ usable land (already) cultivated by 2000. It was therefore not possible to make comparisons between the different years and between the sections of the Breede River. The results for crop under irrigation confirm the description of agricultural activities in the BGWMA indicated by previous studies which suggested that irrigation in the Middle Breede River was dominated by vineyards (Murray, Biesenbach and Badenhorst Inc. 1989; DWAF, 2003). However, there has been expansion in the land area where citrus is cultivated and changes in crop from grape to citrus in the Middle Breede River section seen in recent years.

Farmers were asked to indicate the volume of water used for irrigation (m^3/year) (QB8F) and to elaborate on any restrictions on irrigation water volume allocated over the past 20 years (QB5E/QB13F). The quantity of irrigation water used for crop production, all exceeded 50 000 m^3/year (Figure 4-27). The majority of Farmers indicated that the minimum volume of water required for irrigation was between 6 000 $\text{m}^3/\text{ha}/\text{year}$ and 12 000 m^3/year depending on the crop type. It was not possible to give a detailed breakdown per crop type from their records; therefore a simple multiplication of the land area (ha) with the average of 7 000 $\text{m}^3/\text{ha}/\text{year}$ was used to provide a breakdown per crop type across the catchment.

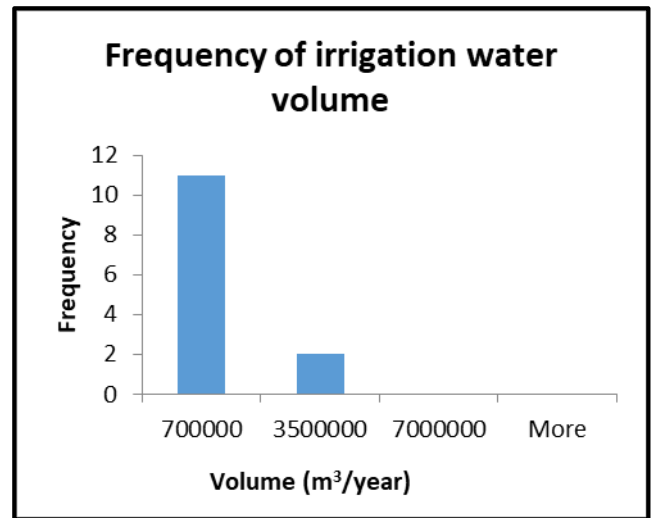
The participants were asked an open-ended question to elaborate on occurrences of and reason(s) for allowance restrictions on water for irrigation purposes in the Breede River catchment between the year 2000 and 2020 (QB5E/QB13F). The thematic analysis of their responses yielded themes which were then identified as the main causes for restrictions in irrigation water allocations. The main themes included:

- Flow restrictions during summer months;
- Flow restrictions during droughts;

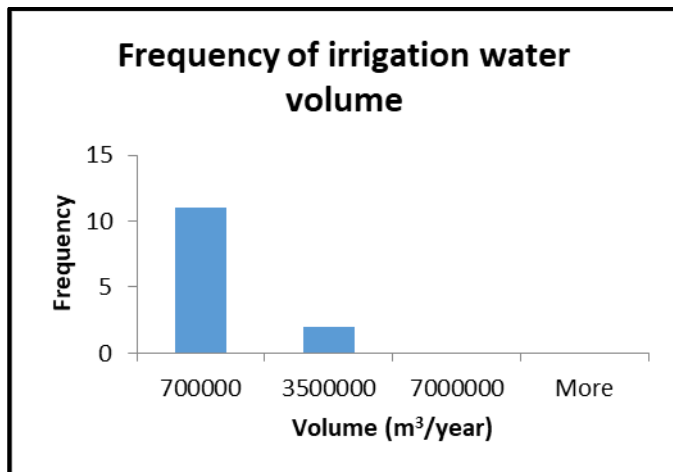
- Increased surface storage reduces flow; and
- Re-allocation and user conflicts.



(a)



(b)



(c)

Figure 4-27: Distribution of the average volume of water for irrigation purposes used in (a) grape, (b) fruit and (c) other (including pasture) irrigation along the Breede River (QB8F).

Most Farmers irrigating from the Breede River indicated that during late summer and periodic droughts the volume of water available for irrigation was affected. Comments included: “During late summer the river flow is low, in last drought even dried-up but no restrictions on allocations - could still use full quota but when river dried-up there was a period of 3 weeks when no irrigation was possible” (F13), and “During late summer most streams dry-up (Oct-March)” (E10). Farmers dependent on irrigation canals indicated that during severe droughts the allocated water was cut

by up to 60%. Most Farmers indicated that where water was abstracted from the Breede River, abstraction continued until no flow in the river was left. This was also linked to water quality concerns as commented by F6: *"Maintenance cost related to cleaning irrigation system and filter due to algae/ silt clogging the system"*, and F7: *"Lower water volume during drought brings changes in water quality"*. Information on the allocation restrictions experienced is important as this can influence the perceptions of water quality since water quality during low flow periods would differ significantly from high flow (flushing) periods. The Experts group agreed that water allocation restrictions occurred during droughts as highlighted by E5 which indicated that: *"In general in 10 year cycles on average 3 years are lower rainfall years where water used for irrigation is restricted"*.

Most Farmers indicated they abstract their allocated volume during the wet winter months and store these in farm dams for use later in the dry summer season as the majority of crops require year round irrigation. The majority of crops require the highest volume of irrigation during the dry summer period. However, a shift in the crop types in the future was highlighted to have the potential to impact irrigation scheduling and availability throughout the year. This has been identified as a potential water availability concern as commented by F7: *"stream modifications channelling mountain stream water into farm dams whereby lower lying farms are not receiving natural flow from streams anymore"*. A shift in the period when the allocated volume will be abstracted in future will have an impact on irrigation and water security in the entire Breede River catchment. Experts indicated that there has been an increase in the applications for new dams or the expansion of existing irrigation dams (in-stream and off-channel dams) on farms to increase water security after the recent (2018) prolonged drought. Many Farmers indicated that during prolonged droughts they make use of ground water as emergency supply for irrigation purposes.

Farmers were asked to indicate the amount of fertilizer as well as herbicides and pesticides used for production in irrigated crops between 2000 and 2020 (QB14F and QB15F). Most Farmers could not provide detailed values for agro-chemical use per year during this period from their records but provided an estimated total. In most instances Farmers indicated that they moved away from granular fertilizer applied in a blanket/ general ton per hectare irrespective of the plants' needs in 2000 to either liquid or dissolvable agro-chemicals that can be applied through the irrigation system in 2020 (Figure 4-28). These systems use less agro-chemicals due to a change in the irrigation system from overhead or flood irrigation to micro and drip irrigation over the years. Micro and drip irrigation uses less water and is directed at the plant stem and roots, thereby limiting the amount of agro-chemical products used. The intention behind the inclusion of this detail was to determine the contribution of agriculture to the pollution load in the surface streams.

However, since Farmers could not provide details on the quantity of agro-chemicals used the results of this section is not considered accurate enough to quantify the proportion of pollution load contributed by the agricultural sector.

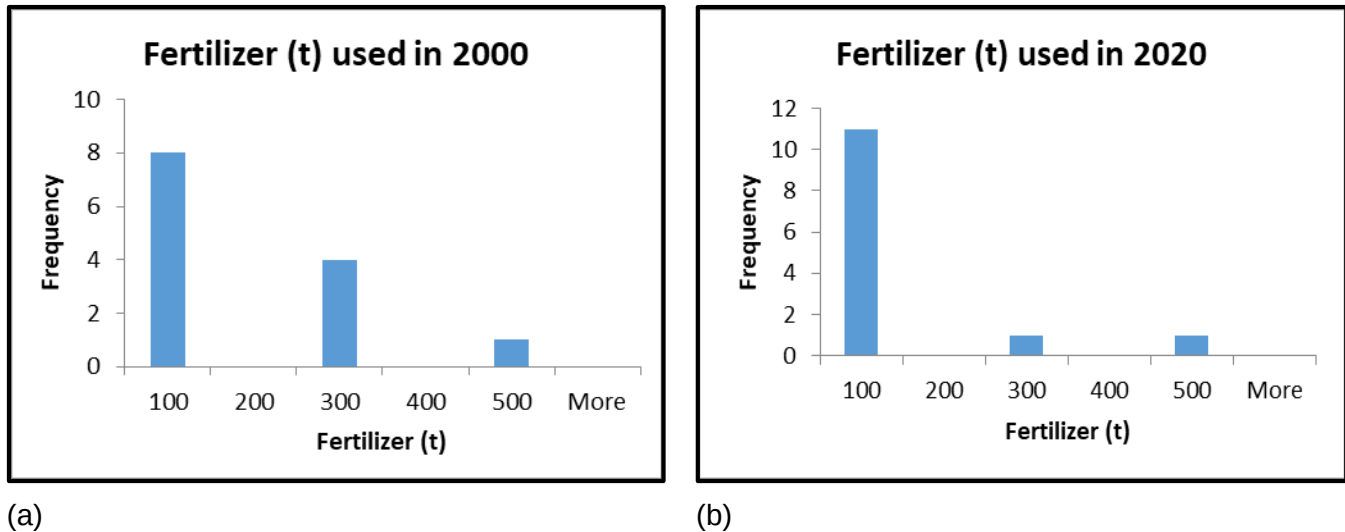


Figure 4-28: Distribution of quantity of fertilizer (ton) used in irrigated crops for (a) 2000 and (b) 2020 (QB14F).

4.3.3 Section C: Water quality

This section was structured according to section C of the questionnaire which focused on the information gathered related to the understanding of the water quality in the Breede River catchment. The evidence from literature suggested that the water quality has been declining in some sections of the catchment. This perception was tested based on impacts experienced by the agricultural sector. The questionnaires for the two groups more or less corresponded with 12 questions each (Annexure A). To assist in streamlining the discussion several questions were combined under an appropriate overarching heading. The relevant questionnaire questions were indicated for easy orientation with the questionnaires (Annexure A).

4.3.3.1 Water quality management

Under this section questions related to the level of understanding of water quality related policies and/or legislation (QC1E/QC1F), implementation of these policies and legislation (QC2E/QC2F) as well as water quality monitoring and information dissemination (QC3E/QC3F) were evaluated.

To test the level of understanding of the policies and/or legislation which regulate water quality in South Africa, participants were asked to rate their level of understanding of these policies and/or legislation (QC1E/QC1F). Farmers indicated that they had a moderate (60%) to low (40%) level of knowledge of water quality legislation, whereas Experts indicated that they had moderate (39%) to high (39%) levels of understanding of the legislation. However, the results relating to the opinion of Farmers and Experts on the question whether water related policies and legislation were well implemented, were not conclusive with 47% of Farmers selecting “Yes” vs 53% “No” and 54% of Experts selecting “Yes” vs 46% “No”. Of the group that indicated that water related policies and legislation were well implemented, Farmers indicated that they rely on the WUA, particularly the CBWUA, to provide them with relevant information on policies and legislation and to deliver any oversight input on their behalf. Those that opined that water related policies and legislation were not well implemented, Farmers indicated that they felt BGCMA were not consistent in enforcing water quality policies and/or legislation with private individuals and companies being treated much stricter compared to local municipalities when contraventions of legislation occurred. They also questioned if enforcement can be done effectively when water quality monitoring is not conducted throughout the catchment on regular intervals. The fact that DWS monitoring ceased in 2018 (see section 4.2) has an impact on the regulator’s ability to trace perpetrators, resulting in pollution incidents not being addressed. In most instances participants were unaware of the extent of the contribution of BGCMA to water management in the catchment. In most instances Farmers only dealt with BGCMA on water allocation and licensing problems.

Participants were asked to indicate which organisation(s) were responsible for providing water quality information and whether they received water quality data for the Breede River catchment from this or other organisations in the past (QC2E/QC2F). Most Farmers indicated that they did not receive water quality data regularly from any organisation, but if required they would contact the Central Breede WUA or BGCMA. Most Farmers were not aware that there was an archive of long term DWS water quality data for the catchment (DWS, 2021).

The Integrated Environmental Management (IEM) system provided for in Chapter 5 of the NEMA, and subsequent amendments, focused mainly on the prevention of environmental degradation, including decline in water quality (pollution control), through a command and control governance model with limited utilization of other instruments and tools such as market/fiscal based, agreement-based and civil-based mechanisms (DEA, 2014). The command and control (monitoring and enforcement) approach is mostly centred on a penalty based system (either fines or criminal prosecution), setting of standards and enforcement of these standards. However, there has been an intentional shift away from command and control to innovative hybridisation of

multiple instruments for environmental governance (DEA, 2014). There has been a major drive for private sector compliance tailored to specific needs as alternatives to command and control that may deliver more efficient and effective results. These include civil based and agreement based approaches such as self-regulation through voluntary tools such as audits by an industry level organisation which set standards and codes of practise (e.g. Eco-labelling) and performance reporting (DEA, 2014). Motivations to participate in voluntary industry level audits and certification include fear of prosecution/ liabilities, business drivers such as requirements by market and ethical reasons.

Most Farmers (13 of 15) acknowledged the fact that they did not monitor their irrigation and return flow water quality regularly as it was not a prerequisite of their water use license. However, the majority (14 of 15) of Farmers did participate in civil/ agreement based producer audits by independent third-party institutions which issue compliance certificates for standards of good agricultural practices. These self-regulation audits include GLOBALG.A.P., Fairtrade, BWI (Biodiversity and Wine Initiative) as well as Wine and Agricultural Ethical Trading Association (WIETA) and Integrated Production of Wine (IPW) which all require monitoring data at different intervals. These audits require water monitoring data of water used for irrigation purposes through occasional water sampling and analyses through accredited laboratories for specific parameters. Without these certifications the products are not accepted on global markets. Cellar effluent and drinking water on farms were also included in the industry audits.

The Experts group also indicated that the monitoring data provided by Central Breede WUA and BGCMA were the main sources for water quality data in the catchment but that there were many studies over the years which collected data as well. The Expert group had more knowledge regarding available collected water quality data and the availability thereof to the public of the Breede River catchment. Although the water quality data collected by BGCMA and CBWUA were not in the public domain the public can apply for access to reports and water quality data through the organisation(s) which conducted the studies. These include reports by the government departments (DWAF, 2003), municipalities (CWDM, 2010), and BGCMA.

4.3.3.2 Water quality concern/ challenge

Under this section questions related to the main water quality concern/ challenge (QC4E/QC4F), water quality parameters of concern (QC5E/QC5F), rating of the water quality in the Breede River catchment since 2000 (QC6E/QC6F), parameter which showed most deterioration between 2000 and 2020 (QC7E), water quality comparison with other WMA (QC9E/QC8F), suitability of the

water for irrigation purposes (QC10E/QC9F), impact of water quality on irrigation system maintenance (QB11F), and source(s) (natural and/or anthropogenic) which influence the water quality (QC8E/QC7F).

Although no regular water quality data monitoring is done throughout the year (see section 4.3.3.1), the majority of Farmers felt confident that they have a general idea of the quality of the water in the catchment and when asked to list their main concerns/ challenges they highlighted the following parameters as concerns (i.e. those classed as 2. Moderate or 3. Poor): TDS/EC (50%), Biological/ *E. coli* (73%), pH (27%), cations: Na, Ca, K (13%), anions: HCO₃, SO₄ (7%) (QC4E/QC4F) (Figure 4-29). Under “Other” the following was listed: Fe, Mn, heavy metals, hormones, siltation, solid waste (plastics etc.), and algae. The main concerns/ challenges differed across the three sections of the catchment with the majority (71%) of Farmers in the Middle Breede River section that considered the TDS/EC of moderate (to poor) quality and all Farmers (100%) in the Lower Breede River section considered the pH to be of moderate quality (QC5E/QC5F) (Figure 4-29). Farmers who indicated that the water quality in terms of biological contamination (*E. coli*) was moderate to poor were generally spread across all the Breede River sections, although only 50% of Farmers in the Lower Breede River section classified this parameter as moderate (Figure 4-30).

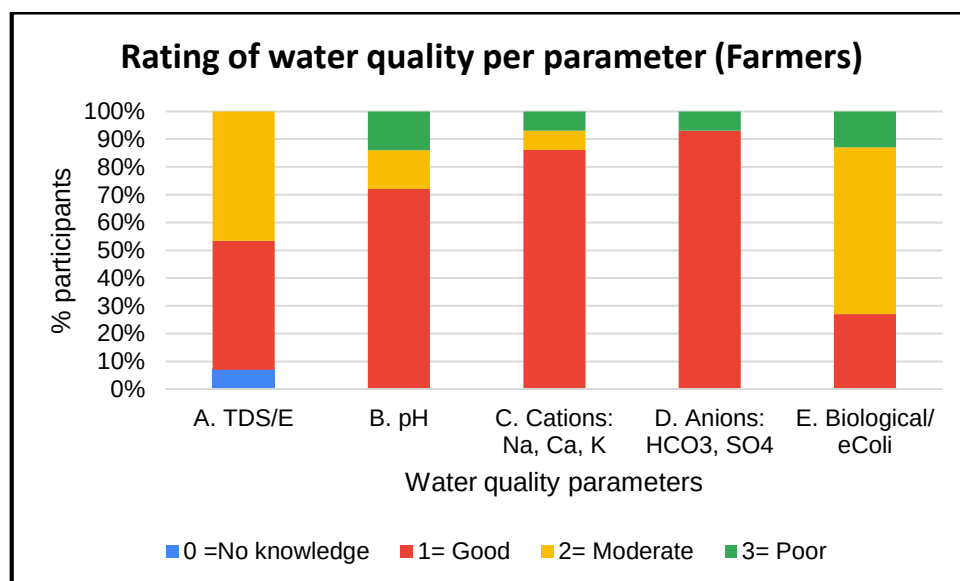


Figure 4-29: Distribution of Farmers’ opinion on the main water quality parameter of concern in the Breede River catchment (QC5F).

The Expert group were also asked to list their main concerns/ challenges and they highlighted the following parameters as concerns (i.e. those classed as 2. Moderate or 3. Poor): Biological/ *E.coli* (69%), TDS/EC (62%), Other (39%), cations: Na, Ca, K (8%), anions: HCO₃, SO₄ (8%), pH (0%) (Figure 4-31).

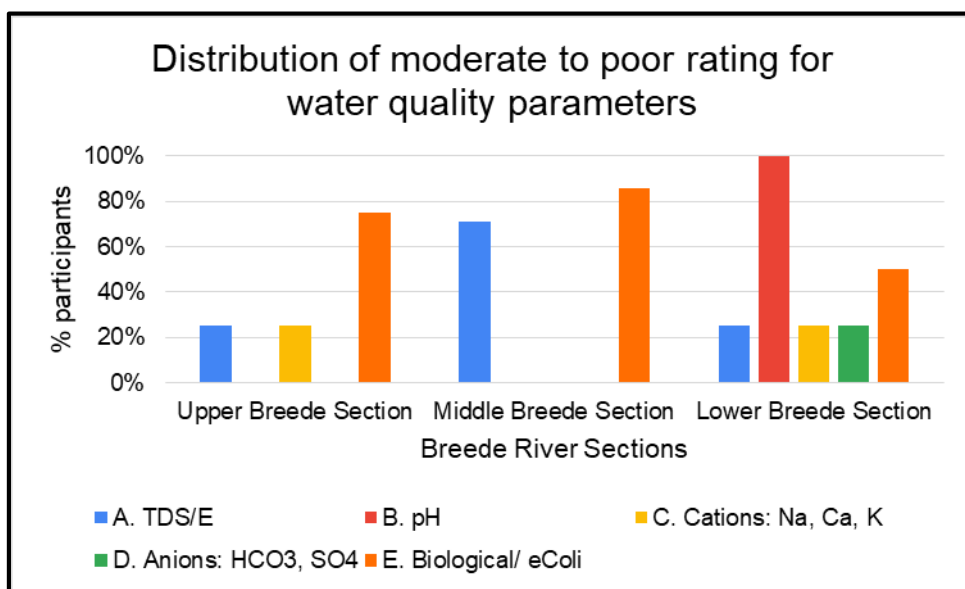


Figure 4-30: Distribution of Farmers' opinion on the main water quality parameter of concern across the Breede River sections (QC5E/QC5F).

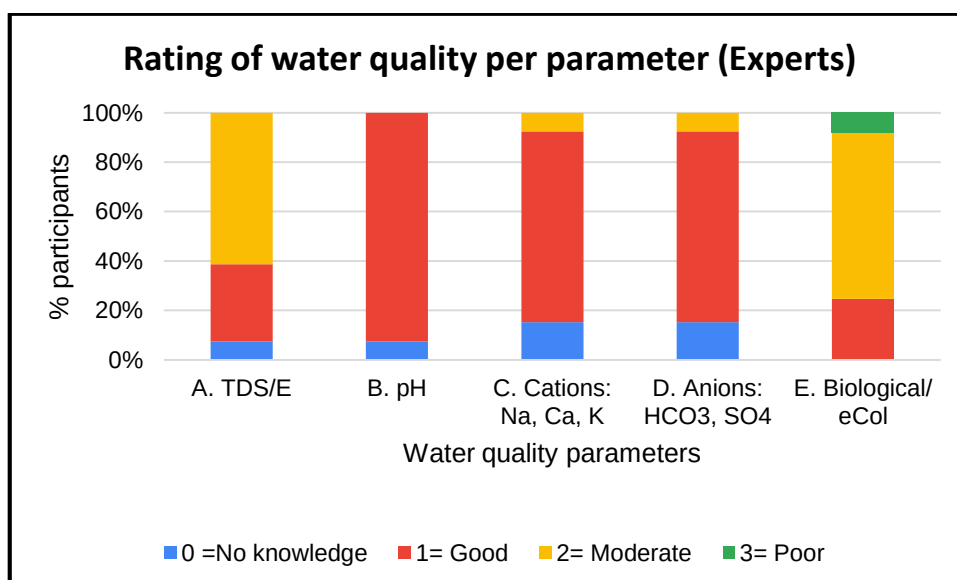


Figure 4-31: Distribution of Experts' opinion on the main water quality parameter of concern in the Breede River catchment (QC4E).

Under “Other” they listed the following: Fe, Mn, heavy metals, hormones, solid waste (plastics etc.) (QC4E/QC4F). These findings are supported by reports of poor water quality related to natural salinity (EC) in the Middle Breede River section as well as biological contamination across different sections of the Breede River related to the WWTW in the catchment (Murray, Biesenbach and Badenhorst Inc. 1989; Kirchner *et al.* 1997; DWAF, 2003; Cullis *et al.*, 2018).

When asked to rate the water quality in the Breede River catchment since the year 2000 the majority of Farmers (60%) indicated that the water quality declined over the past 20 years (QC6E/QC6F) (Figure 4-32 and Figure 4-33). However, the majority (75%) of Farmers in the Upper Breede River section were of the opinion that there was no change in the water quality over this period (Figure 4-33). *E.coli* and TDS/EC were selected by most Farmers as the parameter(s) which showed the most deterioration. When asked the same question the majority of Experts (69%) indicated that the water quality did not change over the past 20 years with 15% indicating that the water quality declined and a further 15% suggesting that it improved (Figure 4-34). The Experts group indicated that TDS/EC (62%) and *E.coli* (39%) were the parameter(s) which showed the most deterioration with pH (31%) and anions (31%) those that showed the least deterioration (QC7E).

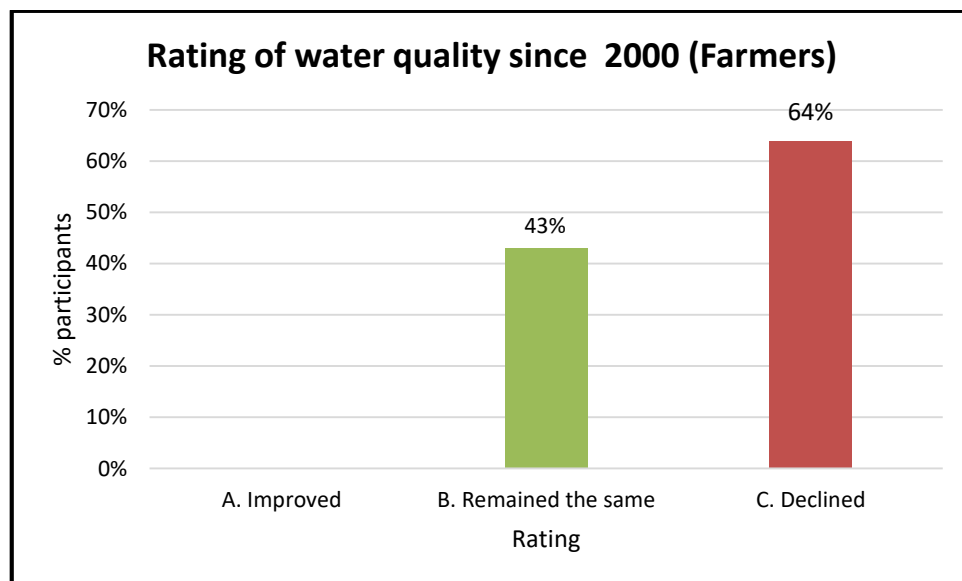


Figure 4-32: Distribution of Farmers’ opinion on the changes in water quality in the Breede River catchment (QC6E/QC6F).

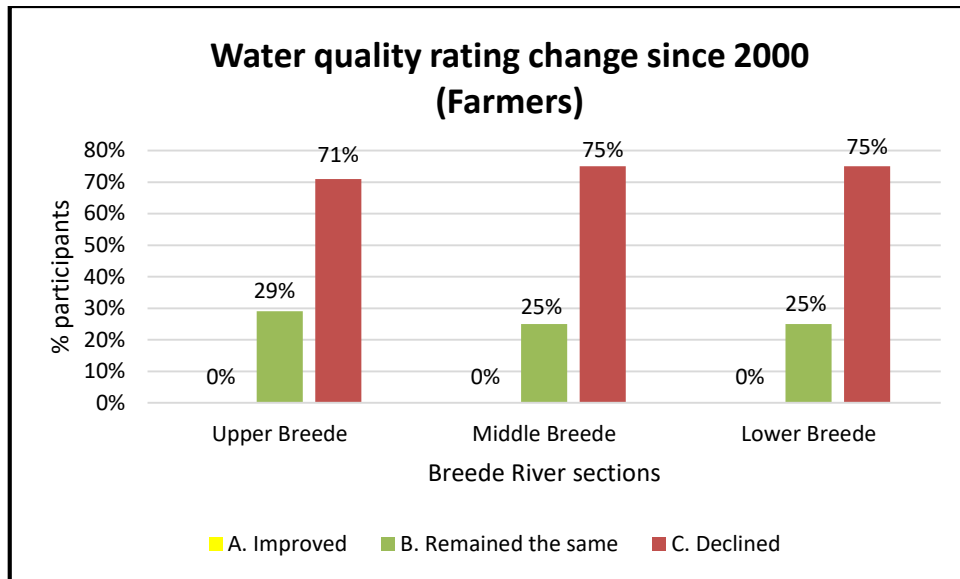


Figure 4-33: Distribution of Farmers' opinion on the changes in water quality across categories per Breede River section (QC6E/QC6F).

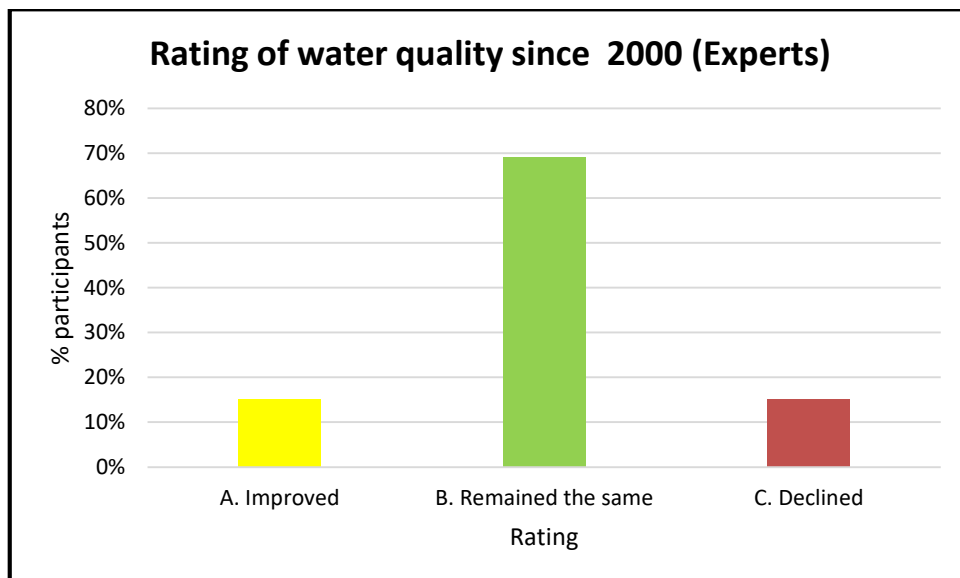
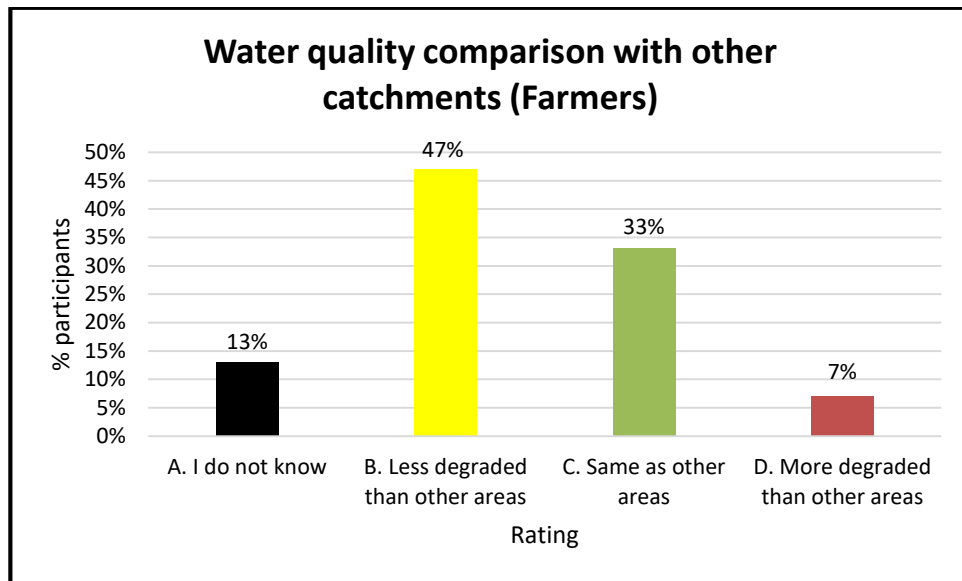


Figure 4-34: Distribution of Experts' opinion on the changes in water quality in the Breede River catchment (QC6E/QC6F).

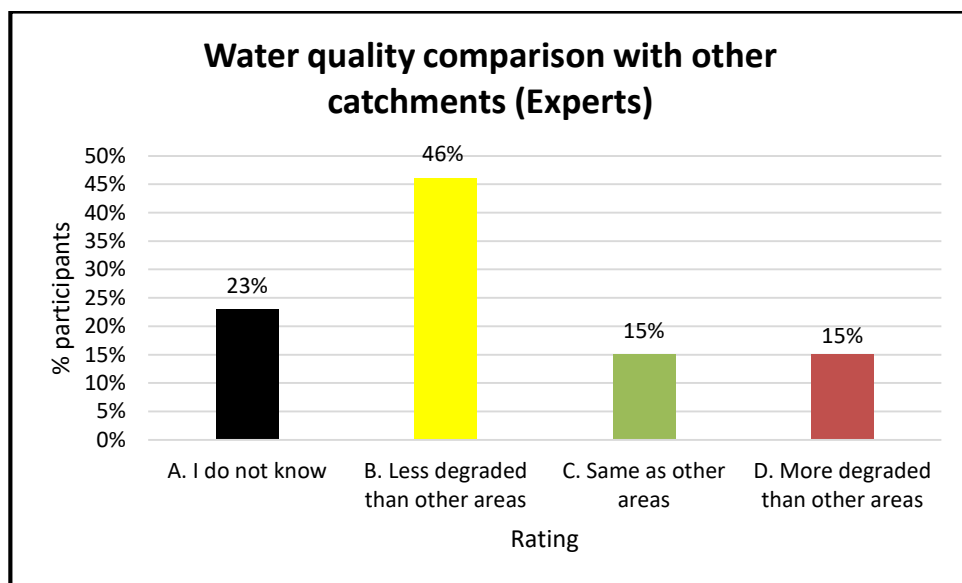
The intention behind the inclusion of this detail was to determine the participant's perception of the water quality in the catchment without providing them with water quality data. Based on the research findings the majority of participants perceived that there is a water quality concern

related to salinity and *E.coli* which were confirmed by the re-evaluation of the water quality in the catchment presented earlier in section 4.2.

When asked to rate the water quality of the Breede River catchment compared to other catchments most participants selected the Berg River as a comparison with the Breede River (QC9E/QC8F). The majority of Farmers (47%) and Experts (46%) opined that the water quality of the BGWMA was less degraded compared to other catchments (Figure 4-35).



(a)



(b)

Figure 4-35: Distribution of (a) Farmers' and (b) Experts' opinion on the level of water quality degradation in the Breede River catchment compared to other similar catchments (QC9E/QC8F).

A water quality study on various South Africa catchments showed that many rivers in intensely farmed agricultural areas in the Western Cape and central interior (Vaal-Harts area) showed increased salination as a result of the impact of agriculture (Van Rensburg *et al.*, 2011). This study showed deterioration of the Berg and Breede Rivers with respect to salinity. With the exception of the tributaries and parts of the lower Breede River, the salinity of these rivers were comparable, which supports the findings of the opinions of Farmers and Experts presented here.

The majority of Farmers (93%) agreed that the water quality meets requirements for the crops cultivated in 2000 compared to 80% agreeing that the water still meets requirements for crops in 2020 (QC9F) (Figure 4-36). Almost half (53%) of the Farmers interviewed indicated that water quality for irrigation purposes in the Breede River catchment meets requirements of the market (QC10F). When asked to elaborate on the water quality parameters of concern to the crops cultivated and the market requirements the majority of Farmers indicated a concern about the *E.coli* and salinity levels of water for irrigation purposes (QC9F) (Figure 4-37).

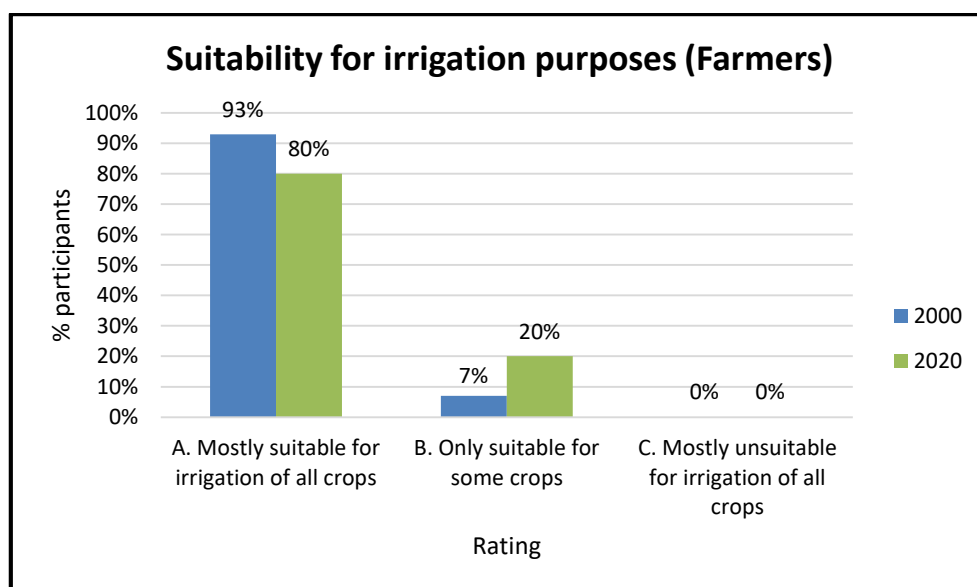


Figure 4-36: Distribution of Farmers' opinion on the suitability of water for irrigation purposes in the Breede River catchment (QC9F).

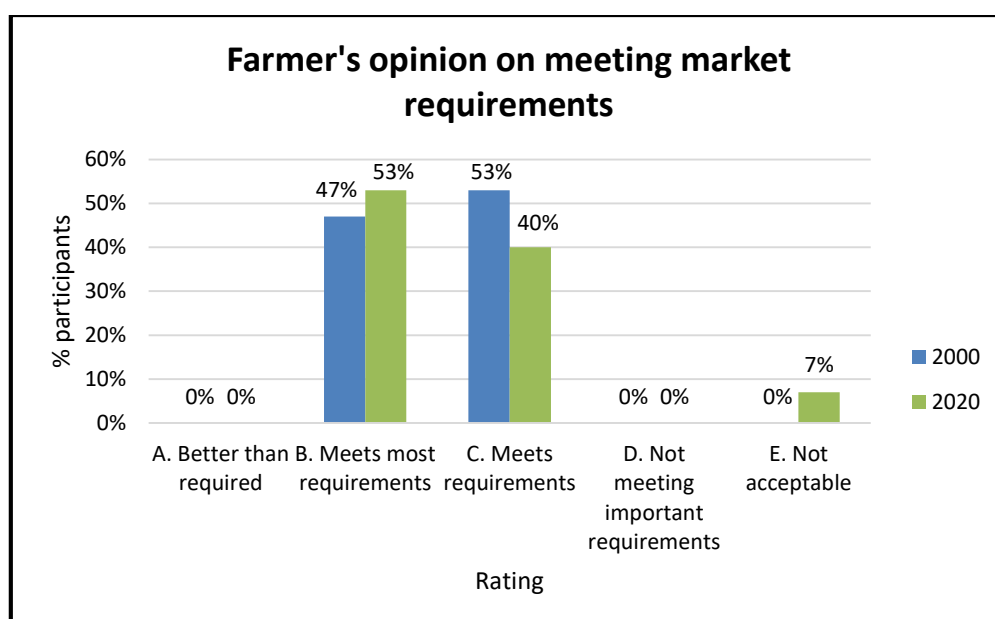


Figure 4-37: Distribution of Farmers' opinion on irrigation water quality requirements of the market in 2000 and 2020 (QC10F).

However, they did not base this concern on data but what they voiced were purely concerns based on the perceptions that most municipal WWTW in South Africa were dysfunctional and that this would negatively impact on the international markets. These perceptions are not unfounded as highlighted in section 2.8. The poor operation and maintenance of WWTW throughout South Africa were point out as a cause for concern due to the large pollution contribution thereof on surface water resources (Mema, 2010). The concerns include human health impacts as well as high nutrient load and algae blooms. Although Experts were not as familiar with the requirements of the various crops and markets the majority (85%) opined that the water in the Breede River was suitable for irrigation of all crops (Figure 4-37) (QC10E).

Farmers were asked to indicate if in their opinion the water quality in the catchment has an impact on irrigation system maintenance (QB11F). The majority of Farmers (10 out of the 14 irrigation Farmers - 71%) indicated that in their opinion the water quality in the catchment did have an impact on irrigation system maintenance (Figure 4-38). However, Farmers could not provide details from their records related to the expenditure on irrigation system maintenance and repairs related to water quality between 2000 and 2020. Nevertheless, the majority of Farmers indicated that this expenditure made up less than 1% of total irrigation costs. They did indicate that although the maintenance cost was not high, the task of maintaining the irrigation system was more time consuming during late summer low flow periods. This is due to silt, algae etc. clogging the filters

installed to prevent damage to the irrigation infrastructure. The intervals between flushing the filters increase from the usual once per day to four or five times per day in the late summer.

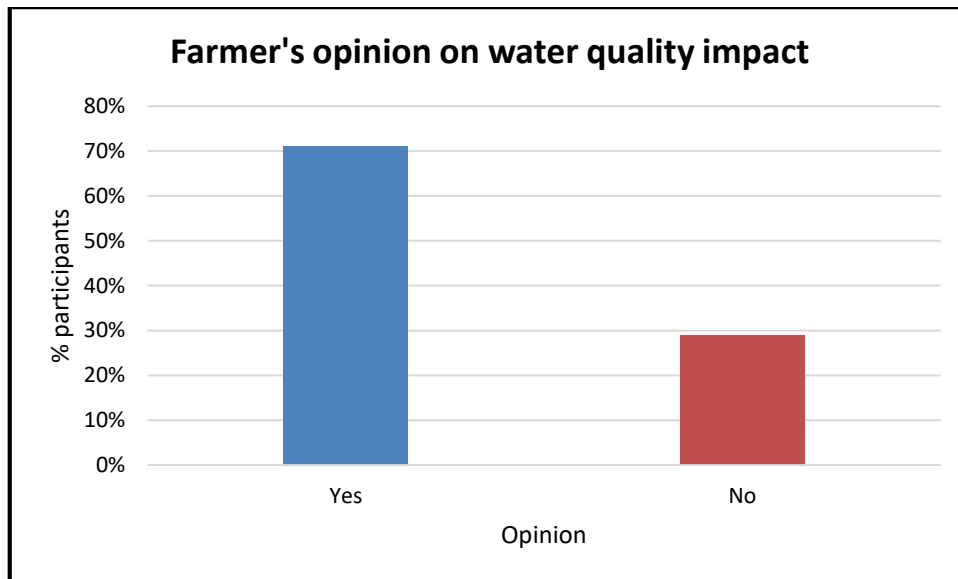


Figure 4-38: Distribution of Farmers' opinion on water quality impact on irrigation system maintenance (QB11F).

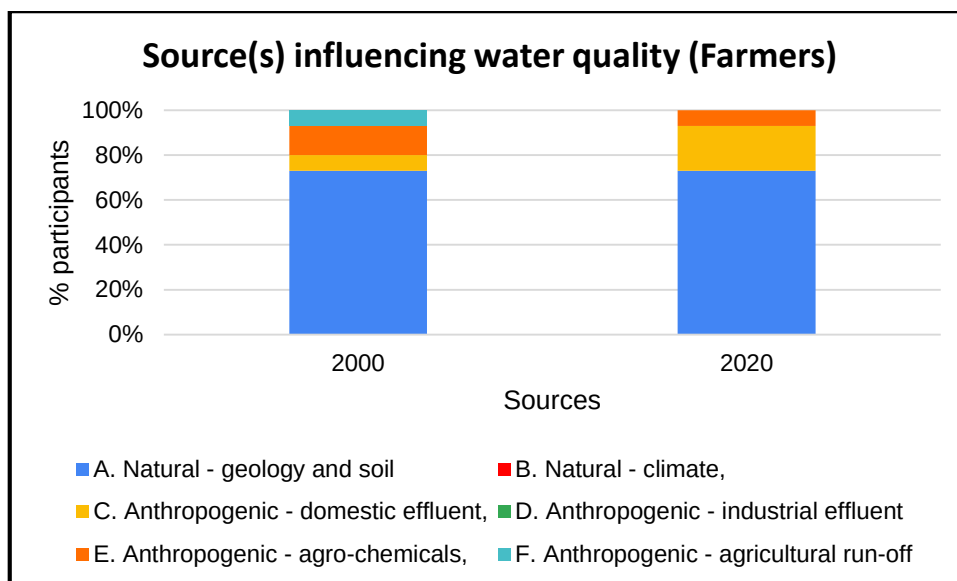
Farmers all indicated that although the cost of maintenance due to water quality concerns are not high, regular maintenance of the irrigation system was key in preventing costly replacement if this is not done. The algae growth is linked to nutrient ($\text{NO}_2^- + \text{NO}_3^-$ and PO_4^{2-}) levels which were shown to be high, especially during late summer periods. Cullis *et al.* (2018) also highlighted the high nutrient levels along the full length of the Breede River.

Farmers in the Lower Breede River section of the catchment indicated that the natural lower pH of water from mountain streams impacted on metal parts of the irrigation system. Corrosion of the irrigation system is countered by neutralising the pH in the holding dams and tanks before it is pumped through the irrigation system.

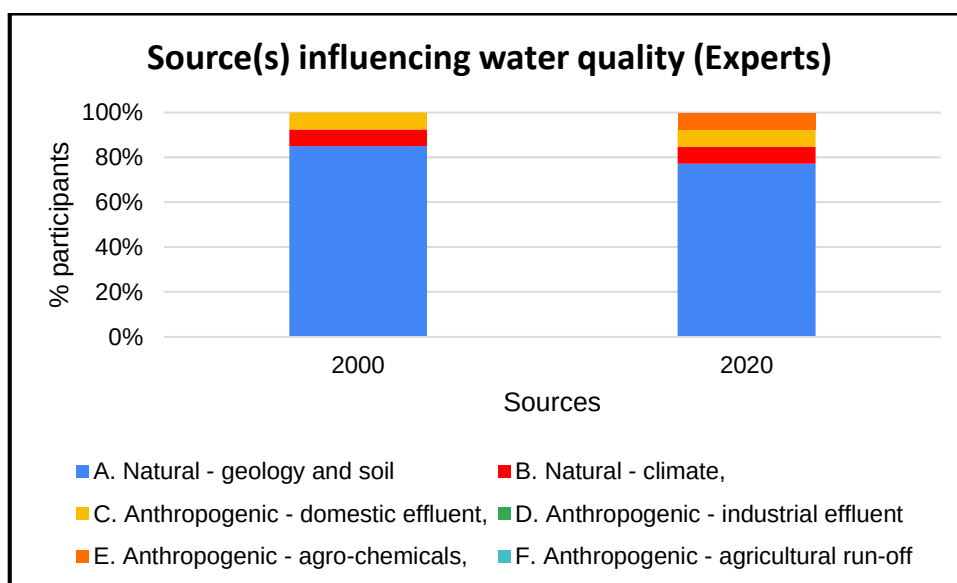
4.3.3.3 Origin/ source(s) which influence the water quality (QC8E/QC7F)

When asked to highlight the origin/ source(s) (natural and/or anthropogenic) which influenced the water quality in the Breede River catchment between 2000 and 2020 (QC8E/QC7F) Farmers found it difficult to separate the concept of general water quality and impacted water quality. The

majority of Farmers (73%) acknowledged natural sources such as the underlying geology and soil as the main source impacting the water quality between 2000 and 2020 (Figure 4-39).



(a)



(b)

Figure 4-39: Distribution of (a) Farmers' and (b) Experts opinion on the sources/ origin which impacted water quality from the BGWMA between 2000 and 2020 (QC8E/QC7F).

Anthropogenic sources such as domestic effluent (7% in 2000 and 20% in 2020), agro-chemicals (13% in 2000 and 7% in 2020) and agricultural effluent/ run-off (7% in 2000) were acknowledged

as the dominant source by Farmers, mainly in the Upper Breede River section. Most Farmers did not acknowledge the agro-chemicals as a potential source which may impact on the water quality as they feel Farmers have become more responsible with the application of these chemicals in recent years through changes in the irrigation regime and generally farming more scientifically whereby over-dosing with agro-chemicals have ceased.

The Expert group were more knowledgeable with respect to the link between the underlying geology and soil as well as the potential impact climate had on the water quality in general (QC8E/QC7F) (Figure 4-39). The Experts acknowledged the underlying geology and soil (85% in 2000 and 77% in 2020) as the main source impacting the water quality with minor sources including climate, domestic effluent and agro-chemicals (Figure 4-39). The water quality results in section 4.2 confirmed that the underlying geology is an important contributor to the water quality, especially the increased salinity detected. However, the contribution by anthropogenic activities were also highlighted from the water quality data interpretation. These findings will be unpacked further as drivers for water quality concerns.

In most instances no additional source was mentioned by those interviewed. The only additional source mentioned by two Farmers of the Lower Breede River section were the impact of vegetation on the pH. In the Lower Breede River section the vegetation lowers the pH in the mountain streams and tributaries to a pH of around 3 (see section 4.2.3). Although participants did not have a strong opinion on industrial effluent as a source, mention was made of potential concerns related to some industrial activities which did impact the water quality in the past. Water users and their potential impacts on the water quality was highlighted in section 2.6.

4.3.3.4 Availability of water in the Breede River catchment (QC11E/QC11F)

Farmers and Experts were asked to elaborate on the availability of water in the Breede River catchment since the year 2000 (QC11E/QC11F). The majority of Farmers (67%) and Experts (46%) indicated that there was no difference in the availability of water in the Breede River catchment over the past 20 years (Figure 4-40). However, some Farmers (33%) and Experts (46%) did indicate that they are concerned about the decline in available water especially during prolonged droughts and during late summer when the flow in the river is low (see section 4.3.2.2).

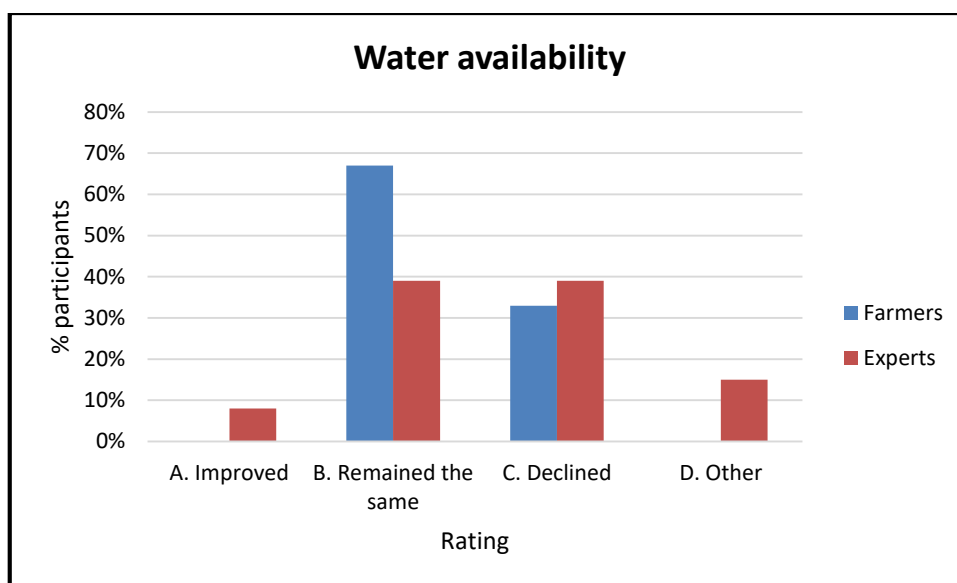


Figure 4-40: Distribution of Farmers' and Experts opinion on (QC11E/QC11F).

These concerns are related to the impact that the decline in volume has on the water quality due to the increased salt concentrations in surface-streams. This was also related to the lack of dilution of the high salt load built up in the river when the inflow of tributaries are also low.

Only one Expert (1 of 13) indicated that the availability of water in the Breede River catchment improved since the year 2000 (REF _Ref85608973 \h Figure 4-40). This was based on the fact that alien plant species, which are known to use more water than indigenous species, were cleared and presumably more water becomes available in the surface streams.

The allocation of additional water is a challenge which requires validation and verification of the water that is already allocated in the catchment. However, before additional water can be allocated it is important to determine: (1) how much more water is available from a specific water resource in the catchment to be allocated, and (2) the most beneficial use of that water (Ncube, 2018). Additionally, BGCMA are required to redress social inequalities through water resource allocations to emerging black farmers in the catchment (BGCMA, 2017a; Ncube, 2018). Emerging farmers are stakeholders in BGCMA and top of the priority list in terms of water allocation (BGCMA, 2017a; Ncube, 2018).

4.3.3.5 Management actions (QC12E/QC12F)

Farmers were asked to elaborate on management actions taken in response to water quality and availability concerns/ challenges in the Breede River catchment between 2000 and 2020(QC12E/QC12F). The majority of Farmers (93%) indicated that they have changed the irrigation system to drip and micro-irrigation which uses less water and are also not affected by the potentially elevated *E.coli* levels in the water for irrigation purposes. The second most dominant management actions/ decisions selected by 60% of Farmers as a response to water quality and availability concerns/ challenges in the Breede River catchment were the use of cover crops and mulching to minimise evaporation. Only a few of the Farmers interviewed indicated that they used netting and that the minimisation of evaporation by netting was not the main purpose of the netting but rather seen as an additional benefit. Other management actions/ decisions listed included the following:

- Implementation of scientific instruments such as continuous soil moisture measurement allowing for more efficient irrigation and optimal water use; and
- Scheduling of irrigation –i.e. in evenings when electricity is cheaper for operating pumps and less evaporation occurs.

However, Farmers in the Lower Breede River section indicated that they still make use of overhead irrigation systems for pastures as there is currently no alternative technology available for these crops.

When Experts were asked to elaborate on management actions taken in response to water quality and availability concerns/ challenges in the Breede River catchment between 2000 and 2020, the majority (93%) indicated that the change in irrigation type as well as the covering of crop with netting to minimise evaporation (46%) were the most dominant management actions/ decisions taken on farm scale. Other management actions/ decisions listed by Experts included the following:

- Implementation of water treatment systems on farms;
- Upgrade of several municipal WWTW, although many still require attention with occasional incidents still occurring; and
- Removal of alien species in the river courses.

4.3.4 Section D: Key drivers of water quality decline in the Breede River catchment

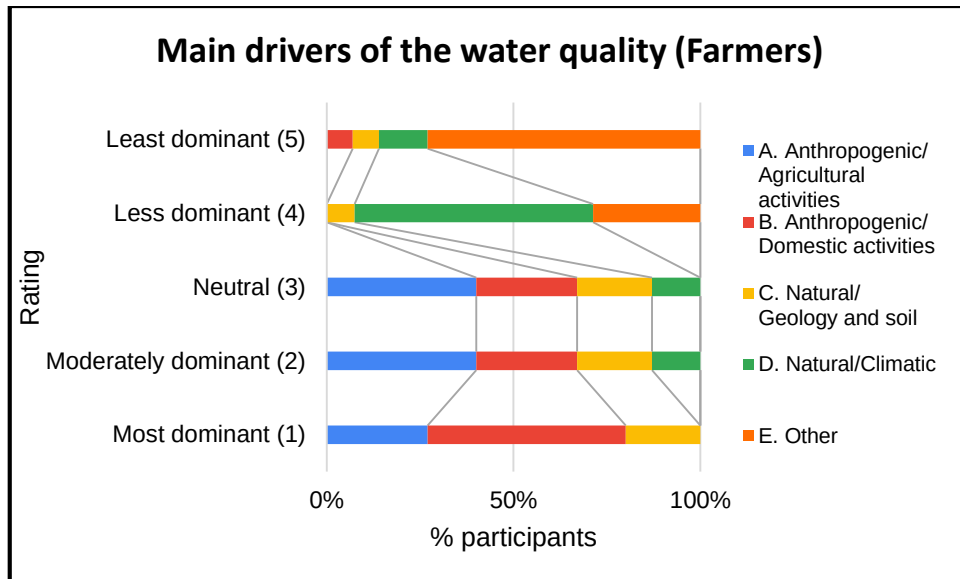
This section was structured according to Section D of the questionnaire which focused on the information gathered relating to the drivers of water quality decline in the Breede River catchment. This section of the results aim to identify the drivers/ stressors with the most substantial effect on the water quality and quantity in the Breede River catchment and consists of a set of eight (8) closed-ended questions each with an associated open-ended question (see Annexure A) and contributes towards addressing Research Objective 2.

In the close-ended questions participants were given the opportunity to rank the main drivers of the water quality in the Breede River by rating their relevance but could also indicate the level of influence the key drivers have on the water quality in the catchment. The open-ended questions provided participants the opportunity of elaborating on their opinion regarding the important key drivers of water quality decline in the Breede River catchment. These responses were important in identification and evaluation of the key drivers. The thematic analysis of responses from the open-ended questions yielded themes which will be discussed here. To assist in streamlining the discussion several questions were combined under an appropriate overarching heading. The relevant questionnaire questions were indicated for easy orientation (Annexure A).

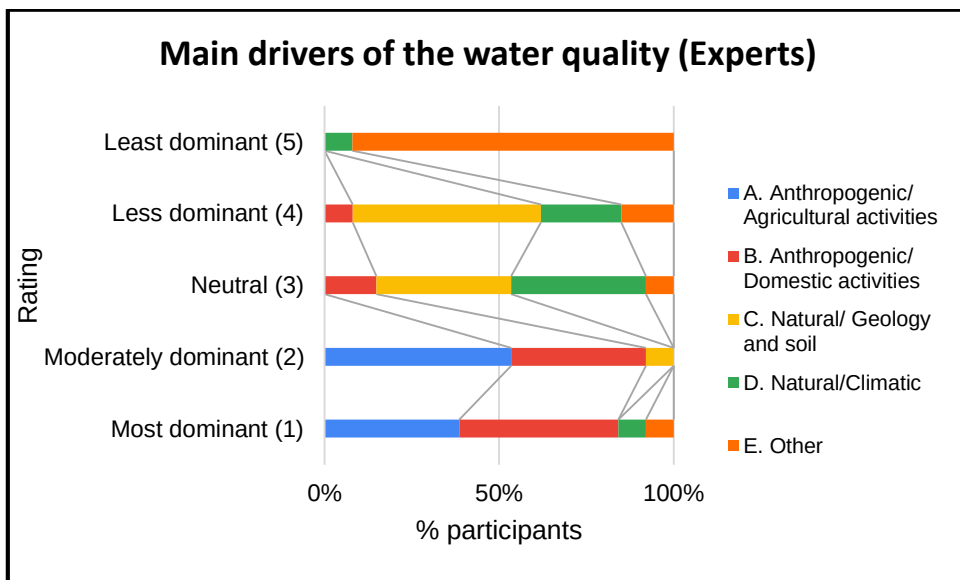
4.3.4.1 Key drivers of the water quality in the Breede River (QD1E/QD1F)

In the first question of Section D (QD1E/QD1F), the Farmers and Experts were asked to indicate the drivers for water quality in the Breede River. The question consisted of a selection of drivers and an open ended section which provided the opportunity to list additional drivers and comment on the perceived drivers.

Participants were asked to rank the most dominant drivers of water quality in the Breede River. The majority (53%) of Farmers indicated the most dominant drivers were anthropogenic/ domestic activities, with agricultural activities (27%), and natural/ geology and soil (20%) as the other main drivers (Figure 4-41a).



(a)



(b)

Figure 4-41: Distribution of the most dominant drivers of the water quality in the Breede River for (a) the Farmers group and (b) the Experts group (QD1E/QD1F).

The second and third most dominant driver indicated by Farmers were anthropogenic/ agricultural activities (40%) with the least dominant driver considered to be climate (60%). Whereas, 54% of Experts selected anthropogenic/ domestic and 39% agricultural activities as the most dominant drivers, geology and soil as well as climate were generally considered to be less dominant drivers (Figure 4-41b).

In the following sections the opinion of participants will be unpacked in a set of closed-ended driver specific questions which required participants to sort the influence of each driver on the water quality in the Breede River catchment into the following categories: (A) Mainly positive influence, (B) Slightly positive influence, (C) No influence, (D) Slightly negative influence and (E) Mainly negative influence (Annexure A). Participants were provided the opportunity of elaborating on their selected rating through an open-ended question. The responses yielded themes presented under each driver.

4.3.4.2 Geology and soil as drivers of water quality (QD7E/QD7F)

The first driver specific question of section D (QD7E/QD7F), aimed at establishing the influence of the underlying geology and soil on the water quality in the Breede River catchment. As discussed earlier in section 2.10, the underlying geology and soil has a strong influence on the elements released into the environment. The majority of Farmers indicated that geology/ soil would have a slightly negative influence (47%) to no influence (33%) on the water quality in the Breede River catchment (Table 4-6). However, 31% of the Experts group were of the opinion that geology/ soil would have no influence on the water quality in the Breede River catchment with the remainder indicating a slightly negative influence (46%) to strong negative (27%) influence (Table 4-6). However, up to 50% of Experts, who indicated that there would be no influence from the underlying geology and soil (31%), acknowledged that they did not have enough knowledge to comment on the potential influence.

As highlighted in section 4.2 the Gibbs diagram showed weathering of rock as the dominant contribution to the high salinity (Na and Cl as well as EC/TDS) which are intensified through the high evaporation rates leading to increased concentration of salts in the surface water but the interaction with the rocks and long residence time also lead to the ground water to become brackish in many parts of the catchment. These findings supports the Farmers opinion on the importance of the underlying geology on the water quality.

The participants were also asked an open-ended question to elaborate on their opinion on the influence of geology/ soil on water quality in the Breede River catchment. The thematic analysis of their responses yielded the following themes:

- Constant natural input which would not change;
- Contribution to salt load;
- Cumulative effect; and

- Manageable influence.

Table 4-6: Summary of opinion of participants on the main drivers/ stressors with the most substantial effect on the water quality (QD7E/QD7F)

	A. Mainly positive influence	B. Slightly positive influence	C. No influence	D. Slightly negative influence	E. Mainly negative influence
Natural drivers					
Geology and soil					
Farmers	0	2	5	7	1
Experts	0	0	4	6	3
Climatic conditions					
Farmers	0	1	3	11	0
Experts	0	0	5	7	1
Anthropogenic drivers					
Growth in agricultural activities					
Farmers	0	0	1	11	3
Experts	0	0	0	11	2
Domestic effluent/ waste water					
Farmers	0	0	2	2	11
Experts	0	0	0	4	9
Population growth					
Farmers	0	0	2	4	9
Experts	0	0	0	7	6
Industrial developments					
Farmers	0	0	7	8	0
Experts	0	0	0	11	2
Cooperative governance					
Farmers	0	0	7	6	2
Experts	2	3	2	4	2

Themes from the Farmers and Experts' comments generally correspond and confirm that there is a strong link between the underlying geology and soil and the salt load in the Breede River. Most Farmers and Experts were in agreement that the underlying geology is a natural input which will remain consistent over time. Comments included: *"Natural high salt in soil from underlying rock - will remain an input"* (F10). Continual leaching of salts from the soil were also considered to be contributing to the salt load and have a cumulative effect as highlighted by the comment: *"where agriculture develop on brackish soil - will wash salts out during irrigation but will increase salt load in Breede River"* (F14). These are in agreement with the findings by Greeff (1990) and Murray Biesenbach and Badenhorst Ing. (1988) that considerable amounts of salt occur in the weathered zone above the Bokkeveld Group sediments along the foothills and valleys which may be leached from the soil and end up in agricultural return flow.

Farmers were of the opinion that the influence of the underlying geology and resulting salt accumulation in the soil can be managed. This is in agreement with Moolman (1999) that proposed the leaching of saline soils in winter periods to avoid the cumulative effect of salinity on the growth in the following season, which will ultimately lead to decreased yield, particularly from grapevines.

4.3.4.3 Climate as drivers of water quality (QD6E/QD6F)

As discussed earlier in section 2.8 climate has an influence on the release of elements into the environment as well as on the rainfall patterns. Farmers were asked to indicate their opinion on the influence of climate on the water quality in the Breede River catchment. In response to QD6E/QD6F the majority of Farmers indicated that climate would have a slightly negative influence (73%) to no influence (20%) on the water quality in the Breede River catchment (Table 4-6). However, 39% of the Experts group were of the opinion that climate would have no influence on the water quality in the Breede River catchment with the remainder indicating a slightly negative influence (54%) to strong negative (8%) influence (Table 4-6).

The participants were also asked to elaborate on their opinion on the influence of climate on water quality in the Breede River catchment in an open-ended question. The thematic analysis of their responses yielded the following themes:

- Natural seasonal variations, drought cycles and dilution rates;
- Winter rainfall flush system; and
- Rainfall patterns change.

Themes from the Farmers and Experts' comments generally correspond and confirm that there is a strong link between the underlying geology and soil as well as the salt load in the Breede River. Comments included: "*Seasonal impact - low flow during summer when most water is extracted for irrigation - decline as no dilution can occur*" (F8). However, during winter rainfall periods the salinity is diluted as suggested by this comment: "*Seasonal impact - low flow during summer when most water is extracted for irrigation - decline as no dilution can occur but all pollutants flushed in winter rainy season*" (F8). The natural seasonal variation and drought cycles impacted the water quality but as suggested by the comment: "*No clear evidence, climate cycles in my opinion best describe impact*" (E8) suggesting that there is no indication that the salinity in the Breede River will become worse.

The high evaporation rate in the study area (see section 2.8) in the study area, which is essentially an arid region, contributes to the increased concentration of salts in water resources. The potential future scenarios under climate change is predicted to worsen the water availability and therefore the quality as the Western Cape is predicted to become warmer and drier (WWF, 2018).

4.3.4.4 Anthropogenic: growth in agricultural activities as drivers of water quality (QD3E/QD3F)

As discussed earlier in section 4.2, growth in agricultural activities has an influence on the release of elements into the environment through the flushing out of elements from agricultural soils which will filter through to the surface water resources through return flow from agricultural areas. In response to QD3E/QD3F in the questionnaire, Farmers were asked to indicate their opinion on the influence of growth in agricultural activities on the water quality in the Breede River catchment. The majority of Farmers indicated that growth in agricultural activities would have a slightly negative influence (73%) to strong negative influence (20%) on the water quality in the Breede River catchment (Table 4-6). However, 85% of the Experts group opined that growth in agricultural activities would have a slightly negative influence on the water quality in the Breede River catchment with the remainder indicating (15%) strong negative influence (Table 4-6).

The participants were also asked in an open-ended question to elaborate on their opinion on the influence growth in agricultural activities has on water quality in the Breede River catchment. The thematic analysis of their responses yielded the following themes:

- Agro chemical;
- Agricultural return flow;
- Available water;
- Link to population growth;
- Flushing salt from virgin land;
- Poultry and dairy farm effluent; and
- Link to environmental impacts.

Themes from the Farmers and Experts' comments generally correspond and support the perception that growth in agricultural activities increase the salt load in the Breede River. Expansion of agriculture/ growth in agricultural activities from a largely dry land pasture agriculture pre-1960 changed to wine grape in middle Breede and Breedekloof part of the upper Breede River. After the building of the Brandvlei Dam, expansion into summer crops i.e. wine and table

grapes increased as the irrigation dam made it possible to build-up enough water in the winter rainfall period that can now be used in summer. In late summer the build-up of salts in the Breede River and canal due to return flow from agriculture is diluted by releasing water from the Brandvlei Dam. The influence of agriculture on the water quality is also related to the expansion of agricultural land where virgin land, where salts need to be flushed out of the soil in areas underlain by the Bokkeveld Shale especially in the Middle Breede River section, is developed. As highlighted in section 2.8 the high salt concentrations in the agricultural return flow has been the focus of several studies in the past (Murray, Biesenbach & Badenhorst, 1989; Kirchner *et al.*, 1997). Furthermore, the practice of disposal of winery waste water without treatment may also have a detrimental impact on the water resource through seepage of contaminants to water resources (Van Schoor; Howell, 2016). Should agricultural activities expand, the contribution from these potential sources would also increase.

Expected increased agriculture is directly linked to an expected increase in the use of agro-chemicals leaching into the river and canals due to return flow washing excess chemicals not used by the plant into the river and canal. But as irrigation changed to more direct irrigation at the plant roots and farming lately being more scientific/ being precision farming, less agro-chemicals are used, i.e. only apply when and where plant can take up the fertilizer, therefore less ending up in return flow into the river or canals. Most Farmers are of the opinion that there is a shift towards farming more scientifically in the younger generation. Most Farmers indicated that they are farming more responsibly by trying best not to affect their neighbours and the environment they depend on by not polluting the river. Pesticides and herbicides are also applied more responsibly by only applying what is required and no longer spraying in general but focused where there are problems.

Comments from Farmers included the potential increased impact of leached salt and agro-chemicals on the water resource: *“No matter how careful one is there is always a possibility of some agro-chemicals ending up in the river due to agricultural run-off”* (F4) and *“As agriculture grows more surface area from which return flow with high salt will flow to river”* (F6). The view by Farmers were supported by the Experts that commented that the growth in agricultural activity was: *“Potentially an important driver as the entire area under irrigation leaches salts into the river”* (E5) and the fact that: *“return flow water is canalised to the canal and rivers taking with it salts but also fertilizer not utilised by the plants”* (E4) that with: *“increase in the agricultural activities the return flow will increase and with that the amount of material washed into the river”* (E4). The cumulative effect of return flow water will have a: *“short term water quality decline as more land*

is developed will release more salts into river until most are leached out, thereafter improves” (E11).

The link between growth in agricultural activities and population growth was also highlighted: *“Indirect impact due to the growth leading to more people moving into the area - increased population require increase in WWTW capacity which is not done” (F13).* There is also a perception held by Farmers that: *“As more farms are developed (additional 500 ha) the volume of water available declines, which has a negative impact on the established farms and their livelihoods” (F7).* Impacts from agricultural growth on the environment was also listed as a concern: *“If not correctly managed, encroachment of agricultural lands into riparian areas, erosion, sedimentation, agricultural return flows / run-off etc. would mainly have a negative influence on the river” (E7).*

4.3.4.5 Anthropogenic: domestic activities as drivers of water quality (QD5E/QD5F)

As discussed earlier in section 4.2.4 and 4.3.3.3 the influence domestic effluent/ waste water has on water quality. In response to QD5E/QD5F in the questionnaire, Farmers were asked to indicate their opinion on the influence of domestic effluent/ waste water on the water quality in the Breede River catchment. The majority of Farmers indicated that domestic effluent/ waste water would have a strongly negative influence (73%) to slightly negative influence (13%) on the water quality in the Breede River catchment (Table 4-6). However, 69% of the Experts group were of the opinion that domestic effluent/ waste water would have a strong negative influence on the water quality in the Breede River catchment with the remainder indicating a slightly negative influence (31%) (Table 4-6).

The participants were also asked in an open-ended question to elaborate on their opinion on the influence of domestic effluent/ waste water on water quality in the Breede River catchment. The thematic analysis of their responses yielded the following themes:

- WWTW capacity and domestic effluent management; and
- Un-serviced urban areas.

Themes from the Farmers and Experts’ comments generally correspond and support the perception that domestic activities impact the water quality in the Breede River. Comments were mainly related to the potential microbiological contamination from domestic effluent: *“Increased population - pressure on WWTW, not all areas serviced - relate to decline in water quality due to sanitation and solid waste impact on rivers” (F14)* and *“WWTW under pressure - further growth*

in towns place more pressure” (F15). Municipal WWTW not functioning optimally was not the only concern as is evident in the comment: “Effluent from informal settlements seen as a potential negative impact” (E11). Experts and Farmers were in agreement that there is a concern regarding the potential water quality impact as is described in the comments: “More effluent from WWTW not being managed properly is a potential driver to decline in water quality” (E5) and “WWTW not maintained is an important driver for decline in water quality” (F8).

The perceptions by Farmers that WWTW were not functioning optimally are supported by the evaluation of the microbiological water quality (section 4.2.4) which showed the TWQR for irrigation and BGWMA RQO limits (based on the Coliform and *E. coli*) were exceeded at the majority of the stations. Despite previous studies showing that the level of microbiological compliance of most WWTW improved between 2010 and 2018 (CWDM, 2010; WCG, 2017; Cullis *et al.*, 2018), some stations downstream from Rawsonville and Worcester still recorded alarmingly high microbiological contamination levels in late summer/ early autumn when the flow in the streams were low with lower values generally coinciding with winter rainfall periods.

4.3.4.6 Population growth as drivers of water quality (QD2E/QD2F)

This section is directly linked to section 4.3.4.5 (Anthropogenic: domestic activities as drivers of water quality) and indirectly to section 4.3.4.4 (Anthropogenic: growth in agricultural activities as drivers of water quality). As discussed earlier in section 4.3.3.3 the influence domestic effluent/ waste water has on the water quality is linked to the growth in population in urban areas. In response to QD2E/QD2F in the questionnaire, Farmers were asked to indicate their opinion on the influence of population growth on the water quality in the Breede River catchment. The majority of Farmers indicated that population growth would have a strong negative influence (60%) to slightly negative influence (26%) on the water quality in the Breede River catchment (Table 4-6). However, 54% of the Experts group opined that growth in population would have a slightly negative influence on the water quality in the Breede River catchment with the remainder indicating (46%) a strong negative influence (Table 4-6). Grey water runoff from informal areas is of concern and considered to be a growing contributor to downstream water quality risks, particularly with regards to microbial concentrations and both total coliforms as well as *E. coli* concentrations.

Economic growth was also mirrored by the population growth in the CWDM and relevant local municipalities. The average municipal population growth from 2011 to 2016 along the Breede River section of BGWMA is estimated at 2.4%, which resulted in household (formal and informal

housing) growth of 5.6% (WCG, 2017; CWDM, 2019). However, Pegram and Baleta (2014) indicated that despite the high employment rate in the agricultural sector, the nature of the employments, i.e. seasonal, semi-skilled or unskilled, workers might still be reliant on the State for basic needs due to the low income earned at these job levels. Population growth generally relate to growth in urban areas including the expansion of informal settlements, where governments already struggle to deliver basic services (water supply, sanitation and formal housing) due to the rapid increase in demand (Cullis *et al.*, 2018). Cullis *et al.* (2018) suggested that there is a link between urbanisation and the degradation of environmental quality. Land use transformations due to rapid urbanization and industrialization generally have a negative impact on river water resource quality (Cullis *et al.*, 2018). The negative impact on river water quality is expected to have a substantial negative economic impact on communities which are dependent on these rivers, particularly agricultural activities (WCG, 2017).

Although Cullis *et al.* (2005) identified urban and peri-urban as non-point-sources of pollution, their impacts are considered smaller as compared to agricultural non-point-source pollution. However, many of these settlements are located next to streams and irrigation canals. In some instances household refuse are dumped into storm water ditches, some areas are also used as toilets. During high rainfall periods the material is washed into the rivers.

The participants were also asked in an open-ended question to elaborate on their opinion on the influence of growth in population on water quality in the Breede River catchment. The thematic analysis of their responses yielded the following themes:

- Increased pollution load;
- Informal settlements;
- Pressure on WWTW;
- Link to agriculture; and
- Link to environment.

Themes from the Farmers and Experts' comments generally correspond and support the perception that growth in urban areas and by implication, population growth, impact the water quality in the Breede River. Most Farmers identified WWTW as a concern as those dependent on the Breede River and irrigation canals for irrigation are concerned that there is a real risk that elevated *E. coli* in water for irrigation purposes might have an impact on their products and the markets they deliver their products to. Many Farmers acknowledged that they did not know what the microbiological water quality in the irrigation water along the Breede River was, the perception

exists that there is reason for concern due to the general perception that all WWTW in South Africa are not functioning optimally. These perceptions were not completely unfounded as was shown in section 2.4.2 which showed that the level of compliance of WWTW for Worcester, Ceres and Wolseley were generally high (based on previous studies: CWDM, 2010; WCG, 2017; Cullis *et al.*, 2018), however the *E. coli* levels since 2018 did not reflect this improvement at most downstream stations. Of concern were the low levels of compliance to the microbiological standards reported for Robertson (CWDM, 2010; Cullis *et al.*, 2018).

However, most Farmers were concerned about the potential damage to the market due to the perception that WWTW are not functioning optimally. Farmers not dependent on the main Breede River and generally receiving water from tributaries considered to be of high quality as they do not pass urban areas has also mentioned occasional elevated *E. coli* levels which they relate to campsites and animals, such as baboon, faeces. Comments by both Farmers and Experts are linked to the pressure on the WWTW and growing informal settlements which are not linked to the municipal WWTW. Comments include: *“Increase in informal settlements in all towns is of concern - mainly not serviced and along river - contribute to pollution (E.coli and solid waste)”* (F10), *“Infrastructure of WWTW of municipalities are not maintained properly and impacts on water quality downstream - as population increase puts more pressure on infrastructure”* (F8), *“Population growth will put pressure on WWTW and negatively affect water quality downstream of WWTW when not managed properly”* (E10), and *“Informal areas on the river banks and next to irrigation canals grow and the illegal dumping continues”* (E6).

The linkage between agricultural growth and the general population growth has been discussed in section 4.3.4.4. However, this linkage was also highlighted here in comments such as: *“Systematic increase in population as crop type changed from wine grape which is mainly machine operated harvesting to fruit which is labour intensive”* (F9) and *“Growth in agriculture around Middle Breede - move towards citrus which is more labour intensive - more people move to the towns - increase in informal settlements not serviced by municipalities”* (F13). However, the growth in population was not reflected in the number of workers on the farms which only showed slight shifts in the number of permanent and seasonal workers between 2000 and 2020 (Figure 4-42 and Figure 4-43). It is however, reflected in the population growth rate of the Breede Valley (2.42), Langeberg (2.51) and Witzenberg (3.16) local municipalities (see section 2.5).

Farmers indicated that the number of permanent employees living on the farm or nearby urban to peri-urban areas range mostly between 1 and 25 with 13% in the <10 employee and 53% in the 10-25 employee category (Figure 4-42). Only in two instances did the number of permanent

employees exceed 50. The seasonal employees were almost equally distributed between the categories in Figure 4-43. Although the majority of Farmers indicated that the number of seasonal employees was less than 100 there were 3 instances where the number exceeded 100.

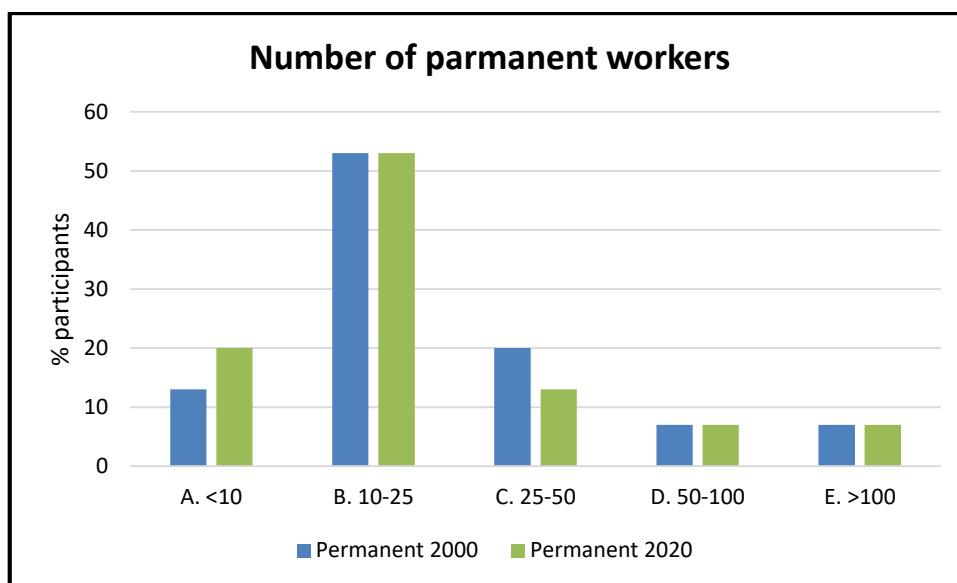


Figure 4-42: Number of permanent workers for 2000 and 2020.

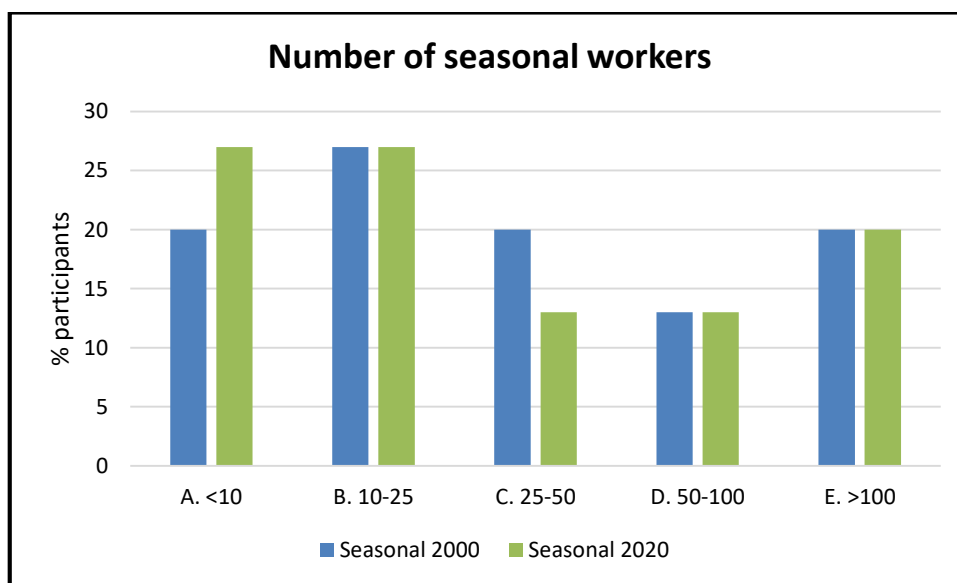


Figure 4-43: Number of seasonal workers for 2000 and 2020.

4.3.4.7 Industrial developments as drivers of water quality (QD4E/QD4F)

A problem area identified by many participants is the so-called Solamoyo site, being a treatment plant for several distillery companies in Worcester where a spray evaporation system was used to aerate and evaporate process water in close proximity to an urban area and run-off identified as a pollution source feeding into the Breede River. In response to QD4E/QD4F in the questionnaire, Farmers were asked to indicate their opinion on the influence of industrial developments on the water quality in the Breede River catchment. The majority of Farmers indicated that industrial developments would have a strong negative influence (53%) to no influence (47%) on the water quality in the Breede River catchment (Table 4-6). However, 85% of the Experts group were of the opinion that industrial developments would have a slightly negative influence on the water quality in the Breede River catchment with the remainder indicating (15%) strong negative influence (Table 4-6).

The participants were also asked in an open-ended question to elaborate on their opinion on the influence of industrial developments on water quality in the Breede River catchment. The thematic analysis of their responses yielded the following themes:

- Agricultural related industries;
- Decline in water quality, and
- Lack of large industries.

Themes from the Farmers and Experts' comments generally correspond and support the perception that industrial activities impact the water quality in the Breede River. As shown in section 2.5 agriculture is the main primary industry in the study area and most secondary and tertiary industries are all related to agriculture. It is therefore expected that growth in the agricultural industry will be mirrored by the growth of associated industries. Any growth would suggest a potential increase in water contamination. However, as highlighted by the comments self-regulation and adherence to water use license conditions are designed to prevent the decline in water quality. Comments include: *"Wineries and fruit packaging facilities are also strictly regulated and require audits regularly; therefore do not consider them as a major polluter"* (F4), *"Industries are required to adhere to legal water quality requirements that prescribes quality of water released to the river and to add chemicals to remove certain contaminants / i.e. treatment before releasing water to the river"* (F6).

Although *"wine cellars are regulated by DWS which includes monitoring water quality from their treatment plants"* (E6), these plants are seen as *"an additional expense by most cellars and they*

will only spend the funds to construct a plant when forced to do so as it is seen as an expense with no return of investment to increase profit” (E6). The potential impact of the lack of regular water quality monitoring in the Breede River has also been highlighted in the comment: *“A few large industries upstream may impact on water quality but because it is not monitored not possible to verify which industry is adding what to the general water quality along the path” (F13).*

4.3.4.8 Cooperative governance as drivers of water quality (QD8E/QD8F)

The role players involved in water management in the study area were discussed in section 2.3. In response to QD8E/QD8F in the questionnaire, Farmers were asked to indicate their opinion on the influence of cooperative governance on the water quality in the Breede River catchment. The majority of Farmers indicated that cooperative governance would have no influence (47%) to a slightly negative influence (40%) on the water quality in the Breede River catchment (Table 4-6). However, the Experts group were divided between all five (5) options in their opinion regarding the influence cooperative governance would have on the water quality in the Breede River catchment (Table 4-6). Up to 46% of Experts are of the opinion that cooperative governance has a negative influence on the water quality in the Breede River catchment with 39% of opinion indicating that it has a positive influence.

The participants were also asked in an open-ended question to elaborate on their opinion on the influence of cooperative governance on water quality in the Breede River catchment. The thematic analysis of their responses yielded the following themes:

- Role players involved; and
- Inconsistency in efficiency of co-operation.

Themes from the Farmers and Experts’ comments generally correspond and support the perception that cooperative governance have an indirect impact on the water quality in the Breede River. Farmers opinion on the influence of cooperative governance on the water quality in the Breede River catchment varied with their knowledge of the entities involved in water quality in the Breede River catchment. Their opinion was either that they do not have enough knowledge on this or that they did feel that there is an absence of coordination of efforts, especially regarding implementation of regulations. Comments include: *“poor enforcement of legislation and poor coordination of efforts to prevent decline in water quality the efforts are not sufficient” (F2).* Participants also indicated that enforcement of law and prosecution of perpetrators is not done consistently as evident from the comments: *“When a private entity transgresses they are issued*

with a non-compliance directive to ensure they comply by a set date. However, when dealing with other government departments, i.e. municipalities, it takes much longer for them to comply” (E6) and “BGCMA and DWS do not treat all water users same - municipalities are not treated as harshly as private water users or it takes longer to rectify non-compliance” (F8).

Experts were generally of the opinion that there were very good cooperation between various parties involved and highlighted the cooperation between BGCMA and the various WUA. The organisations involved were interviewed and indicated that there are regular meetings on water quality and allocation but also quick responses and close cooperation when incidents of pollution or other impacts on the water resource and unauthorised developments were reported or detected. Comments include: *“In the Breede catchment many role players work together to manage water quality issues. Regular meetings between BGCMA, Prov Dept Agric, Dept Env, WU Associations and Cape Winelands District Municipality + Ceres local municipality. But Breede Valley and Langeberg local municipalities largely absent and not contributing to efforts” (E10).*

The institutions involved in water management in the study area as well as the nature of their involvement in water arrangements were highlighted in Table 2-1. In section 2.4 the mandate and membership of the WUA were highlighted, proposing that these organisations represented the interests of their members. This was especially true for the CBWUA which most participants indicated as a key contributor to managing the water quality and quantity in the BGWMA. As will be highlighted later, the Farmers were particularly critical of the cooperation between BGCMA and individual farmers as well as the contribution of the local municipalities in the quest for improving water quality in the catchment.

4.3.5 Section E: Key risks posed by the water quality in the Breede River catchment

This section was structured according to section E of the questionnaire which focused on the information gathered that related to potential risks that may potentially lead to the decline in water quality in the Breede River poses to agriculture in the study area (this contributes towards addressing Research Objective 3 (see Annexure A). This section of the results aims to identify and evaluate the risks posed by the potential decline in water quality in the Breede River catchment related to agricultural activities.

Participants were asked to identify key risks of the perceived decline in water quality in the Breede River catchment in 2000 and also consider impacts beyond 2020. The participants were also

asked open-ended questions to elaborate on their opinion on the impact(s) water quality of the Breede River catchment had and potentially will have on agricultural activities. The thematic analysis of their responses yielded themes to present the findings of this section of the questionnaire.

The probability or likelihood of the identified impacts of the decline in water quality in the Breede River catchment on agricultural activities and the consequence severity posed by these impacts were captured in a risk matrix to define the level of risk posed by each.

4.3.5.1 Risk of impact of water quality on agricultural activities (QE2E/QE2F)

In QE2E/QE2F in the questionnaire, participants were asked to indicate their opinion on the impact water quality has on agricultural activities in the Breede River catchment. Most participants were concerned that there is a potential risk that a decline in water quality could have a negative impact on agricultural activities in the future. The risk profile, as perceived by the Farmers group, changed from 27% indicating a major negative impact on agricultural activities that existed in 2000 to 60% of Farmers perceiving a potential for a major negative impact in 2020 (Table 4-7 and Table 4-8). The majority of Farmers in the Lower (75%) and Middle Breede River section (71%) were of the opinion that the water quality will have a major negative impact on agricultural activities in the future, whereas only 25% of Farmers in the Upper Breede River section agreed with this view.

Table 4-7: Summary of opinion of participants on the key risks of the perceived decline in water quality in the Breede River catchment in 2000.

	Major positive impact	Minor positive impact	No impact	Minor negative impact	Major negative impact
Risk to agricultural activities					
Farmers /15	0	0	3	8	4
Experts /13	1	0	3	8	1
Risk to quality of the crops/ products					
Farmers	0	1	2	10	2
Risk of financial impact on farming operations					
Farmers	0	1	5	8	1
Experts	0	0	5	7	1

The Experts group expressed their opinion that the impact rating for impacts beyond 2020 did not differ drastically from the impacts perceived in 2000 with the majority (62% in 2000 and 69%

beyond 2020) indicating that a minor negative impact on agricultural activities existed (Table 4-7 and Table 4-8). There was also a concern with regards to the increased salt load in the Breede River and irrigation canals in the Middle Breede River section. Other concerns mentioned were the agro-chemicals which are flushed into the water resources through agricultural return flow.

Table 4-8: Summary of opinion of participants on the key risks of the perceived decline in water quality in the Breede River catchment in 2020 and beyond.

	Major positive impact	Minor positive impact	No impact	Minor negative impact	Major negative impact
Risk to agricultural activities					
Farmers /15	0	0	1	5	9
Experts /13	0	1	1	9	2
Risk to quality of the crops/ products					
Farmers	0	1	1	7	6
Risk of financial impact on farming operations					
Farmers	0	1	0	11	3
Experts	0	0	3	7	3
Risk to sustainability of agriculture					
Farmers	0	0	1	11	3
Experts	0	0	3	5	5
Risk to economic growth of the area					
Farmers	0	1	0	5	9
Experts	0	2	2	5	4
Risk of impact on socio-economic development					
Farmers	0	1	0	6	8
Experts	0	1	3	3	6
Risk to environmental sustainability					
Farmers	0	0	3	10	2
Experts	0	1	2	6	4

The participants were also asked in an open-ended question to elaborate on their opinion on the impact water quality has on agricultural activities in the Breede River catchment. The thematic analysis of their responses yielded the following themes:

- Growth in agriculture;
- Market requirements;
- Impact on soil;
- Awareness;
- Crop type; and
- Finding solutions.

The risks of water quality impacting on agricultural activities are linked to the growth of agriculture as well as the crop type which have the potential to increase the salt load as highlighted in the comments: *“Crops changed to fruit which use more water - potential impact due to irrigation return flow with increased salt load”* (F9), *“increased agricultural land developed currently is a risk as it will impact on available water volume in the river - late summer is already a salinity problem”* (F15). The low flow in later summer was also highlighted in 2.8.4.2 which related the low flow to increased salinity levels when higher volumes of water is abstracted for irrigation which leads to higher volumes of saline return flow but the higher evaporation rate in summer periods result in concentrating the salt levels. These conditions are more prominent in the Middle and Lower Breede River sections and were emphasised by previous studies (Murray, Biesenbach & Badenhorst Inc., 1989; Kirchner *et al.*, 1997) but also shown by the seasonal variations highlighted by results of the water quality study (see section 4.2.1).

The risk of continuous irrigation with poor quality water to agricultural activities is linked to impact on soil and yield as highlighted in the comments: *“..soil quality will be affected to a point where damage cannot be reversed to then affect the quality of crops and thereby agriculture activities”* (F13). The risk is also linked to the crop type as vulnerability to specific parameters vary between crops as was indicated in the comment: *“...the type of crop – e.g. tomatoes irrigated with water where E.coli levels are potentially high would suggest these crops cannot be planted in specific areas”* (E4), *“Crops grow optimally at a specific water quality beyond which there is a risk of the crops being damaged and yield declines”* (E11).

The risk posed by water quality on agricultural activities was linked to the potential impact on the market for crops grown in the Breede River catchment. This is very relevant in this catchment where the economy is highly dependent on the export market for agricultural products. The risk posed by poor water quality was linked to *E. coli* levels in water for irrigation purposes as highlighted by both groups in the comments: *“Overall risk of E.coli affecting the crop and thereby affecting agriculture as export markets are at risk”* (F6), *“Risk of a decline in water quality mainly feeds into the potential for the loss of markets which require a specific water quality”* (F8), *“The impact of poor water quality has the potential to impact on export markets as they are very strict with respect to the quality of water used in irrigation and use on the farm”* (E6).

Although the risk is considered to be small the potential impact would be large as highlighted by the following comments: *“If the water quality declines to a point where the quality of crops are affected the potential loss of markets will have a negative impact on activities”* (E9), *“Overall risk of E. coli affecting the crop and thereby affecting agriculture as export markets is a risk factor”*

(F6). The export market require regular audits with the risk of water quality being “*no longer within guidelines as demanded by export markets, which may result in loss of export market. It is becoming a big risk*” (E11). Cullis *et al.* (2018) identified the water quality decline in the Breede River and Berg River catchment, a similar catchment dependent on the agricultural export market, as a critical risk. This study also linked the negative impact on the market, due to water quality decline, and to a decline in employment levels in the catchment.

The risk matrix for risks posed by the water quality in the Breede River catchment on agricultural activities, as perceived by participants, are presented in Table 4-9.

Table 4-9: Risk matrix for risks posed by the water quality and availability in the Breede River catchment on agricultural activities as perceived by participants

Hazard	Risk matrix		
	Likelihood	Consequences	Risk value
Water quality impact on agricultural activities	3	2	6
Water availability impact on agricultural activities	3	3	9
Water quality impact on the quality of the crops/ products	2 to 3	2 to 3	4 to 9
Financial impact of the irrigation water quality	1	3	3
Water quality impact on sustainability of agriculture	1	3	3
Water quality impact on the economic growth of the area	1	3	3
Water quality impact on socio-economic development and community resilience/ vulnerability	1	3	3

Most Farmers indicated a low probability of the water quality impacting negatively on agricultural activities currently due to the way it is being managed. However, the probability for the decline in water quality in the future impacting negatively on agricultural activities is considered to be high and is mostly related to the potential impact from poor management and the maintenance of WWTW as well as the capacity of these facilities to treat the increased volumes of effluent from an increased population. However, the probability for the decline in water quality in the future impacting negatively on agricultural activities is considered high and is mostly related to the

potential impact from poor management and maintenance of WWTW and the capacity of these facilities to treat the increased volumes of effluent from an increased population.

4.3.5.2 Risk of water quality impact on the quality of the crops/ products (QE4F)

In response to QE4F in the questionnaire, only Farmers were asked to indicate their opinion on the impact water quality has on the quality of the crops/ products in the Breede River catchment. Most participants were concerned that there is a potential risk that a decline in water quality could have a negative impact on the quality of the crops/ products. The Farmers perceived the risk in 2000 to be lower than in 2020 and beyond with only 67% of Farmers in 2000 reflecting a minor negative impact on crops/ products, compared to 47% of Farmers in 2020 (Table 4-8 and Figure 4-44).

Farmers were also asked in an open-ended question to elaborate on their opinion on the impact water quality has on the quality of the crops/ products in the Breede River catchment. The thematic analysis of their responses yielded the following themes:

- Perceptions;
- Market loss; and
- Crop resilience.

The risk to the crop quality is closely linked to the risk of the loss of the market, especially the export market. The risk was generally linked to microbiological contamination (*E. coli*) as highlighted by the following comments: *“E. coli may pose a big risk to export markets and quality of crops”* and *“...vegetables might be impacted as irrigation is directly onto the product and not at the stem/ base (F5).* However, Farmers also indicated that the risk level depends on the crop type and the irrigation technique used. This was highlighted in comments: *“As irrigation type differ between crops the risk of E. coli affecting the crops which are irrigated by drip irrigation is low as it is irrigated at the stem of the plant and not on the fruit itself”* and *“.... E.coli on vegetables could have a potentially high risk as water is directly applied to the vegetable” (F6).* However, the main risk identified by the majority of Farmers was the likelihood of a decline in the biological water quality in the future and the impact thereof on the quality of the crop/ product. The shift from 2000, where no major impacts were considered, to 2020 where 40% of Farmers indicated that there is a risk of a major negative impact are mainly related to the concerns around the management and maintenance of the WWTWs of the major towns as well as the growing un-serviced informal housing areas developed along the rivers and canals (Figure 4-44). Most participants

acknowledged that they had no information on the upgrade and expansion plans for the WWTW and no data on the effectiveness of these facilities but are basing their concerns on water quality data collected by them and others for irrigation and drinking water for auditing purposes and the general perception that all WWTW in South Africa are under pressure.

The WWTW in the Upper Breede River (Worcester, Ceres and Wolseley) had high compliance levels (see section 4.2.4). However, the *E. coli* levels since 2018 did not reflect this improvement with the microbiological water quality downstream of Ceres regularly exceeding limits. The majority of participants indicated a medium to high risk related to the impact on the quality of the crops based. Farmers in the Upper and Middle Breede River section were concerned about the potential of *E.coli* pollution in the future.

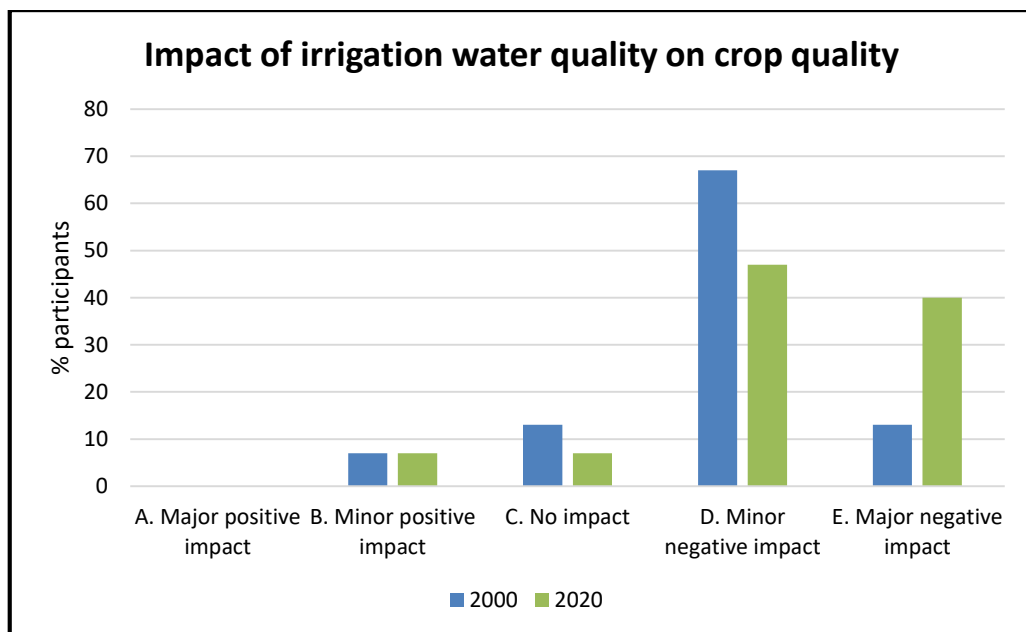


Figure 4-44: Distribution of Farmer's opinion on the impact of irrigation water quality on the quality of the crops/ products (QE4F).

Although there were concerns related to the potential impact of WWTW effluent and informal settlements not serviced and therefore by-passing formal WWTW, the majority of the participants indicated that the consequence of poor quality water for irrigation purposes on the current crop types cultivated in the Breede River is low. This is related to the fact that the water intended for irrigation is directed at the stem of the tree or vine and *E. coli* is therefore not likely to occur on the fruit itself. The impact on crops in the Breede River where vineyards, citrus and other fruit trees dominate was therefore not perceived to be high as water for irrigation purposes from micro-

and drip irrigation systems are directed at the stems and the probability of fruit to be contaminated by *E. coli* considered to be relatively low as indicated by the comments: *“As irrigation type differ between crops the risk of E. coli affecting the crops which are irrigated by drip irrigation is low as it is irrigated at the stem of the plant and not on the fruit itself”* (F6) and *“most crops will not be sprayed with water containing E. coli - vegetables might be impacted as irrigation is directly onto the product and not at the stem/ base”* (F5). The potential for impacts in the future might be higher as commented: *“Although not currently seen as a risk there is a future risk due to uncontrolled development in the urban areas of informal settlements and the risk of E. coli and the related impact on markets”* (F4).

Most Farmers indicated that there is a low probability of the water quality impacting negatively on agricultural activities currently due to the way water for irrigation purposes is being managed. However, there are concerns for crops where overhead irrigation is used as the potential for *E. coli* contamination is high when water used for irrigation purposes is directed onto the leaves and vegetable/fruit crop itself.

Minor impacts were mainly linked to the increase in salt load in water purposed for irrigation and the impact that it would have depends on the type of crops cultivated. Most participants felt that the main crop, i.e. wine grapes, are relatively tolerant to an increased salt load and would therefore not be affected as much as for instance citrus and other fruit. In section 4.2 the increased salinity in parts of the Breede River has been highlighted. Farmers also highlighted the potential risk of increased salt levels (Na) impacting on crop quality and yield as indicated in the comment: *“Some crops are resistant to poorer water quality but there is a limit after which the quality of the crop will suffer. For instance wine grapes are salt tolerant to some extent but they will take time to recuperate after a period of irrigation with brackish water (during drought this happened as ground water was only source and it was either brackish or became brackish over time due to overuse and natural geology), if not the plant will suffer permanent damage* (F2). However, the current practice of releasing water from the Brandvlei Dam is considered sufficient to dilute the salt load to a level acceptable for most crops. There is, however, a concern by Farmers that if the irrigation system in the Middle and Upper Breede River is not managed at the same standard in the future, there is a high probability of a major negative impact on the crop/ product quality.

The potential impacts of poor water quality on agriculture were highlighted in section 2.9. Not only is there an impact on crop yield and quality but the impact on irrigation infrastructure contributes to the cost of pollution to agriculture. The build-up of salts in soil and the impact thereof on the

yield and crop quality is dependent on the crop type and the sensitivity of the crop to saline conditions in the soil. Grapevines were identified as sensitive to soil salinity (Moolman, 1999).

4.3.5.3 Risk of impact of on agricultural activities

In response to QE3E/QE3F in the questionnaire, participants were asked to indicate their opinion on the impact water availability has on agricultural activities in the Breede River catchment. Periodic low water availability in the Breede River is mainly linked to the dry summer season when the streams and Breede River dry-up in late summer. The quality of the water during the late summer periods are of a lower quality due to the fact that the lower quality discharges related to anthropogenic activities (domestic, industrial and agricultural) are not diluted since there is low to no rainfall during this period and therefore no natural flow in the rivers. Irrigation with this water is generally linked to an increase in cleaning intervals for irrigation filter systems due to the build-up of algae in the canals and rivers. The low flow periods also result in intensified salination in the Middle Breede River section. However, the Brandvlei Dam is used to augment the volume of water downstream and thereby also addresses the quality of the water through dilution of the salinity which increases downstream in the direction of Bonnievale and Ashton.

Prolonged droughts also affect the availability of water in the catchment. Most Farmers indicated that the WUA had to impose some restrictions on the normal allocation of water for irrigation purposes to each farm. They indicated that the normal allocation was cut by 25% to 60% in the past. However, those Farmers dependent on tributaries closer to source also had lower water volumes for irrigation and many augmented the water required by abstracting ground water. Ground water is not generally used for irrigation purposes in parts of the Upper and Middle Breede River sections due to the water being brackish. However, Farmers resorted to augmenting available water by adding brackish borehole water to the mix. Mixing brackish borehole water with fresh water, thereby diluting the saline water, was done in extreme cases for a limited period only to avoid degrading the soil and harming the plants. Many Farmers on the mountain slopes indicated that although their ground water is generally good, the borehole quality declined during droughts (became brackish) but once winter rain recharged the ground water the quality improved again. Prolonged irrigation with brackish water not only poses a risk to soil quality but also impacts yield.

The majority of Farmers did not agree that water availability had an impact on the agricultural activities in 2000, with 33% indicating that there was no impact and 47% suggesting that there were only minor negative impacts (Figure 4-45).

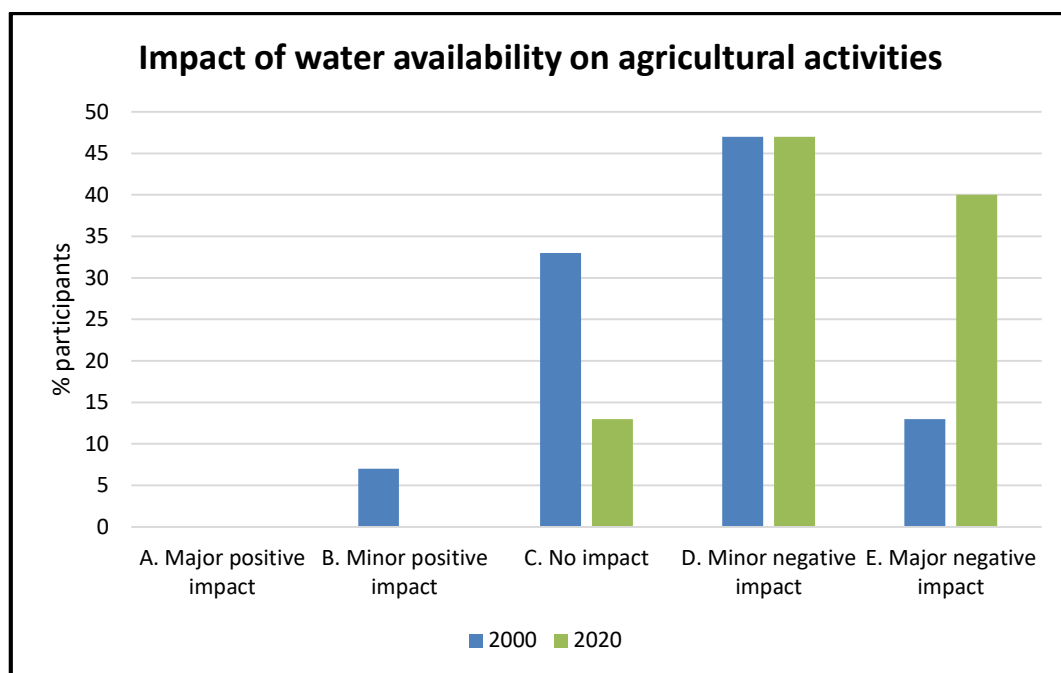


Figure 4-45: Distribution of Farmer's opinion of the impact water availability has on agricultural activities (QE3E/QE3F).

However, Farmers agreed that a more substantial impact is expected into the future (beyond 2020), with 47% suggesting a minor and 40% a major negative impact (Table 4-10 and Table 4-11). However, the Experts group were less optimistic with 69% agreeing that water availability had a negative impact on the agricultural activities in 2000 as well as beyond 2020 (Table 4-10 and Table 4-11).

Table 4-10: Summary of opinion on the key risks of the decline in water availability in 2000 (QE3E/QE3F).

	Major positive impact	Minor positive impact	No impact	Minor negative impact	Major negative impact
Risk to agricultural activities					
Farmers	0	1	5	7	2
Experts	2	0	9	2	0

Table 4-11: Summary of opinion of interviewees on the key risks of the perceived decline in water availability in the Breede River catchment in 2020 and beyond (QE3E/QE3F).

	Major positive impact	Minor positive impact	No impact	Minor negative impact	Major negative impact
Risk to agricultural activities					
Farmers	0	0	2	7	6
Experts	2	0	9	2	0

Up to 15% of Experts opined that water availability in the Breede River catchment will have no impact on agricultural activities with a further 15% expressing that water availability would have a positive impact. The positive impact was linked to water availability improvement due to the removal of alien vegetation in the floodplains.

The participants were also asked in an open-ended question to elaborate on their opinion on the impact water quality has on agricultural activities in the Breede River catchment. The thematic analysis of their responses yielded the following themes:

- Growth in agriculture;
- Irrigation type adaptation;
- Seasonality;
- Crop type;
- Locality;
- Link with water quality; and

- Solutions.

Farmers were concerned that plans to increase the storage capacity of the Brandvlei Dam has not materialised yet, but that additional water users are being added, thereby increasing the likelihood of a situation where water allocations to existing farms will be affected more often. Permitting more water than what is available in the catchment is seen as a risk in over utilisation of the water resources in the catchment. Although Farmers in the Middle and Upper Breede River sections all indicated that they use less water to irrigate larger areas due to the change to micro and drip irrigation systems, they were not prepared to give-up their allocated volume. Farmers also highlighted the fact that adaptations to irrigation practices to more efficient techniques lowered the risk. The risk is also linked to the crop type as irrigation requirements differed as indicated in the comment: *“Not seen as a major risk as the availability of water during the early to mid-summer when irrigation is required for grapes are not generally at risk”* (F6), *“If less water the risk to some crops irrigated with higher salt content water may influence the agricultural activities, but wine grapes are relatively resistant to salts”* (F5).

Most Farmers were of the opinion that they would rather build more storage dams on the farm to hold the portion of their allocated water not utilised for the year than to give-up any portion of their allocated water. This notion was generally linked to droughts and uncertainty of how climate change will affect the water regime in the catchment in the future. The risk posed to agricultural activities by a decline in water availability is mainly linked to the impact it would have on crop yield. The minimum irrigation water volume required by each crop for optimal yield has been established. The likelihood of a decline in the availability of water having an impact on agricultural activities was therefore considered to be high and the consequences of this happening also considered significant. Farmers were concerned with the fact that new agricultural developments, mainly in the Middle but also some in the Upper Breede River sections, were approved with no additional water being added to the already allocated volume available in the catchment. This concern was highlighted in comments: *“Has become more of a risk as new players require a portion of the water used for irrigation from the Greater-Brandvlei irrigation or current Farmers expand operations demanding a larger portion of the available water”* (F4), *“Developing Farmers will need access in future as well”* (F4). Availability of water is also linked to sustainability as was evident from the comments: *“As a minimum volume of water is required to irrigate the crops, a minimum ha of crop is required to farm; if less allocated then will not be able to survive”* (F7) and *“All water available in the catchment has been allocated to existing farms, can only expand on agriculture if the available water is increased”* (F9).

4.3.5.4 Financial risk to agricultural activities (QE4E/QE5F)

In response to QE4E/QE5F in the questionnaire, participants were asked to indicate their opinion on the financial impact water quality has on agricultural activities in the Breede River catchment. The majority (8 of 15) of Farmers (53%) were of the opinion that water quality has a minor negative financial impact on their operations with 33% (5 of 15) indicating that there was no impact in 2000 (Table 4-6). However, the majority (11 of 15) of the Farmers (73%) were of the opinion that in the future water quality will have a minor negative financial impact on their operations with 20% (3 of 15) indicating that they expect a major negative impact (Table 4-8 and Figure 4-46).

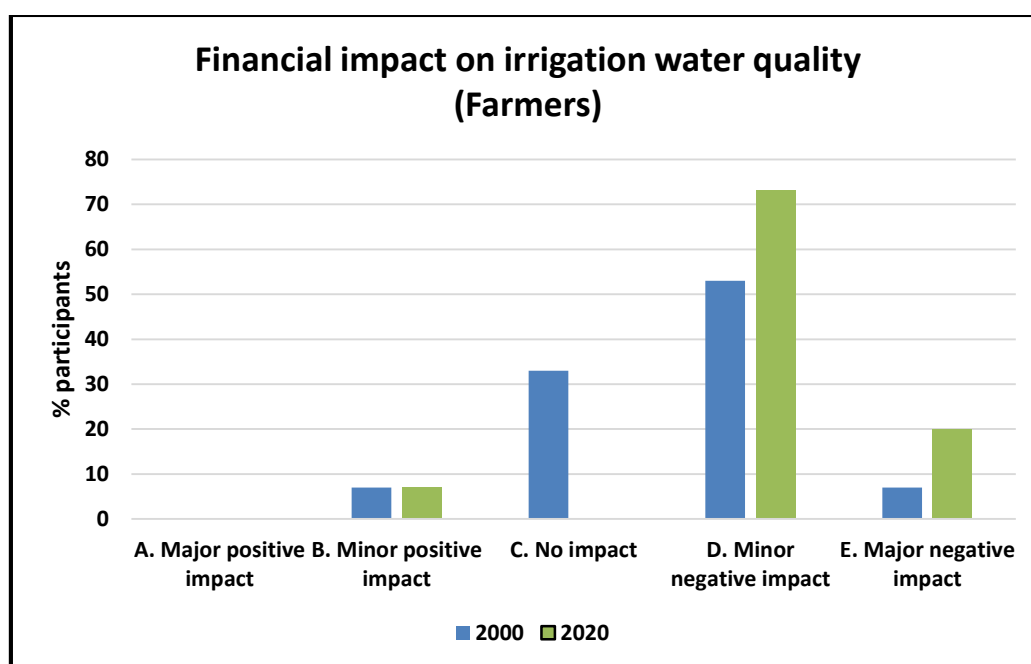


Figure 4-46: Distribution of Farmer's opinion of on the financial impact water quality has on agricultural activities (QE5F).

The Experts group agreed with the Farmers with 54% (7 of 13) being of the opinion that water quality has a minor negative financial impact on agricultural activities and 39% (5 of 13) indicating no impact in 2000 (Table 4-7). However, up to 54% of Experts opined that water quality in the Breede River catchment will have a minor negative financial impact on agricultural activities in the future with 27% (3 of 13) expressing the opinion that there would be a major negative financial impact. Although most Farmers indicated a low probability of the water quality impacting negatively on agricultural activities currently due to the way it is being managed, they considered the probability for the decline in water quality in the future impacting negatively on agricultural

activities as high (Table 4-9). From the responses it appears the perceived risk is mostly related to the potential impact from poor management and maintenance of WWTW and the capacity of these facilities to treat the increased volumes of effluent from an increased population. There was also a concern with regards to the increased salt load in the Breede River and irrigation canals in the Middle Breede River section. Other concerns mentioned were the agro-chemicals which are flushed into the water resources through agricultural return flow.

Participants were also asked in an open-ended question to elaborate on their opinion on the financial risk is associated with the impact that water quality poses to agricultural activities in the Breede River catchment. The thematic analysis yielded the following identified financial risks:

- Increased maintenance costs;
- Additional water treatment costs;
- Impact on the crop quality;
- Impact on crop yield;
- Additional expenses to satisfy market of product quality;
- Loss of market; and
- Loss of investors/ investments.

The themes will be analysed in the succeeding discussion.

4.3.5.4.1 Increase in maintenance costs

The risk posed by water quality on the maintenance cost of irrigation systems is generally considered to be low. In section 2.9 the impacts of poor water quality on irrigation infrastructure were investigated. Previous studies which highlighted the clogging of the irrigation system and the additional costs of maintenance (ARC, 2018) lead to the inclusion of this question, however, the findings in this study indicated that the cost for maintenance of the irrigation system is <1% of the total cost of irrigation. The main concern is, however, the increased intervals of flushing the filters for irrigation systems due to the clogging of filters with algae and silt. These concerns were flagged by both Farmers and Experts as indicated by the following comments: “*Maintenance of irrigation systems increase during low flow due to the clogging of filters*” (F3), “*Other expenses such as changes in the irrigation system adds to expenditure which cannot be added to product*” (F6), and “*algae is becoming an issue = algae linked to nutrients, need better systems on the farm, which has a financial impact*” (E3).

In areas closer to urban areas (formal and informal) and downstream of municipal camping and picnic areas, posed a risk of solid waste (plastic etc.) entering the rivers and irrigation canals, especially after heavy rains flushed the material into water courses. The risk posed by solid waste relates to the potential of plastic being sucked into the pumps which pumps directly from the river, was flagged as a concern as indicated by the following comment: *“Maintenance on irrigation systems when solid waste enters pumps”* (E6).

4.3.5.4.2 Additional expenses on water treatment costs

The safeguarding of water quality for use in irrigation will require additional input costs incurred for the treatment of water prior to use. However, additional expenses will have a negative financial impact as additional costs involved in the implementation of a water treatment system on farm scale will impact on the profitability of the farm. The concern was highlighted by both Farmers and Experts as is evident from the comments: *“Increased input costs involved in the management of water quality”* (F11), *“some farmers undertake the treatment of water for domestic use on farm, but not all can afford this”* (F1), *“Risk also relates to additional input costs incurred by the farmer in the treatment of water to an acceptable level of quality – it will have an impact on income as agriculture has a low profit margin - if additional expenses are incurred it might not be profitable”* (F13), *“More expenses to farm when water needs to be treated in some way before it can be used on the farm (not only irrigation but also drinking water to workers)”* (E6). A constructed water treatment system on farm scale would most likely not be viable as agriculture has a low profit margin as highlighted by the comments above as well as a comment by one of the Experts: *“If water deteriorate to such a level where treatment is required the additional cost of treatment plant to treat water before irrigation can happen will be extremely expensive and beyond the means of most users”* (E11).

4.3.5.4.3 Impact on crop quality and yield

Although the availability of water is considered more important related to crop quality, a decline in water quality may also impact on the quality and yield of crops. The potential risk posed by long-term irrigation with brackish water on soil quality and therefore also the crop quality and yield was highlighted by several participants: *“Some crops more sensitive to salts would be affected ...Higher salt levels in irrigation water can affect soil quality as soil becomes brackish and not suitable for some crops if not flushed out of the soil”* (E4), *“linked to E.colii and Na-salt content - as crops are not resistant to extreme levels before damage to the plant is experienced which has*

an impact on the quality and size of the crop and if there is permanent damage inflicted on the plant, extra expenses will have to be incurred on a replacement process (could take years before new plant will deliver crop of same size)” (E9), “Risk exists that water quality can have an impact on the crop and therefore as financial impact on agriculture” (F7), “...impacts on the crop in such a way that lower volumes are produced...” (F9).

The long-term effect of lower product quality and yield related to water quality will impact negatively on financial sustainability of agriculture along the Breede River catchment. Several participants were of the opinion that the impact of poor water quality on crop quality and yield has the potential to have a negative financial impact, not only on farm scale, but also the entire agricultural sector along the Breede River. This is linked to the possibility of the loss of the markets to which crops/ products are delivered.

4.3.5.4.4 Potential loss of markets

The potential loss of markets due to poor water quality has been highlighted by several participants and previous studies (DWAF, 2003d; Cullis *et al.*, 2018). However, most participants were of the opinion that although the potential impact associated with the loss of agricultural markets might be devastating to the agricultural sector in the Breede River, the likelihood of this happening remains low.

The risk is, however, not limited to farm scale as highlighted by the following comments: *“Risk to the market increased as the knock-on effect of poor biological water quality will have a financial impact on the farm level but also agriculture in general” (F2), “The risk to export market when fruit is not accepted due to E. coli contamination exists. This can have an impact on the entire agricultural sector” (F6), “potential impact beyond agriculture - i.e. impact on region as towns are dependent on agriculture” (E13).* The impact will be felt beyond the farm as consumers of these products will also be affected in some ways as highlighted by the following comments: *“If the water quality (and volume) impacts on the crop in such a way that lower volumes are produced then there will be an impact on the cost of the product to the consumer” (F9), “If water quality declines the product delivered to the market will be of a lower quality...” (E5).* However, consumers will pay less for lower quality product. International market provides higher income compared to local markets and the risk of losing this market is of concern as highlighted in the comments: *“...financial strain on the operation seeing that buyers will pay less for the product if quality is not up to standard” (F8), “Risk to the market increased seeing that the knock-on effect of poor biological water quality will have a financial impact...” (F2), “The risk to export market*

when fruit is not accepted due to E. coli contamination exists. This can have an impact on the entire agricultural sector” (F6), “The financial risk the impact of poor water quality has on agriculture is high especially so for the wine industry as the loss of the market can impact export” (E10).

The potential loss of market due to perceptions of lower product quality was also highlighted as a concern seeing that local markets will not pay the higher premium compared to the well-deserved prices applicable to the more sophisticated international market, which will have a negative impact on agriculture as indicated by: *“..will have impact on income as agriculture has a low profit margin..” (F13).* The international markets served are sophisticated and become more environmentally sensitive, which requires certification (GLOBAL GAP etc), which implies that crops were grown in an environmentally sustainable way with good quality water etc.. The risk to the export market when fruit is not accepted due to *E. coli* contamination has also been highlighted by Cullis *et al.* (2018). Although the risk of water quality is considered to be low, the damage negative perceptions of poor water quality can have on the export markets relates to a high risk due to the high likelihood of this occurring. The perception of poor quality water affecting some crops is not scientifically based but rather of an emotionally nature, as the irrigation practices generally applied prevent contamination of specific crops as highlighted in the comment: *“If WWTW is not managed well the impact on the international market, especially for vegetable crops, will be a problem as irrigation with polluted water will not be acceptable to the market. This is not as big a problem for grapes as drip irrigation at the stem and potential for contamination on fruit is lower” (F9).* There is therefore a mismatch between reality and perceptions which could be a high risk leading to the loss of markets.

4.3.5.4.5 Additional expenses to satisfy market of product quality

Other expenses such as changes in the irrigation system adds to expenditure which cannot be added to product costs. In order to satisfy the requirements for national and international markets several national and international certification systems (GLOBALG.A.P., Fairtrade, BWI, WIETA and IPW) require annual auditing adding to expenses (including regular water quality analyses at a certified laboratory) as highlighted by the comment: *“Added expenses to prove there is no risk to consumer” (F6).*

This risk also include the additional input costs to treat water to an acceptable quality, which will have an impact on income as agriculture has a low profit margin and also on sustainability of agriculture as discussed earlier.

4.3.5.4.6 Loss of investors/ investments

A risk of the loss of investment in agriculture in the catchment related to water quality decline was also highlighted as a potential impact in the future. This risk is related to the potential decline in quality and quantity of crops as a result of a decline in the water quality as highlighted by the comments: *“If water quality negatively impacts crop quality investors would rather move to areas not impacted - therefore the impact on agriculture would be that the industry would not grow further in the catchment”* (F10), *“Risk that decline in water quality and quantity impacts are such that agriculture is not profitable”* (E13). If the return on investment is not maintained investors will move to areas where water quality is not a concern. If investors withdraw the agriculture industry and local economy would potentially be negatively impacted.

4.3.5.5 Risks to sustainability of agriculture (QE5E/QE6F)

In response to QE5E/QE6F in the questionnaire, participants were asked to indicate their opinion on the impact water quality has on the sustainability of the Breede River catchment. The majority (11 of 15) (73%) of Farmers agreed that water quality has the potential for a minor negative to major negative (3 of 15) (20%) impact on sustainability of agriculture in the catchment (Figure 4-47).

This risk is closely linked to the financial risk water quality may pose to agricultural-related industries in general. Farmers linked the concern of sustainability of agriculture to the potential of agriculture becoming unprofitable due to the increased input costs if water treatment is required prior to use, as well as the loss of markets due to the decline in quality and quantity of current high income crops/ products. Participants commented on the potential ripple effect the loss of market may have on related industries (packing stores, cellars etc). The indirect impact on related industries has the potential to severely impact the local economy. However, 39% (5 of 13) of the Experts group opined that water quality will have a minor negative impact with an additional 39% expecting a major negative impact on sustainability of agriculture in the catchment.

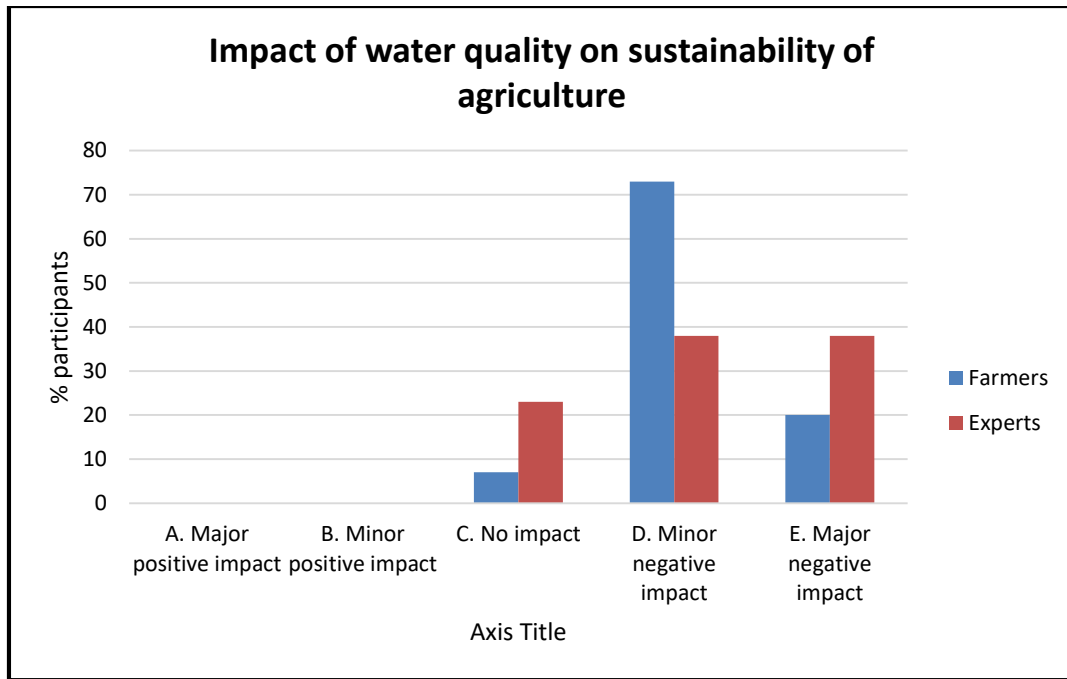


Figure 4-47: Distribution of Farmer's opinion on the impacts water quality has on sustainability of agriculture (QE5E/QE6F).

The participants were also asked in an open-ended question to elaborate on their opinion on the impact water quality has on the sustainability of agriculture in the Breede River catchment. The thematic analysis of their responses yielded the following themes:

- Loss of market;
- Adaptation;
- Economies of scale;
- Availability link; and
- Profitability.

Participants suggested that some areas might be more at risk due to the higher potential for water quality decline. For instance, areas where water for irrigation purposes is withdrawn directly from the Middle Breede River section, might be more at risk due to the potential contamination load. This was highlighted by comments such as: *"In some areas irrigating directly from Breede River might be more at risk if salt load builds up to such an extent that it becomes unusable - where mountain water or irrigation canal water used less at risk"* (F13), *"Some areas which depends on Breede River is at risk as potential exist that quality of crops are affected and also markets affected which result in loss of market of high income crops - some crops may no longer be*

sustainable to plant” (F14). However, some participants were confident that agriculture will adapt to new conditions as indicated by the comment: “If products are not of good enough quality, farmers might lose market for a specific crop type but one would expect that they will change to a different crop type” (F11) and “If salt load increases some crops will not be able to tolerate the increased salt concentrations which might affect the type of crop planted. Might require moving away from high yielding crop with high income – the agricultural sustainability of specific crops will be affected but farmers will adapt to conditions by changing the type of agriculture to more resilient crops” (E4) and “...could diversify crop to more drought/ salt resistant crops” (E9).

The worst case scenario suggests that water used for irrigation requires treatment (disinfection and desalination) prior to use which might be prohibitively expensive for individual Farmers; however, economies of scale might lower the risk as highlighted in the comments: “...as larger producers can afford to treat water to a sufficient quality” (F5), “To remove *E. coli* at farm scale might not be achievable as it will be very costly to construct a treatment plant by each farm - economies of scale might lower the risk as larger producers might be able to afford a treatment plant, but smaller producers will not be able to afford that” (F6) and “Risk of the additional input costs by farmer to treat water to acceptable quality - will have impact on income as agriculture has a low profit margin - if additional expenses it might not be profitable equals not sustainable” (F13).

However, most participants considered the availability of water as a key risk to sustainability of agriculture as indicated by the following comments: “Sustainability is at higher risk due to water availability concerns as a specific volume of water is required for existing farms... Therefore volume and not so much quality puts the existing agricultural activities at risk.” (F7), and “The risk to sustainability of agriculture is not considered to be high due to the fact that agriculture has become a business and no longer a single family operation.... ensuring that agriculture survives in some form ..” (E10).

Investor confidence was also highlighted as a potential threat to the sustainability of agriculture in the area as flagged by the comment: “If no return on investment ... investors move to areas where water quality is not a concern...” (F10). The potential loss of international markets was also considered a risk to sustainability of agriculture in the study area as have been highlighted by the comment: “If export market is lost it will be very difficult to regain a position in that specific market again as the market will be filled by another supplier. Once an area has been labelled as a risk to consumers it is very unlikely that any produce from that area will keep its position in the market or regain that market” (E6).

The risk is related to the perception that new developments are approved without adding additional water to the catchment where available water has already been fully allocated. The perception is that new developments are not done in a coordinated way, adding to the strain on water resources in the catchment. A balance exists between the allocated water and the minimum volume of water required to cultivate a specific crop optimally. Therefore the volume available rather than the water quality is considered a higher risk to sustainability of agriculture in the catchment.

4.3.5.6 Risk of impact on the economic growth of the areas along the Breede River catchment (QE6E/QE7F)

As discussed earlier in section 4.3.5.1 water quality has an impact on the economic growth of the area along the Breede River catchment. In response to QE6E/QE7F in the questionnaire, participants were asked to indicate their opinion on the impact water quality has on the economic growth of the areas along the Breede River catchment.

Farmers and Experts were asked to elaborate on the opinion they expressed on the impacts water quality has on the economic growth in the Breede River catchment. Farmers were of the opinion that water quality has the potential to have a minor (33%) (5 of 15) to major (60%) (9 of 15) negative impact on the economic growth in the Breede River catchment in the future (Figure 4-48). However, the Experts group was slightly more optimistic with 39% (5 of 13) of the opinion that water quality has the potential to have a minor and 31% (4 of 13) a major negative impact on the economic growth in the Breede River catchment in the future. Up to 15% of Experts opined that water quality in the Breede River catchment would have a minor positive impact on economic growth, because the high water quality will attract investments and industries in future.

The participants were also asked in an open-ended question to elaborate on their opinion on the impacts water quality has on the economic growth in the Breede River catchment. The thematic analysis of their responses yielded the following themes:

- Dependent on agriculture/ Knock-on effect;
- Loss of market; and
- Perception.

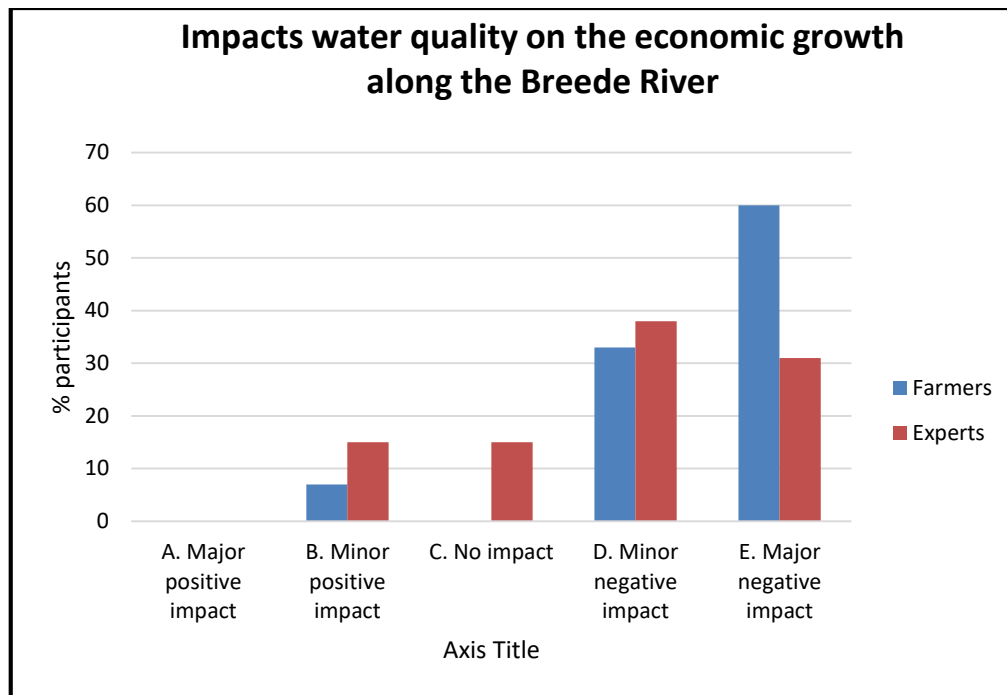


Figure 4-48: Distribution of Farmer's and Expert's opinions of the impact water quality have on the economic growth (QE6E/QE7F).

Participants agreed on the potential knock-on effect the decline in agriculture would have throughout the entire catchment as the region's economy is largely dependent on agriculture as indicated in the following comments: *"The knock-on effect of agriculture being affected negatively will be seen in job losses and increased population influx to towns, all businesses related to agriculture will be affected and the local economy will be impacted negatively"* (E4), *"This will have a large impact on towns in the valley as their economies depends on agriculture. Job losses will lead to lower buying power in towns and have a negative impact on the economy"* (E9), *"farm contributes to the livelihood of farm workers; the decline in water quality and the negative impact on the farm due to loss of export market will have an effect on the number of workers employed and also negatively impact on the general economy of the region"* (F2), *"As all towns are dependent on agriculture, any decline in income from agriculture will negatively affect the economy of the entire region..."* (F11).

However, participants were very much aware of the potential devastating impact the perceptions of poor water quality will have on the international market and eventually the local economy due to lower expenditure at local businesses as highlighted by the comment: *"Perceptions of poor water quality (E. coli) will have a negative impact on the market and linked to the economy of the*

entire region dependent on agriculture” (F10). Farmers indicated that the loss of international markets will result in products being sold at lower cost on local markets with a lower profit margin affecting all related industries as expenditure on farming equipment etc. would be lower: *“Crops might change to lower income crops sold locally”* (F6). There is therefore again a mismatch between reality and perceptions which could be a high risk leading to the loss of markets and the knock-on effect of negatively affecting the economic growth of the region.

Participants also emphasised concerns that the loss of international markets would potentially result in job losses which would affect the buying power in towns and have a negative effect on the local economy. There is also the risk that in response to declining water quality Farmers would move to crops that are less sensitive to for instance *E. coli*, salinity as well as drought, and potentially less labour intensive crops. These concerns were highlighted in the following participant comment: *“Change over to different crops that are less sensitive to E. coli and salt as well as drought have the potential of changing the number of people working on the farm as one moves away from labour intensive crops “* (E6). An indirect impact would be job losses on farms as highlighted by the comments: *“...move away from labour intensive crops resulting in job losses or less products produced requiring fewer people on the farm”* (E5), *“When export markets are lost due to the quality of the fruit and/or E. coli contamination it would ultimately lead to job losses which will have a negative impact on the local economy”* (E6).

If water quality declines to such a point where it is necessary to treat water before usage the input costs will increase which will have an impact on the profit margin, resulting in lower expenditure at local businesses. Participants suggested that the potential impact could be wider than the local retail and industrial sectors but also negatively affect tourism and the hospitality sector in the catchment. However, most participants were of the opinion that although the consequence may be devastating for the agricultural industry and economy of the area, the likelihood of this happening is low as water quality is closely monitored and managed and the agricultural sector is resilient and will adapt to circumstances as it has done in the past. There is therefore a moderate risk of water quality having an impact on the economic growth in the Breede River catchment.

4.3.5.7 Risk of impacts on socio-economic development and community resilience/ vulnerability in the Breede River catchment (QE7E/QE8F)

In response to QE7E/QE8F in the questionnaire, participants were asked to indicate their opinion on the impact water quality has on the socio-economic development and community resilience/ vulnerability in the Breede River catchment.

Farmers and Experts were asked to rate the impact water quality has on socio-economic development and community resilience/ vulnerability in the Breede River catchment. The majority of Farmers were of the opinion that water quality has a major (53%) (8 of 15) to minor (40%) (6 of 15) negative impact on socio-economic development and community resilience/ vulnerability in the Breede River catchment (Figure 4-49). The Experts group agreed with the Farmers with 46% (6 of 13) being of the opinion that water quality has a major and 27% (3 of 13) a minor negative impact on socio-economic development and community resilience/ vulnerability in the Breede River catchment. Up to 27% of Experts opined that the water quality in the Breede River catchment has no impact on socio-economic development and community resilience/ vulnerability.

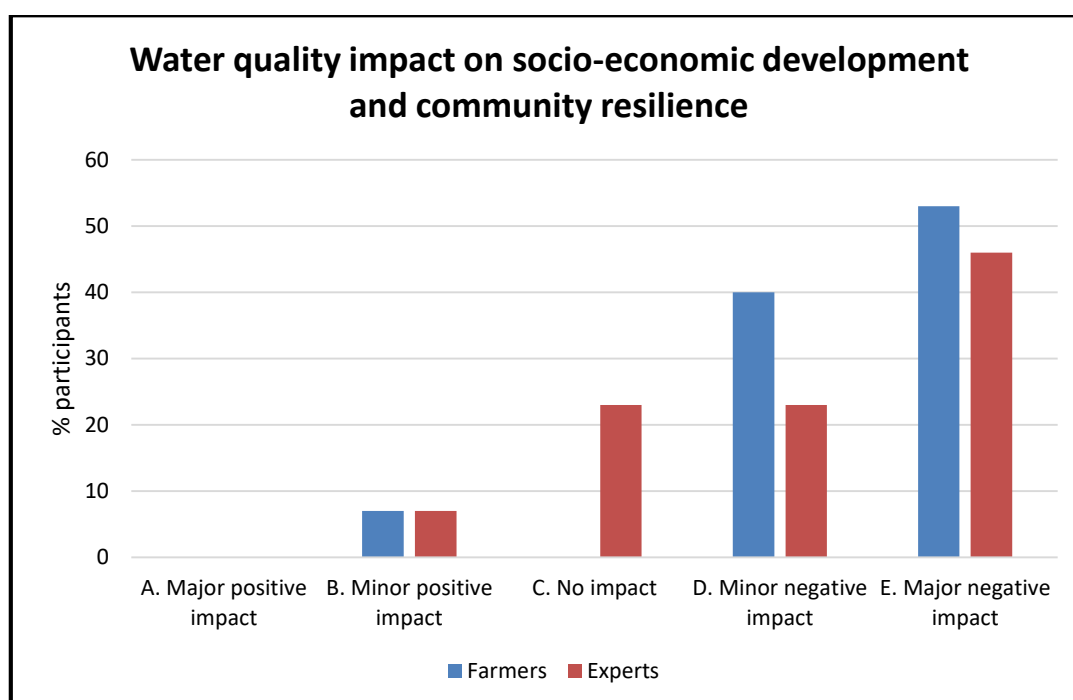


Figure 4-49: Distribution of Farmers' and Experts' opinion on the impact irrigation water quality had on socio-economic development and community resilience/ vulnerability (QE7E/QE8F).

The participants were also asked in an open-ended question to elaborate on their opinion on the impact water quality has on agricultural activities in the Breede River catchment. The thematic analysis of their responses yielded the following themes:

- Farm worker job losses leading to influx to informal settlements;
- Socio problems; and
- Service delivery pressure.

Farmers agreed the potential socio-economic impacts would be related to a decline in the economies of the towns largely dependent on agriculture. Farmers agreed the potential socio-economic impacts would be related to job losses due to the impact the loss of especially international markets would have on the agricultural industry. When the markets for labour intensive crops are lost it would lead to job losses. Job losses result in the influx of farm workers into towns, contributing to the growth of informal settlements, which in turn could lead to further deterioration of water quality and impact on agriculture if towns are not prepared for additional service delivery requirements for the growing urban population.

The impact will be felt on farms as well as in towns as highlighted by comments: *“Will have a negative impact on the socio-economic situation of farm workers when the export market is lost and workers not have an income and need to move to towns, contributing to informal settlements and on its turn could lead to further deterioration of water quality and agriculture”* (F2), *“If export market is lost - job losses on farms will result in influx into towns and will impact on the town's economy”* (F5). One participant suggested the effect of lower buying power in town on retailers in these towns is generally felt long after a poor agriculture season: *“In general 12-18 months after a poor season the effect is felt in the town - in the supermarkets, retailers etc - all that supports agriculture - lower buying power in town”* (F5).

The participants were concerned that the influx into informal settlements could lead to social evils such as an increase in crime as indicated by the comment: *“When the export market is lost it will lead to job losses and influx of jobless people into towns, expansion of informal settlements. Risk exists that increase of poor/jobless people into towns leads to a socio-economic impact”* (F6), *“...as in the Karoo currently due to the drought, people will be forced to move to towns as there will be no work on the farms.... in towns it will also add to socio-economic problems”* (F7), *“With the decline in the economy and population growth in towns comes social issues such as an increased crime rate etc”* (E4) and *“and exacerbate the existing socio-economic condition, crime etc”* (E6). Although there is a risk of job losses leading to socio-economic impacts in towns,

participants considered this the “*worst case scenario as there is no likelihood for this to occur in the foreseeable future*” (F8). However, the influx to informal urban settlements around the larger towns due to seasonal workers not returning to their homes after each harvest season are linked to a decline in water quality (section 4.3.4.4 to 4.3.4.6) as mentioned by: “*Agriculture in some areas depend on seasonal workers; more often these workers stay in the region, exerting pressure on the municipalities to deliver services - increased pressure on WWTW*” (F15). There is therefore a moderate risk that water quality would have an impact on socio-economic development and community resilience/ vulnerability in the Breede River catchment.

4.3.5.8 Risk of impact on environmental sustainability of the Breede River catchment (QE8E/QE9F)

In response to QE8E/QE9F in the questionnaire, participants were asked to indicate their opinion on the impact water quality has on environmental sustainability of the Breede River catchment. Participants were asked to elaborate on the opinion they expressed on the impacts water quality has on environmental sustainability of the Breede River catchment. The Breede River catchment has been modified and is essentially a very dry area where irrigation is only possible due to the Brandvlei Dam and the irrigation canal system. Although the catchment is already highly modified by agricultural developments the decline in water quality will impact the environment negatively.

Farmers generally agreed that water quality has a minor negative (67%) (10 of 15) impact on environmental sustainability of the Breede River catchment with 46% (6 of 13) of Experts agreeing (Figure 4-50). However, 30% (4 of 13) of Experts and 26% (4 of 15) Farmers were of the opinion that a major impact on environmental sustainability exists in the Breede River catchment and that it can be linked to water quality.

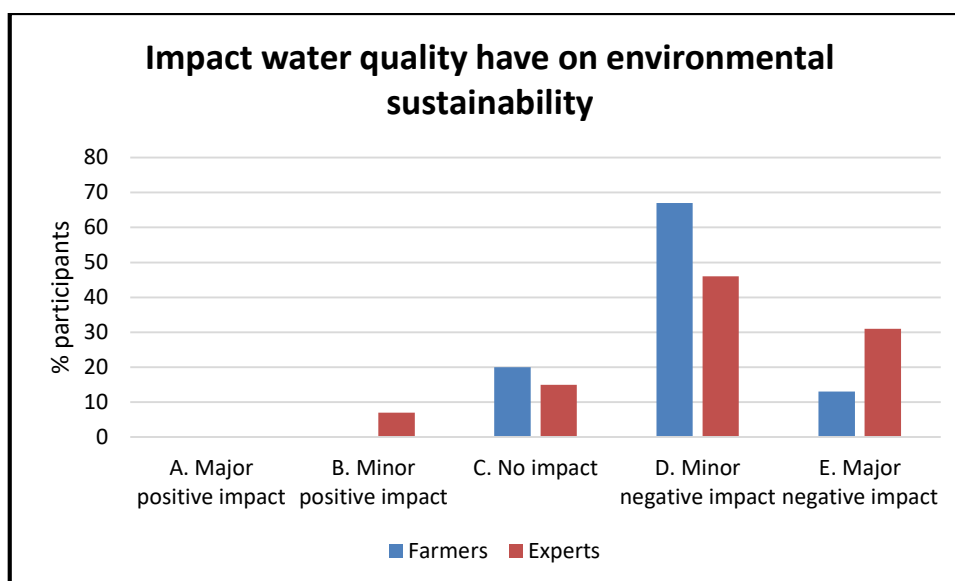


Figure 4-50: Distribution of Farmers' and Experts' opinion on the impact irrigation water quality has on environmental sustainability (QE8E/QE9F).

Agriculture has been linked to increased nutrients with an increase in algae and alien plants which thrive on the nutrients washed from agricultural land as well as nematode species spreading through the irrigation canals and river. When water quality is poor, more fertilizer might be required, which leads to a further impact on the environment when ending up in return flow. Degradation of the natural ecosystem leads to an increase in pests which attack crops.

The participants were also asked in an open-ended question to elaborate on their opinion on the impact water quality has on agricultural activities in the Breede River catchment. The thematic analysis of their responses yielded the following themes:

- Link with alien species;
- Managed on farm scale;
- Link with irrigation practices;
- Link with impacts on agriculture;
- Biodiversity/ ecology impact;
- Soil quality; and
- Link to human health.

Although Farmers agreed that agriculture contributes to pollution of the water resource, they felt that the impact is limited. Farmers indicated that the use of agro-chemicals on farm-scale

decreased since 2000. However, participants indicated that some environmental impact is related to agriculture as highlighted in the comments: *“Increase in eelworm (nematodes) due to agriculture activities...”* (F5), *“As alien plants thrive on the nutrients washed from agricultural land they have become a problem”* (F8). However, the net effect of not looking after the environment will impact on agriculture itself as highlighted by the comments: *“When water quality is poor, more fertilizer might be required which leads to a further impact on the environment when ending up in return flow some nematode varieties spreading through the irrigation canals and river is of concern as it affects crop quality”* (F6).

Participants generally agree that removing alien species from their farms contribute to improving biodiversity and the natural ecosystem in general as highlighted in the comments: *“Currently working on improving the environment to rectify the impact from past farming practices by removing alien plant species and re-introducing plants which will improve the water quality in the river itself”* (F2). Farmers were in agreement that the impact can be managed *“on farm scale to prevent the environment being affected”* (F4); however, should the profitability of agricultural activities be impacted negatively these efforts might be abandoned as evidenced by the comment: *“When financial situation changes this effort will not continue, therefore see a link between water quality decline and decline in environmental sustainability”* (F2). The efforts in sustaining the environment are to the benefit of agriculture as highlighted in the comment: *“Degradation of the natural ecosystem leads to increase in pests which attack crops; if the crops already have a poor immune system brought on by poor water quality, crops will be affected”* (F6).

The Papenkuil wetland and the services provided has been affected by agriculture *“Poor water quality can impact on downstream wetland and affect the services provided- i.e. cleaning of the water for downstream users”* (F8). Impact of another nature on water quality related to the ecosystem and biodiversity in the lower Breede River and tributaries (Buffeljags River) include the loss of species (fish) (Annabel Horn, personal communication, 23 July 2021; Aileen Anderson, personal communication, 18 August 2021).

Although some Farmers (5 of 15) are aware of the various efforts by conservancies, NGOs, BGCMA and Cape Nature to clear alien species and monitor water quality in the catchment, most are not aware of the work done by these organisations. The likelihood of an impact occurring is high although the consequence is currently moderate but has the potential of being significant. The expected future risk is therefore high to extremely high.

4.3.5.9 Actions to minimise the impacts caused by the decline in water quality (QE9E/QE10F)

In response to QE9E/QE10F in the questionnaire, participants were asked in an open-ended question to elaborate on potential actions which could be taken to minimise the impacts caused by the decline in water quality in the Breede River catchment. The thematic analysis of their responses yielded the following themes:

- Prevention,
 - Treatment,
 - Management of infrastructure,
- Monitoring,
- Enforcement of legislation,
- Communication and education,
- Control of invasive alien species,
- Implementation of new technologies, and
- Research.

Participants suggested that the prevention of the decline in water quality would be easier than to manage the impacts caused, as is evident from the comments by both Farmers and Experts: *“In general, farmers are more aware of their impact on the entire system and act more responsibly than in previous decade / by the previous generation”* (F6), *“Rather prevent a problem to occur or to escalate than to try fixing it later when it might be more difficult to do so”* (E6). As part of prevention efforts participants indicated that the treatment and management of water generated on the farm and also of domestic and industrial effluent are required as highlighted by the following comments: *“Ensure that no pollution from farm enter river...”* (F15), *“Agricultural return flow should be treated (active or passive) to remove salts and not allowed to enter river”* (E10), *“good management of municipal areas, chemical control on farm, run-off water”* (F1). The management, maintenance and upgrade of municipal WWTW infrastructure were flagged by both participation groups (6 of 15 Farmers and 5 of 13 Experts) as a crucial factor in managing the impact as highlighted in the comments: *“Efforts to manage biological pollution needs to be in place”* (F2), *“WWTW needs to be upgraded and maintained to prevent spillages”* (F8), *“Manage informal settlements better”* (F10) through *“management of population and growth of informal settlements”* (F3), *Investing in improved waste water treatment and purification methods and systems”* (E7) and *“WWTW needs attention and upgrade to cope with the volumes of sewage to be treated”* (E9). The monitoring of all pollution sources are proposed as not all sources are linked to the

treatment and maintenance of municipal WWTW infrastructure: *“Actions need to be taken to monitor other non-agricultural activities and their impact on water quality in order to minimise the impact on agriculture which is the most important contributor to the local economy”* (E4). However, some participants were of the opinion that the monitoring and management of water resources in the BGWMA by CBWUA and BGCMA is sufficient and need to continue: *“Structures are in place to manage the decline in water quality on behalf of all water users”* (E4). Several comments alluded to the fact that the monitoring and enforcement of environmental regulations are not strict enough and need to be improved as highlighted by the following comments: *“Stricter control and monitoring of all waste water generated”* (F14), *“BGCMA need to be more consistent in how they apply the law...”* (F7), *“BGCMA must be more pro-active”* (F11), *“Better enforcement of waste water laws”* (F13), *“... must be followed-up to trace the polluter, bringing the perpetrator to book in order to rectify the problem as soon as possible”* (E5) and *“Enforcement of legislation is required to ensure pollution is prevented and where transgressed that steps are taken to correct the problem”* (E6). The enforcement of environmental management tools such as those EIA and EMP requirements were also included in this theme: *“Intensified agriculture is likely to increase water pollution; thus the effective implementation of EMPs, MMPs, etc. are crucial to effectively manage the industry”* (E7).

The communication and education of all water users in the BGWMA could assist the main role-players in managing the water quality. This was highlighted by several participants to ensure: *“All water users take responsibility for their use of water and waste water”* (E13), *“Raising public awareness of the effect of our actions on the environment, teaching children, fostering a love for nature in children (school curriculums), educating farmers and farm workers”* (E7), *“Farmers must be made more aware of the impact their practices might have on the environment and users downstream”* (F2), *“Role players such as farmers must be more aware of the impact of their activities on water quality, general awareness”* (F5). The awareness not only included making farmers more aware of the impact of poor water quality but also extends to them being assisted in their activities related to irrigation scheduling as indicated by the comment: *“Communication of potential quality concerns must be done regularly to assist farmers in planning how irrigation under potential quality decline will be managed”* (E5), but also of their impact on the water resource and ecosystem: *“Farmers must not only be made more aware of the impact their practices might have on the environment and users downstream”* (F2) but also of the actions they can take to the prevention of pollution including the following: *“rehabilitation of rivers to put plants back which are taking up heavy metals etc to improve river (water quality)”* (E3), *“Remove alien*

species to prevent flood damage” (F14), and “.... plant indigenous plants along river to assist in improving the environment and in effect the water quality” (F6).

There was a general perception that: *“...farmers are more aware of their impact on the entire system and act more responsible than previous decade / generation” (F6)* with Farmers implementing techniques and technologies not available in the past in the prevention and control of pollution and general water management including: *“Continuous soil moisture monitors installed helps determine when to irrigate crop for maximum output and avoid over irrigation and return flow” (F6)*, however, some proposals indicate that technology development is required as available methods are not sufficient in preventing and/ or minimising impact on the water quality at an acceptable cost to the agricultural sector as testified by the following comments: *“In future farmers might need to manage water quality on site” (F11)*, and *“Agricultural return flow should be treated”* and *“New agricultural techniques should be developed to lessen the impact from agriculture” (E10)*, *“Using more environmentally friendly agro-chemicals where possible” (E7)* and *“Use consultants to bring new technology to farm more responsibly and more efficiently - see Netherlands, Japan, Israel” (F10).*

Although several future research focuses have been identified: *“Research in the field of potential water quality impact” (E5)*, *“Ensuring that the latest research is being incorporated into EIAs and decision-making (e.g. approve developments based on input from biodiversity maps to eliminate encroachment on watercourses and maintain buffer zones and corridors)” (E7)*. The following comment suggests that findings from previous studies were never implemented and suggest the focus should not be on more research but rather on the application of these findings in the prevention and management of water quality in the BGWMA: *“research should be more focused and a 10% / 90% split should be obtained at least where research consists of 10% of cost and implementation of research outcomes to improve the situation 90%. Having a million studies and no action is worthless” (E8).*

Participants also alluded to the concern that not enough water is available in the BGWMA and that allocation of water for new operations places the already strained resource under more pressure if no additional storage capacity is generated. Comments suggest that additional storage might be an option, but would require substantial investment in construction: *“Construct weirs in Breede River to form more low level dams to store water for late summer periods - winter rain can be stored where it is now lost to the ocean” (F13)* and *“Build more weirs to store water in stream (Michells Pass area) to make use of water all year and not let so much water flow into ocean which could have been utilised” (F14).*

4.3.5.10 Effectiveness of actions taken to minimise the impact caused by the decline in water quality (QE10E/QE11F)

In QE10E/QE11F in the questionnaire participants were asked, in an open-ended question, to elaborate on their opinion on the effectiveness of actions taken by various role players to minimise the impacts caused by the decline in water quality in the Breede River catchment.

Most of the comments from participants were related to what the different role players should be doing rather than focusing on the efficiency of current initiatives. The thematic analysis of the responses yielded the following themes:

- Level of cooperation between role players involved including BGCMA and municipalities,
- Efforts not sufficient, and
- Initiatives by the general public.

There was no clear agreement between participants on whether the efforts by various role-players were coordinated sufficiently to work towards the common goal, i.e. minimising the impacts caused by the decline in water quality. Some participants commented that the efforts by role players were fragmented: *“The role players need to combine efforts and act on each one’s responsibility to protect the water resource”* (F2), *“collective efforts not existing - individuals do good work but not all role players involved”* (E3), *“A holistic approach in the management of water in the entire catchment is required”* (F4), *“some effort is made by farmers, CMA and WUA but not all role players’ have proceeded to embark on effective actions”* (F6). Whereas others suggested that the efforts were well coordinated: *“all role players in the Western Cape are working together with farmers – Department of Agriculture”* (F2). However, comments on specific role players suggest that their efforts are not perceived to effectively manage the impact caused by the decline in water quality as pointed out by the following comments: *“municipalities not managing WWTW properly”* (F1), *“BGCMA needs to relook their policies and consistency in applying these policies”* (F8), *“Municipalities - not all effective in preventing WWTW spillages and BGCMA - generally effective but can improve”* (F11).

The comments by several participants related to the work done by BGCMA were inconsistent with Experts generally acknowledging the success of the efforts by BGCMA whereas Farmers generally not agreeing with this view as evidenced from the following comments: *“BGCMA-generally effective but can improve”* (F11), *“Structures such as the water user associations, BGCMA are key to manage the impacts on water quality”* (E4) compared to *“BGCMA needs to be more pro-active to ensure water quality and quantity is secured and should not react only after*

a problem is brought to their attention” (F8), “Although BGCMA acts quickly and efficiently when problems are reported they generally act reactively and not pro-actively” (E9), and “Currently not enough done by government/ BGCMA to enforce water laws related to polluters” (F13).

Although not highlighted by most participants, the contribution by the general public was also criticised and not effective *“Efforts are not sufficient - role players: farmers, general public, government/ municipalities (F2), and “Communication/ education and awareness - the general public needs to be educated and to take responsibility to prevent solid waste from entering the river systems” (E6).* However, as highlighted previously there is a general lack of knowledge, especially among Farmers, of the involvement and initiatives by NGO's and other environmental conservation organisations in the BGWMA.

4.4 Chapter summary

Results showed that there were periods in the past when the TWQR and BGWMA RQO limits for various parameters were exceeded and that this occurred more regularly in the main river and tributaries in the Middle Breede River section. The time series data of the main water quality parameters in the BGWMA showed similar spatial variation with two distinct groups, those with higher parameter values, mainly from the Middle Breede River section and those with lower values mainly from the Lower Breede and Riviersonderend sections.

Since the pH values at the majority of the monitoring stations remained relatively constant at $6.5 < \text{pH} < 8.4$, the impact on agriculture was low over the past 30 years and is not expected to become a problem in the foreseeable future. At these pH levels no substantial corrosive impacts on the irrigation equipment, no encrustation of irrigation pipes and clogging of micro-irrigation systems, and no damage to crops (fruit and other crops) or diminished yield and crop quality are expected. The pH value regularly dropping to around four (4) in the Upper and Lower Breede River and Riviersonderend sections, where organic acids leaching of water from un-decomposed fynbos and forest plants along mountain streams, resulted in the natural lower pH values for water in the Western Cape. Although not considered to be detrimental to most crops, the lower pH is likely to have a corrosive effect on irrigation equipment and impact the effectiveness of agro-chemicals. The seasonality observed in the pH values were linked to: atmospheric solutes, dust and organic materials, sea salt deposition, organic acids, weathering of bedrock, precipitation patterns and seasonal activities such as farming.

The Gibbs diagrams showed surface water in the Middle and Lower Breede River sections have moderate TDS levels which are linked to the natural weathering of the underlying geological

formations and subsequent concentration through evaporation. However, the contribution of marine aerosols (contribution to Na, Cl and SO_4) due to the proximity to the ocean should not be excluded especially in the Lower Breede River and Riviersonderend sections. The Upper Breede River section reflected some dilution of the original rock weathering dominated TDS levels by precipitation, which is known to be higher in the mountainous areas. The Piper diagrams support the findings from the Gibbs diagram by identifying the domination of Na, Cl and HCO_3 in all sections of the BGWMA investigated linked to the influence of the weathering of underlying geology. This finding is in agreement with previous studies which suggested that the salinity in the Breede River were closely related to the underlying Bokkeveld Group shales. The finding regarding the link between salinity, underlying geology and agricultural activities in the Breede River is further supported by similar findings from the Berg River where the land use is similarly dominated by agriculture.

The EC, which is an indication of the salinity level in a water resource, is an important water quality parameter in agriculture due to the impact on soil, plant growth and yield. The high salt content may originate naturally from the weathering of the underlying geology and excessive evaporation especially during droughts but may also arise from activities such as agricultural. The components of EC which showed elevated levels which may impact on agricultural activities in the study area included: Na, Cl, $\text{NO}_3 + \text{NO}_2$ and PO_4 . The spatial variation of the EC along the Breede River showed values increasing in a downstream direction as observed in the main Breede River as well as tributaries. This was also highlighted by previous studies which showed the headwaters of the Breede River and foothill mountain stream areas generally showed lower EC values compared to the valley area. The EC increase downstream is closely related to the inflow of some tributaries but also the contribution from agricultural return flow.

Although TWQR (40 mS/m) were exceeded at the majority of the stations they generally fall within the BGWMA RQO for EC which allows fluctuation between 70 and 120 mS/m. However, some impact on crop yield is expected as decrease in grapevines yield occurs where soil EC exceeds 75 mS/m. Irrigation with highly saline water will lead to the build-up of salts in the soil profile, which may affect crops sensitive to soil salinity, such as grapevines, leading to reduced yield. Salinity also impacts the palatability of water to livestock and have a detrimental effect on animal health. At the salinity levels experienced in the study area grapevines still seem to perform reasonably well. The emergency practice of irrigation with saline water in the absence of better quality irrigation water during prolonged droughts is therefore not detrimental in the short term but it should only be used as a temporary measure. Salts should be leached from the soil after one or two seasons as the cumulative effect of salinity and increased salinity in the soil in one season

has a substantial impact on the growth in the following season. Sodium (Na) often accumulates in saline soils, particularly in low rainfall areas where leaching might be limited. The levels of Na in surface water are generally low in areas of high rainfall, and high in arid areas with low mean annual precipitation. Other sources of Na include industrial wastes, especially processes generating brines, and domestic waste water. The similarities in the spatial variations observed for Na and Cl is supported by the strong correlation on the Pearson's correlation matrix suggesting a common source. However, Cl is known to originate from natural sources, irrigation return flows, sewage and industrial effluents. Although no BGWMA RQO were set for Na, Cl and SAR, the Na and SAR DWS TWRQ for irrigation are set at 70 mg/l and 0 to 1.5 respectively. The spatial variation of the Na, Cl and SAR along the Breede River showed values increasing in a downstream direction as observed in the main Breede River as well as tributaries with steady increase since the 1970s especially in the lower part of the Middle Breede River section. The detailed time series plots also show a cyclical pattern for Na with poorer quality water during the dry season (October to April), supported by previous studies which suggested that crop quality and yield in the affected sections are compromised. Irrigation with water with high Na concentrations may lead to accumulation in the soil which have an impact on physical conditions of soil and/or absorption by leaves resulting in reduced yield where the leaves are the marketed product. Uptake of Na by plant roots can result in the accumulation of sodium to levels that are toxic to plant growth, and may be the cause of reduced yield or diminished crop quality, including the fruit size and appearance.

The water in the Upper Breede River section and upper part of the Middle Breede River section up to station H4H017Q01 are suitable for irrigation purposes with respect to SAR, but water in the tributaries including the Riviersonderend and the Lower Breede River sections are not suitable for this purpose. Na is not considered an essential plant nutrient with many crops accumulating Na to elevated levels in plant tissues leading to toxicity. The uptake of Na by vineyards and other plant roots affect plant growth, reduce fruit size and yield and diminished crop quality.

Of the anions $\text{NO}_3 + \text{NO}_2$ and PO_4 did not show any correlations with other parameters, suggesting the sources of these ions differed from that of the other ions. None of the monitoring station had a $\text{NO}_3 + \text{NO}_2$ concentration exceeding the 5 mg/l TWQR for irrigation water suggesting that the nitrogen concentration would not affect crop yield. Crops such as grapes and fruits are sensitive to nitrogen concentrations in irrigation water exceeding 5 mg/l. When grapevines are irrigated with high levels of N it may lead to delayed poor yield of grapes with low sugar. However, the potential for stimulation of algal growth and mesotrophic conditions are relatively high in the Upper and Breede River sections. The spatial variation in the nitrogen concentration along the Breede River

main stream showed that the Upper Breede River section closer to Ceres showed a sharp increase in $\text{NO}_3 + \text{NO}_2$ and PO_4 concentrations since 2000, linked to WWTW upstream (Ceres). Nutrients concentrations appear to decrease downstream of Worcester/ Brandvlei Dam but spike again in the Middle Breede River at Robertson which supports findings from previous studies which linked it to return flows from the Worcester and Robertson WWTW and non-point source pollution from un-serviced peri-urban informal settlements. The link between nitrogen levels and increased farming activities which could result in elevated $\text{NO}_3 + \text{NO}_2$ in irrigation return flow should, however, not be disregarded. This trend was also observed in the Berg River, which has similar land use and impacts to the Breede River, and were generally linked to a combination of droughts, population growth and a fast growing local economy which has put severe pressure on water resources and WWTW. The improvement in the $\text{NO}_3 + \text{NO}_2$ in the Lower Breede River section can be linked to natural processes which removes nitrogen.

Nutrients are essential for plant growth and reproduction, but at elevated levels they can be harmful and pose risk to humans and animals and promote the growth of waterweeds such as water hyacinth and grasses. Nutrients such as nitrogen and phosphorus generally originate from anthropogenic activities such as agricultural runoffs (fertilizers), untreated domestic sewage and industrial effluent discharges. The impact of high nutrient levels on agriculture include poor crop quality, toxicity to animals as well as algae growth which clog irrigation equipment. Phosphorous is a vital nutrient necessary for plant growth but above 0.05 mg/l the risk for algal blooms and eutrophication developing due to nutrient loading increases the likelihood of bio-fouling in irrigation equipment

Based on the Coliform and *E coli* TWQR for irrigation and BGWMA RQO limits the majority of the stations exceeded these limits at regular intervals with Faecal Coliform counts as high as 240 000 c/100 ml and *E coli* counts of up to 110 000 c/ 100 ml recorded at stations higher-up in the Upper Breede River section. Monitoring stations in the Middle Breede River section showed a similar trend although the levels rarely exceeded 1 000 counts/ 100 ml. The level of compliance of the municipal WWTW from previous studies were compared which indicated that the level of microbiological compliance of most WWTW improved between 2010 and 2018, the only exception being Montague. Of concern is the low levels of compliance to the microbiological standards reported for Robertson. An alarming trend is the elevated levels for *E coli* (up to 6 000 c/100 ml) recorded more recently (2019-2020) at stations downstream from Worcester, suggesting failure of the upgraded WWTW.

The WQI findings showed that the water quality in the tributaries were unsuitable for irrigation. The lower part of the mainstream in the Middle Breede River section improved over time from tolerable to acceptable or ideal. The Lower Breede River section (and Riviersonderend section) had the best suitable water quality with most parameters classed as ideal. EC and PO₄ were the parameters which were most often not classed as ideal. This is also true for all stations since 2000.

Water-dependent industries such as agriculture are particularly vulnerable to the decline in water quality. Although the risks posed to the agricultural industry in the Breede River catchment have been acknowledged by previous studies, the nature and extent thereof were unpacked by this study.

The discussion of the background information gathered on participants (Section A) applicable to this study contributed towards demonstrating the credibility of the qualitative and quantitative data collected during the interviews and completion of the questionnaires during this research study. Background information gathered related to the irrigation practices in the study area (Section B) assisted in aligning responses (mainly from the Farmers group questionnaires) according to sub-catchments, crop type etc. which assist in highlighting important trends in water quality and related impacts.

Key drivers/ stressors with the most substantial effect on the water quality and quantity in the Breede River catchment were identified through a set of closed-ended and open-ended questions (Section D) and contributed towards addressing Research Objective 2. In the close-ended questions participants given the opportunity to rank the main drivers of the water quality in the Breede River by rating their relevance but also to indicate the level of influence the key drivers have on the water quality in the catchment. The open-ended questions provided participants the opportunity to elaborate on their opinion regarding the important key drivers of water quality decline in the Breede River catchment. These responses were important in identification and evaluation of the key drivers. The thematic analysis of their responses yielded themes which guided the discussion.

The identified drivers of the water quality in the Breede River were mostly associated with negative impacts on the water quality. Farmers indicated the most dominant drivers as: domestic effluent > population growth > agricultural growth > co-operative governance > geology/ soil, whereas the Experts listing the dominant drivers as: domestic effluent > population growth > geology/ soil > co-operative governance/ industrial developments/ growth in agricultural activities > climatic conditions.

Geology and soil as drivers of water quality: Underlying geology and soil has an influence on the release of elements into the environment through natural weathering and leaching. The majority of Farmers and Experts indicated that geology/ soil would have a slight negative influence to no influence on the water quality in the Breede River catchment. This is contradictory to the findings in this study (Section 4.2) and previous studies which showed that the underlying geology and soil is the main contributor to the high salinity levels in the irrigation water in the Breede River catchment. Farmers and Experts considered the influence underlying geology and soil as a natural input which will remain consistent over time and therefore ranked this factor as a low potential driver for the water quality decline in the Breede River. However, in subsequent sections both groups agreed that the underlying geology did have an important influence on the surface water quality.

Climate as drivers of water quality: Climate has an influence on the release of elements into the environment as well as on the rainfall patterns. However, Farmers and Experts indicated that climate currently have only a slight negative to no influence on the water quality in the Breede River catchment. Although only a minor section of participants were of opinion that climate change have a potential strong negative influence on the water quality, the reality is that large parts of the Western Cape are already listed as “absolute water scarce” with climate change expected to exacerbate water availability and quality, which will have a negative impact on the agricultural industry, food security and economic growth.

Most participants agreed that there is a periodic decline in water quality which could be linked to occurrences of natural dry periods (late summer and droughts), they did not link these with climate change. They agreed that the salinity levels are high due to high evaporation rates during these periods as well as the lack of sufficient fresh water acting as dilution of the salinity levels in surface water is low during dry periods. Furthermore, the salinity levels would be remediated by winter rainfall and/or release of fresh water from the Brandvlei Dam which flush the system. This is exacerbated by being located in a predominantly winter rainfall region, where the availability of water during winter storms does not coincide with the needs for summer irrigation.

Anthropogenic: growth in agricultural activities as drivers of water quality: The growth in agricultural activities has an influence on the release of elements into the environment through the flushing out of elements from agricultural soils which will filter through to the surface water resources through return flow from agricultural areas. The Farmer and Expert groups indicated that growth in agricultural activities would mainly have a slight negative influence on the water quality in the Breede River catchment which was mainly linked to the increased volume of

irrigation return flow water, which are highly saline and contain agro-chemicals, leaching from the soil and enter the surface water resources. Furthermore, development of virgin land, where salts were not previously flushed out of the soil in areas underlain by Bokkeveld Group shale (Middle Breede River section), would contribute to the salinity levels in the surface water. The link between growth in agricultural activities and population growth was also highlighted.

Anthropogenic: domestic activities as drivers of water quality: The majority of Farmers and Experts were in agreement that domestic effluent/ waste water would have a strong negative to slight negative influence on the water quality in the Breede River catchment. The negative impact is mainly related to the potential microbiological contamination from domestic effluent from WWTW inefficiency and untreated domestic waste emanating from un-serviced informal settlements situated close to surface streams.

Population growth as drivers of water quality: The majority of Farmers and Experts indicated that population growth would have a strong negative to slight negative influence on the water quality in the Breede River catchment. Although population growth were generally linked with growth in agriculture as well as the move towards citrus, which is more labour intensive, results did not reflect the suggested increased number of workers on the farms between 2000 and 2020. Nevertheless, population growth were generally associated with increased pressure on municipal WWTW infrastructure as well as increased grey water runoff from expanding informal settlements. These sources were of concern and considered to be a growing contributor to downstream water quality risks, particularly with regards to microbial concentrations and both total coliforms and *E. coli* concentrations impacting downstream water uses. These findings were in agreement with previous studies which identified the domestic effluent as an important source of pollution. Furthermore, the growth in population, industrial development, and improved living standards in the Greater Cape Town area are expected to place additional pressure on the BGWMA water resources as the volume of water transferred from this catchment to sustain the demand in the Greater Cape Town is expected to increase.

Industrial developments as drivers of water quality: The majority of Farmers indicated that future industrial developments would have a strong negative influence to no influence on the water quality in the Breede River catchment whereas the majority of the Experts group were of opinion that industrial developments would have a slight negative influence on the water quality. Most industries in the study area are currently associated with agriculture with wineries, fruit packaging, distilleries as well as dairies and dairy manufacturing dominating. Although the potential for

contamination were considered to be low due to industry audits as well as DWS license agreement monitoring, some distillery effluent were identified as sources of pollution.

Cooperative governance as drivers of water quality: The majority of Farmers indicated that cooperative governance would have no influence to a slight negative influence on the water quality in the Breede River catchment. Experts were of the opinion that cooperative governance have a positive influence on the water quality due to the good cooperation between various parties involved and highlighted the cooperation between BGCMA, various WUA and local, district, provincial and national departments. However, there seems to be a difference of opinion as to the consistency with which law enforcement is executed with non-compliance directives enforced less strictly between different government departments compared to how private companies are treated, highlighted by Farmers.

This was then followed by the identification and evaluation of the risks posed by the potential decline in water quality in the Breede River catchment to agricultural activities identified through a set of closed-ended and open-ended questions (Section E) and contributed towards addressing Research Objective 3. In the close-ended questions participants were given the opportunity to rank the main risks of the perceived decline in water quality in the Breede River catchment in 2000 and also considered impacts beyond 2020. The open-ended questions provided participants the opportunity to elaborate on their opinion regarding the important key risks water quality had and potentially will have on agricultural activities, socio-economic development and environmental sustainability in the Breede River catchment. The thematic analysis of their responses yielded which guided the discussion. The probability or likelihood of the identified impacts of the decline in water quality and the consequence severity posed by these impacts were captured in a risk matrix to define the level of risk posed by each.

The identified risks of the water quality in the Breede River were mostly associated with negative impacts of the water quality. Farmers indicated the most dominant risk as: risk to agricultural activities/ risk to economic growth of the area > risk of impact on socio-economic development > risk to quality of the crops/ products > risk of financial impact on farming operations/ risk to sustainability of agriculture > risk to environmental sustainability. Experts on the other hand listed the dominant risks of the water quality as: risk of impact on socio-economic development > risk to sustainability of agriculture > risk to economic growth of the area/ risk to environmental sustainability > risk of financial impact on farming operations > risk to agricultural activities.

Risk of impact of water quality on agricultural activities: The majority of Farmers indicated that the likelihood of negative impacts from water quality on agricultural activities were high and was

mostly related to the potential impact of salt load on the soil quality, crop yield as well as microbiological impact on crop quality and market. Since the consequences were considered to be moderate, the risk was therefore considered to be high.

Water quality impact on the quality of the crops/ products: The majority of Farmers indicated that the likelihood of negative impacts from water quality on the quality of the crops/ products were moderate to high and was mostly related to the potential impact of *E. coli* and salinity on the crop quality, loss of export market and depended on the crop type and crop resilience under saline conditions. Since the consequences were considered to be moderate to high, the risk was therefore considered to be high to extremely high.

Water availability impact on agricultural activities: The majority of Farmers indicated that the likelihood of negative impacts from water availability impact on agricultural activities were high and was mostly related to the water quality, crop type, irrigation type and potentially impact the growth in agriculture. Since the consequences were considered to be high, the risk was therefore considered to be extremely high.

Financial impact of the irrigation water quality: The majority of Farmers indicated that the likelihood of negative financial impacts from irrigation water quality on agriculture were very low and was mostly related to the additional expenses related to increased maintenance costs on irrigation systems, water treatment costs, additional expenses to satisfy market of product quality (industry auditing expenses), as well as impacts on crop quality and crop yield. In addition the perceived poor quality of irrigation water (mainly related to *E. coli* contamination) may lead to the loss of markets and investments. Although the consequences were considered to be high, the risk was considered to be moderate.

Water quality impact on sustainability of agriculture: The majority of Farmers indicated that the likelihood of negative impacts from water quality on sustainability of agriculture were very low and was mostly related to the potential impact of the loss of export markets and lower profitability. However, the potential for adaptation of agriculture to adverse water quality and availability conditions (more resistant crop types etc.) and economies of scale (larger more industrialised farming setups) played a role in the consequence and likelihood rating. Although the consequences were considered to be high, the risk was considered to be moderate.

Water quality impact on the economic growth of the area: The majority of Farmers indicated that the likelihood of negative impacts from irrigation water quality on economic growth of the area were very low and was mostly related to the potential impact of the loss of export market (due to

perceptions of poor water quality) on the wider economy of the region as the majority of the economy was in some way dependent on agriculture. The mismatch between reality and perceptions was the impetus which elevated the risk level to moderate due to the potential knock-on effects of the loss of markets. The knock-on effect therefore suggest a negative impact on the economy of the region. Although the consequences were considered to be high, the risk was considered to be moderate.

Water quality impact on socio-economic development and community resilience/ vulnerability:

The majority of Farmers indicated that the likelihood of negative impacts from water quality on socio-economic development of the area were very low and was mostly related to the potential impact of a decline in agriculture with associated job losses (farm and related industries) and the knock-on effect of the influx of unemployed people to informal settlements leading to pressure on service delivery (including WWTW) and social problems (crime etc.). Although the consequences were considered to be high, the risk was considered to be moderate.

With regards to the actions to minimise the impacts caused by the decline in water quality, the results of this study indicate that participants considered the prevention, monitoring and enforcement of legislation to be the most important actions to be taken. Other actions included: communication and education of the public with regards to water quality and prevention of pollution as well as the control of invasive alien species. Although new irrigation technologies have been employed, reducing the volume of water required to irrigate the same area, new technological developments and research were identified as needs for the sustainability of agriculture.

With regards to the effectiveness of actions taken to minimise the impacts caused by the decline in water quality, participants did not agree on the effectiveness of the actions from the main role players. Participants did not agree that efforts from all role-players were coordinated sufficiently to work towards the common goal, i.e. minimising the impacts caused by the decline in water quality. Farmers were particularly critical of the formal structures (BGCMA, DWS) involved in Command and Control (CaC) although Experts indicated that there is well co-ordinated efforts between different government spheres in streamlining the enforcement of legislation. In addition the self-regulation efforts through industry auditing (GLOBAL GAP etc.) were listed as an efficient action, however, there are some concerns regarding the procedures which may be open to manipulation.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

Globally water supplies continue to decrease due to depletion and pollution of resources, while industrial and agricultural developments expand in order to meet the needs for the growing population. This is especially true in developing countries, like South Africa, where the urbanisation rate often result in a decline in water resource quality and quantity. Although water is critical for economic development, economic growth is also the likely cause of declining water quality and may exacerbate the water scarcity problem.

Water quality of most of South Africa's rivers has deteriorated over the past 20 years, including the Breede River catchment. Water-dependent industries such as agriculture are particular vulnerable to the decline in water quality. Since the economy of the Breede River catchment is dependent on agriculture, the decline in the water quality pose risks to the agricultural industry and consequently the economy of the entire Breede River catchment. Some of these risks were identified by previous studies, however, the nature and extent thereof were unclear. The aim of this study was therefore to investigate the decline in water quality and the associated drivers and risks to the agricultural industry in the Breede River catchment. In order to meet this aim, three Research Objectives were set:

- To re-evaluate the water quality in the Breede River catchment.
- To identify the key drivers of the decline in water quality of the agricultural sector in the Breede River catchment.
- To identify and evaluate the risks posed by the declining water quality in the Breede River catchment to agricultural activities.

This study is significant as the long-term water quality changes in the Breede River catchment and the perceptions of Farmer and environmental Experts, related the key drivers of the decline in water quality and the risks posed thereof on agricultural activities, have not been researched until now.

Chapter 1 of this dissertation introduced the research study by discussing the link between water quality, population growth, economic development and expansion of agriculture as well as the background of water quality in the Breede River catchment. Chapter 2 presented the literature review covering aspects such as sustainable development, water management, and background

to the study area including the water quality in the Breede River catchment. Chapter 3 covered the research approach, ethical considerations, sampling, data collection, data analysis and discussion, and the limitations of the methodology adopted to attain the set aim and research objectives. Chapter 4 presented the findings of the qualitative and quantitative investigation as well as discussion thereof to address the study aim as well as the research objectives.

This chapter summarise the main study findings, discuss the conclusions, as well as comment on the extent to which the research objectives have been met and the research question answered. Applicable recommendations for future research emanating from the findings were also presented.

5.2 Summary of main findings and conclusions

The three Research Objectives were met through the introduction in Chapter 1, literature review in Chapter 2 of sources such as journal articles, acts of parliament, official publications, research reports, maps, databases and the internet, as well as the results of the empirical study covered under Chapter 4. This will be discussed in the following section.

Research Objective 1 was to re-evaluate the water quality in the Breede River catchment. In the introduction in Chapter 1 the importance link between development and water quality decline was highlighted which were expanded on in the literature review in Chapter 2, which showed that the water quality decline in the Breede River were a known concern and discussed the water quality requirements for agriculture in general as well as for the crops grown in the study area. Furthermore, natural and anthropogenic impacts on the water quality were highlighted. In Chapter 4, covering data analysis and discussion long-term datasets of DWS and BGCMA was scrutinised for data quality and acceptable data used to evaluate the water quality for four sections of the BGWMA over the period 1970 to 2018. Results showed that the water in the BGWMA is domination of Na, Cl and HCO_3 linked to the underlying geology, which were in agreement with previous studies which suggested that the salinity in the Breede River were closely related to the underlying Bokkeveld Group shales. The potential negative impact of the water quality on agriculture were highlighted by the Na concentrations and SAR in the irrigation with water in the lower parts of the Middle Breede River including tributaries as well as the Riviersonderend and the Lower Breede River sections. The continuous leaching of the weathering products from the underlying geology resulted in saline return flow with the cumulative effect leading to the increase in salinity downstream. Uptake of Na deposited by irrigation water accumulate in the soil to levels toxic to plant growth (including vineyards), causing reduced yield or diminished crop quality,

including the fruit size and appearance. The nutrients ($\text{NO}_3 + \text{NO}_2$ and PO_4) concentrations, which stimulate algal growth and lead to mesotrophic conditions, were linked to return flows from the WWTW and non-point source pollution from un-serviced peri-urban informal settlements. The impact of high nutrient levels on agriculture include poor crop quality, toxicity to animals as well as algae growth which clog irrigation equipment. Elevated Coliform and *E coli* levels in the Upper and Middle Breede River sections confirmed that there is contamination from municipal WWTW. The impact of high Elevated Coliform and *E coli* levels on agriculture depends on the crop type as irrigation systems used for vineyard and fruit trees prohibit contamination on the fruit/ product whereas other crops where irrigation occurs directly on the product would not be safe for human consumption. The WQI showed that the irrigation water in the mainstream of the Breede River and Riviersonderend section were suitable for irrigation but the tributaries were unsuitable for this purpose based mainly on the EC and PO_4 .

Research Objective 2 was to identify the key drivers of the decline in water quality of the agricultural sector in the Breede River catchment. In the introduction in Chapter 1 the link between water quality and agriculture was highlighted which were expanded on in the literature review in Chapter 2, which presented potential drivers for the decline in water quality in the Breede River catchment. In order to determine these drivers a sequential mixed methods data collection strategy comprising the integration of the quantitative and qualitative research methods was adopted and conducted through semi-structured one-on-one interviews (presented in Chapter 3). A total of 28 participants (15 Farmers and 13 Experts) took part in this study through two focussed questionnaires comprising of five sections and with open- and closed-ended questions, of which Section D was relevant for this objective.

In addressing Research Objective 2, the key findings of the study emerged from the responses provided including thematic analyses of the open-ended responses. In Chapter 4, the results of the questionnaire identified drivers of the water quality in the Breede River were mostly associated with negative impacts on the water quality. Farmers indicated the most dominant drivers as: domestic effluent > population growth > agricultural growth > co-operative governance > geology/ soil, whereas the Experts listing the dominant drivers as: domestic effluent > population growth > geology/ soil > co-operative governance/ industrial developments/ growth in agricultural activities > climatic conditions.

Research Objective 3 was to identify and evaluate the risks posed by the declining water quality in the Breede River catchment to agricultural activities. In the introduction in Chapter 1 the link between water quality and potential risks to agriculture were highlighted which were expanded on

in the literature review in Chapter 2. In order to determine the risks the open- and closed-ended questions in Section E of the questionnaires were relevant for this objective.

In addressing Research Objective 3, the key findings of the study emerged from the responses provided including thematic analyses of the open-ended responses. In Chapter 4, the results of the questionnaire identified by Farmers indicated the most dominant risk as: risk to agricultural activities/ risk to economic growth of the area > risk of impact on socio-economic development > risk to quality of the crops/ products > risk of financial impact on farming operations/ risk to sustainability of agriculture > risk to environmental sustainability. Experts on the other hand listed the dominant risks of the water quality as: risk of impact on socio-economic development > risk to sustainability of agriculture > risk to economic growth of the area/ risk to environmental sustainability > risk of financial impact on farming operations > risk to agricultural activities.

The risk matrix, which rated the probability of the identified impacts of the decline in water quality in the Breede River catchment on agricultural activities and the consequence severity, identified high risks as: the impact of water quality and availability on agricultural activities and water quality impact on the quality of the crops/ products with the impact of availability of water on agricultural activities closely associated with water quality also considered a high risk. The financial impact, impact on sustainability of agriculture, economic growth of the area as well as the impact on socio-economic development and community resilience/ vulnerability were rated as moderate to low risks mainly due to the low probability of these impacts occurring. This was an important finding as a previous study, which speculated that the decline in water quality (especially the microbiological water quality) could impact on the export market, could now be quantified. However, a risk which was not included in the questionnaire but became evident from the interviews, is the risk from unsubstantiated perceptions which has the potential to evoke emotive responses from consumers and has a high probability of leading to a negative reaction by international consumer markets which has far reaching consequences for the agricultural sector and the economy at large in the Breede River catchment. The differences between a scientific experts' and the lay persons' perception of environmental and technological risks are cause for concern, especially the influence it have on the way in which people understand risks and make decisions. Farmers identified contamination associated with WWTW as a real risk to water for irrigation purposes which might have an impact on their products due to elevated *E. coli* levels in the future. The microbiological water quality results (section 4.2.4) confirmed the concern as the TWQR for irrigation and BGWMA RQO limits (based on the Coliform and *E. coli*) were exceeded at the majority of the stations. Produce can be contaminated before, during and after harvest as well as when handled by humans during packing. The foodborne disease, associated with *E. coli*

contamination, can enter plants through roots and small openings in the fruit skin. However, the potential for water with compromised microbiological quality to impact on product quality is not a settled case since in fruit production irrigation water does not generally come into direct contact with fruit as irrigation systems, such as micro or drip irrigation, deliver water at the base of trees or vines. Furthermore, in cases of waxy and smooth fruit types, irrigation water does land on the fruit but it tends to roll off preventing pathogens to attach. In addition irrigating from a holding dam also allows pathogens to settle into the sediment below. The perception of poor quality water (ie *E. coli* contaminated) affecting all crops is therefore not scientifically based but rather of an emotional nature. There is therefore a mismatch between reality and perceptions which could elevate the low risk (based on low probability) to a high risk due to the high likelihood of this occurring.

The lack of good quality water can also be regarded as a potential “barrier-to-trade”. The loss of the export market is often related to the perception that fruit exported from developing countries, such as South Africa, are produced under unhygienic conditions or are regarded as of inferior quality. The potential loss of international markets due to perceived poor water quality and perceptions of lower product quality will have a negative impact on the farm scale but also the agricultural sector in the region in general. The impact has a knock-on effect which will impact on the labour market when job losses occur due to the loss of high income markets and ultimately negatively impact on the economy of the urban areas in the catchment as a result of lower available expenditure. The wider economy of the region will also be impacted negatively as economic activity was shown to be general dependent on agriculture.

The unsubstantiated perceptions are therefore regarded as a risk on its own as it has the potential to elevate the risk level in several categories including the risk to the economic growth, socio-economic development and community resilience, financial risk to agricultural activities, quality of crops, agricultural activities in general as well as sustainability thereof.

5.3 Contributions and recommendations for future research and practice

This study is significant because it gave an overview of the long-term water quality of the Breede River and the suitability of the water for agriculture. It further also identified the key drivers and risks of the decline in water quality. The impacts on agriculture were also linked to regional economic development, socio-economic development and community resilience and environmental sustainability. The nature and extent of the risks posed to the agricultural industry in the Breede River catchment were assessed and quantified. Some of the suggestions made

could be incorporated into water resource management plans for the Breede River, which if implemented could alleviate the pressure on the water resource. The areas of recommendations are:

- *Effective enforcement of legislation:* The perception by participants were that legislation related to water quality were not enforced consistently as all users were not treated equally, monitoring were not sufficient to prevent pollution as the number of stations and spatial and temporal resolution/ distribution of BGCMA monitoring stations were insufficient and no DWS monitoring was carried out since 2018;
- *Efficient management of WWTW infrastructure should be implemented:* The perception by participants were that insufficient infrastructure maintenance and monitoring at WWTW contribute to the decline in the water quality and should be attended to as a matter of urgency; and
- *Communication with and education of all role players, including residents and farmers, regarding the impacts of their actions on water quality should be considered.* This should include awareness of access to information such as the water quality databases, control of invasive alien species, and implementation of local solutions to prevent solid waste to enter the water resources.

The following are recommended areas of future research as identified during the undertaking of this study:

- Focussed research could further unpack the risks of the decline in water quality on the economy of the Breede River catchment;
- The drivers for water quality decline and risks thereof to agricultural activities in the Breede River catchment could in the future be investigated quantitatively;
- The impact climate change has on the sustainability of the agricultural sector, including the water quality, in the Breede River catchment should be investigated;
- Research focussed on solutions (treatment) to prevent poor quality (saline) agricultural return flow water entering the water resource can assist in alleviating the cumulative effect and decline in water quality; and
- The effectiveness of industry auditing (GLOBAL GAP etc.) and the potential contribution thereof on effective water quality management on farm scale was identified as a potential subsequent study.

In conclusion, the evaluation of the nature and extent of the water quality decline proved there are reasons for concern in the Middle Breede River and tributaries. The impact of the water quality on agriculture in the Breede River catchment were linked to salinity, nutrients and microbiological contamination. It was against the above that the aim of this study was to investigate the key drivers and risks associated with the decline in water quality to the agricultural sector in the Breede River catchment. The implementation of the recommendations can help to improve the water quality in the Breede River catchment. Moreover, it can assist in cultivating a sustainable future for agriculture in the Breede River catchment under a changing climate.

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ANNEXURE A: QUESTIONNAIRES

Summary of questions with coding indicating the Farmers (F) and Experts (E) groups

Section		Survey question
A: PARTICIPANT ORGANISATION	QA1E/QA1F	What is your highest qualification level?
	QA2E/QA2F	What is your occupational field?
	QA3E/QA3F	How long have you been working in your occupational field?
	QA4F	In which sector(s) are you placed? Select more than one where applicable.
B: BACKGROUND ON IRRIGATION PRACTICES	QB1E/QB1F	In which part of the Breede -Gouritz Water Management Area does your operation fall/ do you mainly work?
	QB2E/QB2F	What is the main source of water in the area? Please mark all relevant options by selecting 1 to 4 where 1= dominant to 4= least dominant.
	QB3F	Do you make use of any form of irrigation on the farm? If your answer is "B. No", please skip forward to question B16.
	QB3E/QB4F	What is the main source of water for irrigation purposes for the area of the catchment you mainly work in? Please mark all relevant options by selecting 1 to 7 where 1= dominant to 7= least dominant.
	QB4E/ QB5F	Which of the following crops are under irrigation on the farm between 2000 and 2020? Please mark all relevant options by selecting 1 to 5 where 1= dominant to 5= least dominant.
	QB6F	What was the land area under irrigation in the year 2000 per crop type? Kindly mark only one per crop type.
	QB7F	What was the land area under irrigation in the year 2020 per crop type? Kindly mark only one per crop type.
	QB8F	What was the quantity of water for irrigation purposes used for crop production and processing (m3/year) between 2000 and 2020? Please select one option per year.
	QB9F	What was the expenditure on water for irrigation costs (R) per crop type in 2000? Kindly select only one per crop type.
	QB10F	What was the expenditure on water for irrigation costs (R) per crop type in 2020? Kindly select only one per crop type.
	QB11F	In your opinion does the water quality in the catchment have an impact on irrigation system maintenance?
	QB12F	What was the expenditure on pumping/ electricity costs for irrigation (R) between 2000 and 2020 (include conventional as well as renewable energy costs)? Kindly select one option for each year
	QB5E/QB13F	Kindly elaborate on occurrences of water for irrigation allowance restrictions in the Breede River catchment between the year 2000 and 2020. Kindly elaborate on the reason(s) for the restrictions.
	QB14F	What was the quantity of fertilizer used for production in irrigated crops between 2000 and 2020 (ton or liters)? Kindly select one option for each year.
	QB15F	What was the quantity of herbicides and pesticides used for production in irrigated crops between 2000 and 2020 (liters)? Please select one option each for herbicides and pesticides.
	QB16F	What was the number of permanent and seasonal employees working in irrigated crop production between 2000 and 2020? Please select one option each for permanent and seasonal workers.
	QB17F	What was the number of permanent and seasonal employees working in processing between 2000 and 2020? Please select one option each for permanent and seasonal workers.

Section		Survey question
C: WATER QUALITY	QC1E/QC1F	What is your level of understanding of the policies and/or legislation which regulate water quality in South Africa? Kindly select one option.
	QC2E/QC2F	In your opinion, do you think that the water related policies and legislation are well implemented?
	QC3E/QC3F	Which organisation(s) are responsible for providing water quality information to the public of the Breede River catchment? In your answer, kindly elaborate on how often you have received water quality data for the Breede River catchment from this or other organisations in the past.
	QC4E/QC4F	In your opinion, what is the main water quality concern/ challenge in the Breede River catchment? Kindly elaborate on your answer.
	QC5E/QC5F	In your opinion please rate the quality for each parameter only for the section of the Breede River catchment where your operation is located (Scale: 0 =No knowledge 1= Good, 2= Moderate, 3= Poor)
	QC6E/QC6F	In your opinion, please rate the water quality in the Breede River catchment since the year 2000.
	QC7E	Please select the parameter option which, in your opinion, showed the most deterioration between 2000 and 2020. Please mark all relevant options by selecting 1 to 6 where 1= dominant to 6= least dominant.
	QC8E/QC7F	In your opinion what is the origin/ source(s) (natural and/or anthropogenic) which influence the water quality in the Breede River catchment (between 2000 and 2020)? Please select all relevant options.
	QC9E/QC8F	Please select one option that describes your opinion on how the water quality of the Breede River Water Management Area compares to other water management areas.
	QC10E/QC9F	Please select the options that describe your opinion of the suitability of the water in the Breede River catchment for irrigation purposes based on the water quality in 2000 and 2020. Kindly select one option per year.
	QC10F	Please select the options that best describe your opinion on how irrigation water quality from the Breede River catchment differed from the requirements of the market you delivered your products to in 2000 and 2020. Kindly select one option for each year.
	QC11E/QC11F	In your opinion, please rate the water availability in the Breede River catchment since the year 2000.
	QC12E/QC12F	Please select the management actions/ decisions taken in the Breede River catchment in response to water quality and availability concerns/ challenges between 2000 and 2020. Kindly select all relevant options by selecting 1 to 4 where 1= dominant to 4= least dominant.
D: KEY DRIVERS OF WATER QUALITY DECLINE IN THE BREEDE RIVER	QD1E/QD1F	Please select one option that best describes your opinion on the main drivers of the water quality decline in the Breede River. Please mark all relevant options by selecting 1 to 5 where 1= dominant to 5= least dominant.
	QD2E/QD2F	Please select one option that best describes your opinion on how population growth influences the water quality in the Breede River catchment.
	QD3E/QD3F	Please select one option that best describes your opinion on how growth in agricultural activities influence the water quality in the Breede River catchment.
	QD4E/QD4F	Please select one option that best describes your opinion on the influence of industrial developments on the water quality in the Breede River catchment.
	QD5E/QD5F	Please select one option that best describes your opinion on the influence of domestic effluent/ waste water on the water quality in the Breede River catchment.
	QD6E/QD6F	Please select one option that best describes your opinion on the influence of climate on the water quality in the Breede River catchment.
	QD7E/QD7F	Please select one option that best describes your opinion on the influence of geology/ soil on the water quality in the Breede River catchment.
	QD8E/QD8F	Please select one option that best describes your opinion on the influence of cooperative governance on the water quality in the Breede River catchment.

Section		Survey question
E: KEY RISKS POSED BY THE WATER QUALITY OF THE BREEDE RIVER CATCHMENT	QE1E/QE1F	In your opinion, what are the main risks posed by the water quality of the Breede River catchment?
	QE2E/QE2F	Please select one option that describes your opinion of the impact water quality of the Breede River catchment had on agricultural activities between 2000 and 2020. Kindly select one option per year.
	QE3E/QE3F	Please select the option that best describes your opinion on the impact water availability in the Breede River catchment had on agricultural activities. Kindly select one option per year.
	QE4F	Please select one option that best describes your opinion on the impact irrigation water quality from the Breede River catchment had on the quality of the crops/ products you delivered (in 2000 and 2020). Kindly select one option per year.
	QE4E/QE5F	Please select one option that best describes your opinion of the financial impact the irrigation water quality from the Breede River catchment had on farming operations (between 2000 to 2020). Kindly select one option per year.
	QE5E/QE6F	Please select one option that best describes your opinion on how water quality impacted sustainability of agriculture along the Breede River catchment.
	QE6E/QE7F	Please select one option that best describes your opinion on how water quality impacts the economic growth of the areas along the Breede River catchment.
	QE7E/QE8F	Please select one option that best describes your opinion on how water quality impacts socio-economic development and community resilience/ vulnerability in the Breede River catchment.
	QE8E/QE9F	Please select one option that best describes your opinion on the impacts of water quality on environmental sustainability of the Breede River catchment.
	QE9E/QE10 F	In your opinion what actions could be taken to minimise the impacts caused by the decline in water quality in the Breede River catchment? Kindly elaborate on your answer by indicating who should be involved.
	QE10E/QE1 1F	In your opinion how effective were actions taken by various role players in the Breede River catchment in minimising the impacts caused by the decline in water quality. Kindly elaborate on your opinion to substantiate your answer.

ANNEXURE A1: QUESTIONNAIRE (FARMERS)

SECTION A: PARTICIPANT ORGANISATION					
In this section general background questions will be asked. This information will enable the researcher to group responses according to focus groups.					
A1. What is your highest qualification level?					
A. Matric certificate	B. BSc/ BA/ BTech	C. MSc/ MA/ MTech	D. PhD	E. Other	
Kindly elaborate on your qualification details:					
A2. What is your occupational field?					
A. Farmer/ farm manager		B. Process manager		C. Other	
Kindly elaborate on details of occupation/ affiliation.					
A3. How long have you been working in your occupational sector?					
A. 1-5 years	B. 6-10 years		C. 11-15 years	D. 16 years and longer	
A4. In which sector(s) are you placed? Select more than one where applicable.					
A. Farmer: Grapes	B. Farmer: Fruit	C. Farmer: Grain	D. Farmer: Mixed/ Other	E. Agricultural processing	F. Wine cellar/ bottling
If your answer is "D. Farmer: Mixed/ Other", kindly elaborate on the sector(s).					

SECTION B: BACKGROUND ON IRRIGATION PRACTICES

In this section background information is gathered which will assist the researcher in grouping the responses according to specific sections of the catchment, crop segments, irrigation type etc.

B1. Kindly indicate in which part of the Breede-Gouritz Water Management Area does your farm/operation fall?

A. Upper Breede River section		B. Middle Breede River section	
C. Lower Breede River section		D. Riviersonderend River section	
E. Overberg sections		F. Gouritz sections	

B2. What is the main source of water for your operation? Please mark all relevant options by selecting 1 to 4 where 1= dominant to 4= least dominant.

A. Surface water	B. Ground water	C. Rainfall	D. Municipal

B3. Do you make use of any form of irrigation on the farm? If your answer is "B. No", please skip forward to question B16.

A. Yes	B. No

B4. What is the main source of the water for irrigation purposes for your operation? Please mark all relevant options by selecting 1 to 7 where 1= dominant to 7= least dominant.

A. Directly from Breede River	B. Directly from tributaries	C. Irrigation canal	D. Irrigation dam	E. Ground water	F. Rain fed irrigation dams	G. Other

In your answer, kindly elaborate on the details of the source of water for irrigation purposes for your operation by providing details with regards to the tributary/ irrigation dam/ canal name.

River/ stream name	
Irrigation canal name	
Irrigation dam name	
Other	

B5. Which of the following crops are under irrigation on the farm between 2000 and 2020? Please mark all relevant options by selecting 1 to 5 where 1= dominant to 5= least dominant.

A. Grape	B. Fruit	C. Grain	D. Mixed	E. Other

If your answer is "D. Mixed" or "E. Other", kindly elaborate on your option. Kindly elaborate how crops under irrigation changed between 2000 and 2020.

B6.What was the land area under irrigation in the year 2000 per crop type? Kindly mark only one per crop type.

	A. Grape	B. Fruit	C. Grain	D. Mixed	E. Other
0-100ha					
100-250ha					
250-500ha					
500-1 000ha					
>1 000ha					

B7.What was the land area under irrigation in the year 2020 per crop type? Kindly mark only one per crop type.

	A. Grape	B. Fruit	C. Grain	D. Mixed	E. Other
0-100ha					
100-250ha					
250-500ha					
500-1 000ha					
>1 000ha					

B8.What was the quantity of irrigation water used for crop production and processing (m³/year) between 2000 and 2020? Please select one option per year.

	A. <5 000 m ³ /year	B. 5 000-15 000 m ³ /year	C. 15 000-25 000 m ³ /year	D. 25 000-50 000 m ³ /year	E. >50 000 m ³ /year
2000					
2020					

In your answer, kindly elaborate on the volume breakdown per crop type. Please indicate the volume used for processing.

B9.What was the expenditure on irrigation water costs (R) per crop type in 2000? Kindly select only one per crop type.

	A. Grape	B. Fruit	C. Grain	D. Mixed	E. Other
<R100 000					
R100k-R250k					
R250k-R500k					
R500k-R1mil					
R1mil-R2.5mil					
>R2.5mil					

B10. What was the expenditure on irrigation water costs (R) per crop type in 2020? Kindly select only one per crop type.

	A. Grape	B. Fruit	C. Grain	D. Mixed	E. Other
<R100 000					
R100k-R250k					
R250k-R500k					
R500k-R1mil					
R1mil-R2.5mil					
>R2.5mil					

B11. In your opinion does the water quality in the catchment have an impact on irrigation system maintenance?

A. Yes	B. No

If "Yes" what was the expenditure on irrigation system maintenance and repairs related to water quality (R) in 2000 and 2020? Kindly select one option for each year.

	A. <R100 000	B. R100k-R250k	C. R250k-R500k	D. R500k-R1mil	E. R1mil-R2.5mil	F. >R2.5mil
2000						
2020						

In your answer, kindly elaborate on the maintenance related to water quality complications.

B12. What was the expenditure on pumping/ electricity costs for irrigation (R) between 2000 and 2020 (include conventional as well as renewable energy costs)? Kindly select one option for each year.

	A. <R1mil	B. R1mil-R2.5mil	C. R2.5mil-R5mil	D. R5mil-R10mil	E. R10mil-R25mil	F. >R25mil
2000						
2020						

B13. Kindly elaborate on occurrences of irrigation water allowance restrictions in the Breede River catchment between the year 2000 and 2020. Kindly elaborate on the reason(s) for the restrictions.

B14. What was the quantity of fertilizer used for production in irrigated crops between 2000 and 2020 (ton or liters)? Kindly select one option for each year.

	A. None/ organic farming	B. <10t	C. 10-100t	D. 100-250t	E. 250-500t	F. 500- 1 000t	G. >1 000t
2000							
2020							

In your answer, kindly elaborate on the fertilizer type.

B15. What was the quantity of herbicides and pesticides used for production in irrigated crops between 2000 and 2020 (liters)? Please select one option each for herbicides and pesticides.

	A. None/ organic farming	B. < 1 000 L	C. 1 000- 10 000 L	D. 10 000 – 25 000 L	E. 25 000 L- 50 000L	F. 50 000 L- 100 000L	G. >100 000 L
Herbicides							
Pesticides							

In your answer, kindly elaborate on the herbicide and pesticide types used.

B16. What was the number of permanent and seasonal employees working in irrigated crop production between 2000 and 2020? Please select one option each for permanent and seasonal workers.

	A. <10	B. 10-25	C. 25-50	D. 50-100	E. >100
Permanent					
Seasonal					

B17. What was the number of permanent and seasonal employees working in processing between 2000 and 2020? Please select one option each for permanent and seasonal workers.

	A. <10	B. 10-25	C. 25-50	D. 50-100	E. >100
Permanent					
Seasonal					

SECTION C: WATER QUALITY

This section focuses on the understanding of the water quality in the Breede River catchment. The evidence from literature suggests that the water quality has been declining in some sections of the catchment. This perception will be tested in this section based on evidence of impacts experienced by the agricultural sector.

C1.What is your level of understanding of the policies and/or legislation which regulate water quality in South Africa? Please select one option.

A. Low	B. Moderate	C. High

C2.In your opinion, do you think that the water related policies and legislation are well implemented?

A. Yes	B. No

If not, kindly elaborate on what you base your answer.

C3. Which organisation(s) are responsible for providing water quality information to the public of the Breede River catchment? In your answer, kindly elaborate on how often you have received water quality data for the Breede River catchment from this or other organisations in the past.

C4. In your opinion, what is the main water quality concern/ challenge in the Breede River catchment? Kindly elaborate on your answer.

C5. In your opinion, please rate the quality for each parameter only for the section of the Breede River catchment where your operation is located (Scale: 0 =No knowledge 1= Good, 2= Moderate, 3= Poor).

A. TDS/EC	B. pH	C. Cations: Na, Ca, K	D. Anions: HCO ₃ , SO ₄	E. Biological/ E. coli	F. Other

If "Other" please elaborate.

C6. In your opinion, please rate the water quality in the Breede River catchment since the year 2000.

A. Improved	B. Remained the same	C. Declined	D. Other

Please elaborate on your opinion on the change of the water quality in the Breede River catchment since 2000. In your answer also indicate which parameter, in your opinion, showed the most deterioration.

C7. In your opinion what is the origin/ source(s) (natural and/or anthropogenic) which influence the water quality in the Breede River catchment (between 2000 and 2020)? Please select all relevant options.

	A. Natural – geology and soil	B. Natural-climate	C. Anthropogenic-domestic effluent	D. Anthropogenic-industrial effluent	E. Anthropogenic-agro-chemicals	F. Anthropogenic-agricultural run-off	G. Other
2000							
2020							

In your answer, kindly elaborate on your opinion on the sources which influence the water quality in the Breede River catchment (between 2000 and 2020).

C8. Please select one option that describes your opinion on how the water quality of the Breede River Water Management Area compares to other water management areas.

A. I do not know	B. Less degraded than other areas	C. Same as other areas	D. More degraded than other areas	E. Other

In your answer, kindly elaborate on your rating of the water quality of the Breede River catchment compared to other catchments.

C9. Please select the options that describe your opinion on the suitability of the water in the Breede River catchment for irrigation purposes based on the water quality in 2000 and 2020. Kindly select one option per year.

	A. Mostly suitable for the irrigation of all crops	B. Only suitable for some crops	C. Mostly unsuitable for the irrigation of all crops
2000			
2020			

In your answer, kindly elaborate on the

C10. Please select the options that best describe your opinion on how irrigation water quality from the Breede River catchment differed from the requirements of the market you delivered your products to in 2000 and 2020. Kindly select one option for each year.

	A. Better than required	B. Meets most requirements	C. Meets requirements	D. Not meeting important requirements	E. Not acceptable
2000					
2020					

In your answer, kindly elaborate on your rating on how irrigation water quality from the Breede River catchment differed from the requirements of the market you delivered your products to (between 2000 to 2020).

C11. In your opinion, please rate the water in the Breede River catchment since the year 2000.

A. Improved	B. Remained the same	C. Declined	D. Other

In your answer, kindly elaborate on

C12. Please select the management actions/ decisions you took in response to water quality and availability concerns/ challenges in the Breede River catchment between 2000 and 2020. Kindly select all relevant options by selecting 1 to 4 where 1= dominant to 4= least dominant.

A. Change in irrigation type	B. Implement water treatment system	C. Cover crop with netting to minimise evaporation	D. Other

In your answer, kindly elaborate on the management actions/ decisions you took in response to water quality and availability concerns in the Breede River catchment (between 2000 to 2020).

SECTION D: KEY DRIVERS OF WATER QUALITY DECLINE IN THE BREEDE RIVER

In this section the main drivers/ stressors with the most substantial effect on the water quality and quantity in the Breede River catchment will be unpacked.

D1. Please select the option(s) that best describe your opinion on the main drivers of the water quality in the Breede River. Please mark all relevant options by selecting 1 to 5 where 1= dominant to 5= least dominant.

A. Anthropogenic/ Agricultural activities	B. Anthropogenic/ Domestic activities	C. Natural/ Geology and soil	D. Natural/ Climatic	E. Other

In your answer, kindly elaborate on your selection of drivers with the most substantial effect on the water quality in the Breede River catchment.

D2. Please select one option that best describes your opinion on how population growth influences the water quality in the Breede River catchment.

A. Mainly positive influence	B. Slightly positive influence	C. No influence	D. Slightly negative influence	E. Mainly negative influence

In your answer, kindly elaborate on your opinion on the influence of population growth on the water quality in the Breede River catchment.

D3. Please select one option that best describes your opinion on how growth in agricultural activities influences the water quality in the Breede River catchment.

A. Mainly positive influence	B. Slightly positive influence	C. No influence	D. Slightly negative influence	E. Mainly negative influence

In your answer, kindly elaborate on your opinion on how growth in agricultural activities influences the water quality in the Breede River catchment.

D4. Please select one option that best describes your opinion on the influence of industrial developments on the water quality in the Breede River catchment.

A. Mainly positive influence	B. Slightly positive influence	C. No influence	D. Slightly negative influence	E. Mainly negative influence

In your answer, kindly elaborate on your opinion on the influence of industrial developments on the water quality in the Breede River catchment.

D5. Please select one option that best describes your opinion on the influence of domestic effluent/ waste water on the water quality in the Breede River catchment.

A. Mainly positive influence	B. Slightly positive influence	C. No influence	D. Slightly negative influence	E. Mainly negative influence

In your answer, kindly elaborate on your opinion on the influence of domestic effluent/ waste water on the water quality in the Breede River catchment.

D6. Please select one option that best describes your opinion on the influence of climate on the water quality in the Breede River catchment.

A. Mainly positive influence	B. Slightly positive influence	C. No influence	D. Slightly negative influence	E. Mainly negative influence

In your answer, kindly elaborate on your opinion on the influence of climate on water quality in the Breede River catchment.

D7. Please select one option that best describes your opinion on the influence of geology/ soil on water quality in the Breede River catchment.

A. Mainly positive influence	B. Slightly positive influence	C. No influence	D. Slightly negative influence	E. Mainly negative influence

In your answer, kindly elaborate on your opinion on the influence of geology/ soil on water quality in the Breede River catchment.

D8. Please select one option that best describes your opinion on the influence of cooperative governance on the water quality in the Breede River catchment.

A. Mainly positive influence	B. Slightly positive influence	C. No influence	D. Slightly negative influence	E. Mainly negative influence

In your answer, kindly elaborate on your opinion on the contribution of cooperative governance on the water quality in the Breede River catchment.

SECTION E: KEY RISKS POSED BY THE WATER QUALITY OF THE BREEDE RIVER CATCHMENT

In this section the key risks of the perceived decline in water quality in the Breede River catchment, over the past 20 years, are unpacked.

E1. In your opinion, what are the main risks posed by the water quality of the Breede River catchment?

E2. Please select the option that describes your opinion of the impact water quality of the Breede River catchment had on agricultural activities between 2000 and 2020. Kindly select one option per year.

	A. Major positive impact	B. Minor positive impact	C. No impact	D. Minor negative impact	E. Major negative impact
2000					
2020					

In your answer, kindly elaborate on your opinion on the impact(s) water quality of the Breede River catchment had on agricultural activities, including irrigation systems, between 2000 and 2020.

E3. Please select the option that best describes your opinion of the impact on agricultural activities. Kindly select one option per year.

	A. Major positive impact	B. Minor positive impact	C. No impact	D. Minor negative impact	E. Major negative impact
2000					
2020					

In your answer, kindly elaborate on the impact on agricultural activities

E4. Please select one option that best describes your opinion of the impact irrigation water quality from the Breede River catchment had on the quality of the crops/ products you delivered (in 2000 and 2020). Kindly select one option per year.

	A. Major positive impact	B. Minor positive impact	C. No impact	D. Minor negative impact	E. Major negative impact
2000					
2020					

In your answer, kindly elaborate on how irrigation water quality from the Breede River catchment impacted on the quality of the crops/ products you delivered (between 2000 to 2020).

E5. Please select one option that best describes your opinion of the financial impact the irrigation water quality from the Breede River catchment had on your operation (in 2000 to 2020). Kindly select one option per year.

	A. Major positive impact	B. Minor positive impact	C. No impact	D. Minor negative impact	E. Major negative impact
2000					
2020					

In your answer, kindly elaborate on how irrigation water quality from the Breede River catchment impacted on your operation financially (between 2000 to 2020).

E6. Please select one option that best describes your opinion on how water quality impacted sustainability of agriculture along the Breede River catchment.

A. Major positive impact	B. Minor positive impact	C. No impact	D. Minor negative impact	E. Major negative impact

In your answer, kindly elaborate on your opinion on the impacts of water quality on sustainability of agriculture along the Breede River.

E7. Please select one option that best describes your opinion on how water quality impacts the economic growth of the areas along the Breede River catchment.

A. Major positive impact	B. Minor positive impact	C. No impact	D. Minor negative impact	E. Major negative impact

In your answer, kindly elaborate on your opinion on the impact water quality has on the economic growth of the areas along the Breede River.

E8. Please select one option that best describes your opinion on how water quality impacts socio-economic development and community resilience/ vulnerability in the Breede River catchment.

A. Major positive impact	B. Minor positive impact	C. No impact	D. Minor negative impact	E. Major negative impact

In your answer, kindly elaborate on your opinion on the impact water quality has on socio-economic development and community resilience/ vulnerability in the Breede River catchment.

E9. Please select one option that best describes your opinion on the impact water quality has on environmental sustainability of the Breede River catchment.

A. Major positive impact	B. Minor positive impact	C. No impact	D. Minor negative impact	E. Major negative impact

In your answer, kindly elaborate on your opinion on the impact water quality has on environmental sustainability of the Breede River catchment.

E10. In your opinion what actions could be taken to minimise the impact caused by the decline in water quality. Kindly elaborate on your answer by indicating who should be involved.

E11. In your opinion how effective were actions taken by various role players in the Breede River catchment in minimising the impact caused by the decline in water quality. Kindly elaborate on your opinion to substantiate your answer.

ANNEXURE A2: QUESTIONNAIRE (EXPERTS)

SECTION A: PARTICIPANT ORGANISATION

In this section general background questions will be asked. This information will enable the researcher to group responses according to focus groups.

A1. What is your highest qualification level?

A. Matric certificate	B. BSc/ BA/ BTech	C. MSc/ MA/ MTech	D. PhD	E. Other

Kindly elaborate on your qualification details:

A2. What is your occupational field?

A. Municipality: Environmental services	B. Municipality: Water and sanitation	C. Municipality: Other	D. Environmental expert/ EAP	E. Environmental: Water management	F. Agricultural: Water distribution	G. Agriculture: Agro- chemicals	H. Other

Kindly provide details on the sector(s). Additionally, kindly provide details of occupation/ affiliation.

A3. How long have you been working in your occupational field?

A. 1-5 years	B. 6-10 years	C. 11-15 years	D. 16 years and longer

SECTION B: BACKGROUND ON IRRIGATION PRACTICES

In this section background information is gathered which will assist the researcher in grouping the responses according to specific sections of the catchment, crop segments, irrigation type etc.

B1. In which part of the Breede-Gouritz Water Management Area does your operation fall/ do you mainly work?

A. Upper Breede River section		B. Middle Breede River section	
C. Lower Breede River section		D. Riviersonderend River section	
E. Overberg sections		F. Gouritz sections	

B2. What is the main source of water in the area? Please mark all relevant options by selecting 1 to 4 where 1= dominant to 4= least dominant.

A. Surface water	B. Ground water	C. Rainfall	D. Municipal

B3. What is the main source of the water for irrigation purposes for the area of the catchment you mainly work in? Please mark all relevant options by selecting 1 to 7 where 1= dominant to 7= least dominant.

A. Directly from Breede River	B. Directly from tributaries	C. Irrigation canal	D. Irrigation dam	E. Ground water	F. Rain fed irrigation dams	G. Other

In your answer, kindly elaborate on the details of the source of water for irrigation purposes in your area by providing details with regards to the tributary/ irrigation dam/ canal name.

River/ stream name	
Irrigation canal name	
Irrigation dam name	
Other	

B4. Which of the following crops are dominantly under irrigation in the area? Please mark all relevant options by selecting 1 to 5 where 1= dominant to 5= least dominant.

A. Grape	B. Fruit	C. Grain	D. Mixed	E. Other

If your answer is "D. Mixed" or "E. Other", kindly elaborate on your option.

B5. Kindly elaborate on occurrences of irrigation water allowance restrictions in the Breede River catchment between the year 2000 and 2020. Kindly elaborate on the reason(s) for the restrictions.

SECTION C: WATER QUALITY

This section focuses on the understanding of the water quality in the Breede River catchment. The evidence from literature suggests that the water quality has been declining in some sections of the catchment. This perception will be tested in this section based on evidence of impact experienced by the agricultural sector.

C13. What is your level of understanding of the policies and/or legislation which regulate water quality in South Africa? Kindly select one option.

D. Low	E. Medium	F. High

C14. In your opinion, do you think that the water related policies and legislation are well implemented?

A. Yes	B. No

If not, kindly elaborate.

C15. Which organisation(s) are responsible for providing water quality information to the public of the Breede River catchment? In your answer, kindly elaborate on how often you have received water quality data for the Breede River catchment from this or other organisations in the past.

C16. In your opinion, what is the main water quality concern/ challenge in the Breede River catchment? Kindly elaborate on your answer.

C17. In your opinion please rate the quality for each parameter only for the section of the Breede River catchment where your operation is located (Scale: 0 =No knowledge 1= Good, 2= Moderate, 3= Poor)

A. TDS/EC	B. pH	C. Cations: Na, Ca, K	D. Anions: HCO ₃ , SO ₄	E. Biological/ E. coli	F. Other

If "Other" please elaborate.

C18. In your opinion, please rate the water quality in the Breede River catchment since the year 2000.

A. Improved	B. Remained the same	C. Declined	D. Other

Please elaborate on your opinion on the change of the water quality in the Breede River catchment since 2000.

C19. Please select the parameter option which, in your opinion, showed the most deterioration between 2000 and 2020. Please mark all relevant options by selecting 1 to 6 where 1= dominant to 6= least dominant.

A. TDS/EC	B. pH	C. Cations: Na, Ca, K	D. Anions: HCO ₃ , SO ₄	E. Biological/ E.coli	F. Other

C20. In your opinion what is the origin/ source(s) (natural and/or anthropogenic) which influence the water quality in the Breede River catchment (between 2000 and 2020)? Please select all relevant options.

A. Natural – geology and soil	B. Natural-climate	C. Anthropogenic-domestic effluent	D. Anthropogenic-industrial effluent	E. Anthropogenic-agro-chemicals	F. Anthropogenic-agricultural run-off	G. Other
2000						
2020						

In your answer, kindly elaborate on your opinion on the sources which influence the water quality in the Breede River catchment (between 2000 and 2020).

C21. Please select one option that describes your opinion on how the water quality of the Breede River Water Management Area compare to other water management areas.

A. I do not know	B. Less degraded than other areas	C. Same as other areas	D. More degraded than other areas	E. Other

In your answer, kindly elaborate on your rating of the water quality of the Breede River catchment compared to other catchments.

C22. Please select the options that describe your opinion on the suitability of the water in the Breede River catchment for irrigation purposes based on the water quality in 2000 and 2020. Kindly select one option per year.

	A. Mostly suitable for irrigation of all crops	B. Only suitable for some crops	C. Mostly unsuitable for irrigation of all crops
2000			
2020			

C23. In your opinion, please rate the water in the Breede River catchment since the year 2000.

A. Improved	B. Remained the same	C. Declined	D. Other

In your answer, kindly elaborate

C24. Please select the management actions/ decisions taken in the Breede River catchment in response to water quality and availability concerns/ challenges between 2000 and 2020. Kindly select all relevant options by selecting 1 to 4 where 1= dominant to 4= least dominant.

A. Change in irrigation type	B. Implement water treatment system	C. Cover crop with netting to minimise evaporation	D. Other

In your answer, kindly elaborate on the management actions/ decisions taken in response to water quality and availability concerns in the Breede River catchment (between 2000 to 2020).

SECTION D: KEY DRIVERS OF WATER QUALITY DECLINE IN THE BREEDE RIVER

In this section the main drivers/ stressors with the most substantial effect on the water quality and quantity in the Breede River catchment will be unpacked.

D1. Please select one option that best describes your opinion on the main drivers of the water quality decline in the Breede River. Please mark all relevant options by selecting 1 to 5 where 1= dominant to 5= least dominant.

A. Anthropogenic/ Agricultural activities	B. Anthropogenic/ Domestic activities	C. Natural/ Geology and soil	D. Natural/Climatic	E. Other

In your answer, kindly elaborate on your selection of drivers with the most substantial affect on the water quality in the Breede River catchment.

D2. Please select one option that best describes your opinion on how population growth influence the water quality in the Breede River catchment.

A. Mainly positive influence	B. Slightly positive influence	C. No influence	D. Slightly negative influence	E. Mainly negative influence

In your answer, kindly elaborate on your opinion on the influence of population growth on the water quality in the Breede River catchment.

D3. Please select one option that best describes your opinion on how growth in agricultural activities influences the water quality in the Breede River catchment.

A. Mainly positive influence	B. Slightly positive influence	C. No influence	D. Slightly negative influence	E. Mainly negative influence

In your answer, kindly elaborate on your opinion on how growth in agricultural activities influences the water quality in the Breede River catchment.

D4. Please select one option that best describes your opinion on the influence of industrial developments on the water quality in the Breede River catchment.

A. Mainly positive influence	B. Slightly positive influence	C. No influence	D. Slightly negative influence	E. Mainly negative influence

In your answer, kindly elaborate on your opinion on the influence of industrial developments on the water quality in the Breede River catchment.

D5. Please select one option that best describes your opinion on the influence of domestic effluent/ waste water on the water quality in the Breede River catchment.

A. Mainly positive influence	B. Slightly positive influence	C. No influence	D. Slightly negative influence	E. Mainly negative influence

In your answer, kindly elaborate on your opinion on the influence of domestic effluent/ waste water on the water quality in the Breede River catchment.

D6. Please select one option that best describes your opinion on the influence of climate on the water quality in the Breede River catchment.

A. Mainly positive influence	B. Slightly positive influence	C. No influence	D. Slightly negative influence	E. Mainly negative influence

In your answer, kindly elaborate on your opinion on the influence of climate on the water quality in the Breede River catchment.

D7. Please select one option that best describes your opinion on the influence of geology/ soil on the water quality in the Breede River catchment.

A. Mainly positive influence	B. Slightly positive influence	C. No influence	D. Slightly negative influence	E. Mainly negative influence

In your answer, kindly elaborate on your opinion on the influence of geology/ soil on the water quality in the Breede River catchment.

D8. Please select one option that best describes your opinion on the influence of cooperative governance on the water quality in the Breede River catchment.

A. Mainly positive influence	B. Slightly positive influence	C. No influence	D. Slightly negative influence	E. Mainly negative influence

In your answer, kindly elaborate on your opinion on the contribution of cooperative governance on the water quality in the Breede River catchment.

SECTION E: KEY RISKS POSED BY THE WATER QUALITY OF THE BREEDE RIVER CATCHMENT

In this section the key risks of the perceived decline in water quality in the Breede River catchment, over the past 20 years, are unpacked.

E1. In your opinion, what are the main risks posed by the water quality of the Breede River catchment?

E2. Please select one option that describes your opinion on the impact of water quality of the Breede River catchment had on agricultural activities between 2000 and 2020. Kindly select one option per year.

	A. Major positive impact	B. Minor positive impact	C. No impact	D. Minor negative impact	E. Major negative impact
2000					
2020					

In your answer, kindly elaborate on your opinion on the impact(s) water quality of the Breede River catchment had on agricultural activities, including irrigation systems, between 2000 and 2020.

E3. Please select one option that best describes your opinion of the impact on agricultural activities					
	A. Major positive impact	B. Minor positive impact	C. No impact	D. Minor negative impact	E. Major negative impact
2000					
2020					

In your answer, kindly elaborate on the impact on agricultural activities

E4. Please select one option that best describes your opinion on the financial impact the irrigation water quality from the Breede River catchment had on farming operations (between 2000 to 2020). Kindly select one option per year.					
	A. Major positive impact	B. Minor positive impact	C. No impact	D. Minor negative impact	E. Major negative impact
2000					
2020					

In your answer, kindly elaborate on how irrigation water quality from the Breede River catchment impacted financially on farming operations (between 2000 to 2020).

E5. Please select one option that best describes your opinion on how water quality impacted sustainability of agriculture along the Breede River catchment.				
A. Major positive impact	B. Minor positive impact	C. No impact	D. Minor negative impact	E. Major negative impact

In your answer, kindly elaborate on your opinion on the impact of water quality on the sustainability of agriculture along the Breede River.

E6. Please select one option that best describes your opinion on how water quality impacts the economic growth of the areas along the Breede River catchment.				
A. Major positive impact	B. Minor positive impact	C. No impact	D. Minor negative impact	E. Major negative impact

In your answer, kindly elaborate on your opinion on the impacts water quality has on the economic growth of the areas along the Breede River.

E7. Please select one option that best describes your opinion on how water quality impacts socio-economic development and community resilience/ vulnerability in the Breede River catchment.				
A. Major positive impact	B. Minor positive impact	C. No impact	D. Minor negative impact	E. Major negative impact

In your answer, kindly elaborate on your opinion on the impact water quality has on socio-economic development and community resilience/ vulnerability in the Breede River catchment.

E8. Please select one option that best describes your opinion on the impact of water quality on the environmental sustainability of the Breede River catchment.

A. Major positive impact	B. Minor positive impact	C. No impact	D. Minor negative impact	E. Major negative impact

In your answer, kindly elaborate on your opinion on the impact of water quality on the environmental sustainability of the Breede River catchment.

E9. In your opinion what actions could be taken to minimise the impact caused by the decline in water quality in the Breede River catchment? Kindly elaborate on you answer by indicating who should be involved.

E10. In your opinion how effective were actions taken by various role players in the Breede River catchment in minimising the impact caused by the decline in water quality. Kindly elaborate on your opinion to substantiate your answer.

ANNEXURE B: RESOURCE QUALITY OBJECTIVES IN PRIORITY RESOURCE UNITS OF THE BREEDE RIVER (SA, 2018)

Parameter	Compliance description	Upper	Middle	Lower
Phosphate (PO ₄ -P)	Nutrient levels must be maintained in the river at a mesotrophic or better condition.	<0.025-0.075 mg/l	<0.075 mg/l	<0.075 mg/l
Total inorganic nitrogen (TIN)	Nutrient levels must be maintained in the river at a mesotrophic or better condition.	<0.70-1.75 mg/l	<1.75 mg/l	<1.75 mg/l
Electrical conductivity (EC)	Salt concentrations need to be maintained at present state levels.	<30-220 mS/m	<220 mS/m	<270 mS/m
pH range	pH, temperature, and dissolved oxygen are important for the maintenance of ecosystem health.	4.5>ph<7.5 6.5 >ph<8.5	6.5 >ph<8.5	6.5 >ph<8.5
Dissolved oxygen		>6 -8 mg/l	>6 mg/l	>6 mg/l
Water temperature		No more than 2°C change from natural monthly range	No more than 2°C change from natural monthly range	No more than 2°C change from natural monthly range
Toxins	Toxicity levels must not pose a threat to aquatic ecosystems	Ammonia <0.073 mg/l		Ammonia <0.073 mg/l
Pathogens Escherichia coli	Concentrations of waterborne pathogens should be maintained in an Acceptable category for full contact recreation.	<130-165 cfu/100 ml	<165 cfu/100 ml	<165 cfu/100 ml

ANNEXURE C: TARGET WATER QUALITY RANGES (DWAF, 1996A-F)

	Domestic	Recreational	Industrial	Agriculture	
				Livestock watering	Irrigation
Chlorine (mg/l)	0-100	N/A	0-500	0-1500 (a) 0-3000 (b)	0-100
Coliforms (counts/100 l)	0 (d) 0-5 (e)	Full contact 0-150 (d), 0-130 (c) Intermediate contact 0-1 000 (d)	N/A	0-200 (d)	<1 (d)
Fluoride (mg/l)	0-1	N/A	N/A	0-2	0-2
Magnesium (mg/l)	0-30	N/A	N/A	0-500	N/A
Nitrate/Nitrite (mg/l)	0-6	N/A	N/A	0-100 NO ₃ 0-10 NO ₂	0 - 0.5 (irrigation equipment)
pH	6-9	6.5-8.5	5-10	N/A	6.5-8.4
Potassium (mg/l)	0-50	N/A	N/A	N/A	N/A
Sodium (mg/l)	0-100	N/A	N/A	0-2 000	70
Sodium Absorption Ratio (SAR)	N/A	N/A	N/A	N/A	0-1.5
Sulphate (mg/l)	0-200	N/A	0-500	0-1 000	N/A
Suspended Solids (mg/l)	N/A	N/A	0-25	N/A	0-50 (f)
Total Dissolved Solids (mg/l)	0-450	N/A	0-1 600	<1 000 (g) <2 000 (h) < 3 000 (i)	40

NA - Not available

(d) Faecal coliforms

(g) Dairy, pigs & poultry

(a) Monogastrics & Poultry

(e) Total coliforms

(h) Cattle & horses

(b) Other livestock

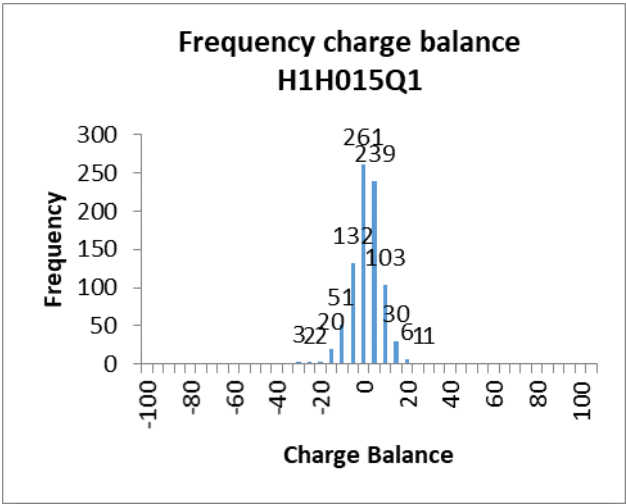
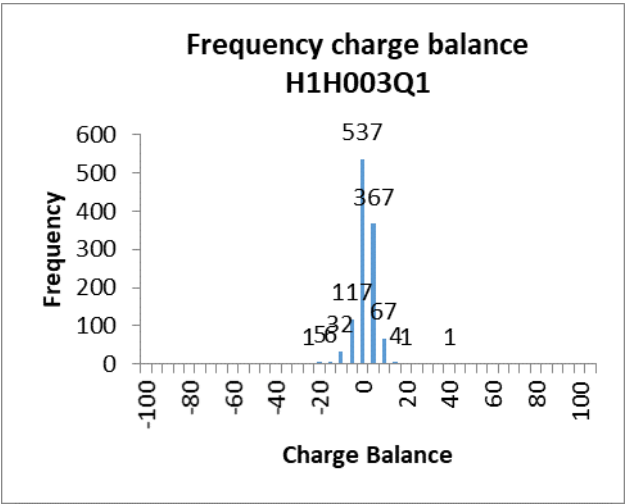
(f) Clogging of drip irrigation systems

(i) Sheep.

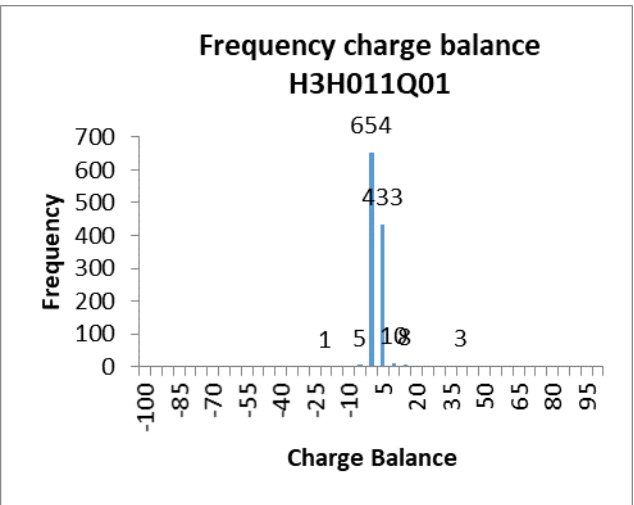
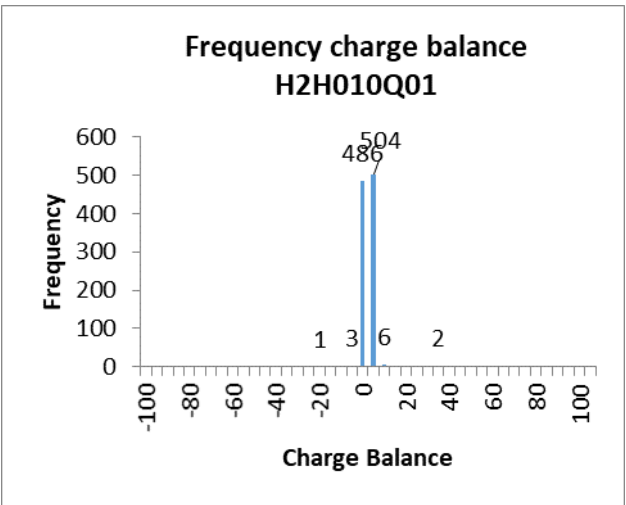
(c) E.Coli

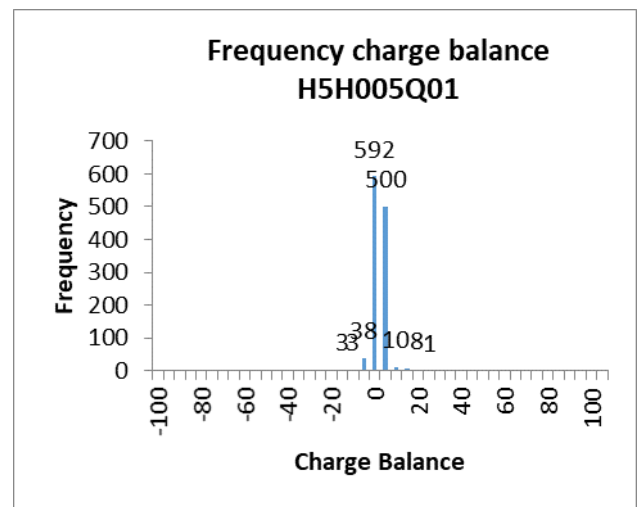
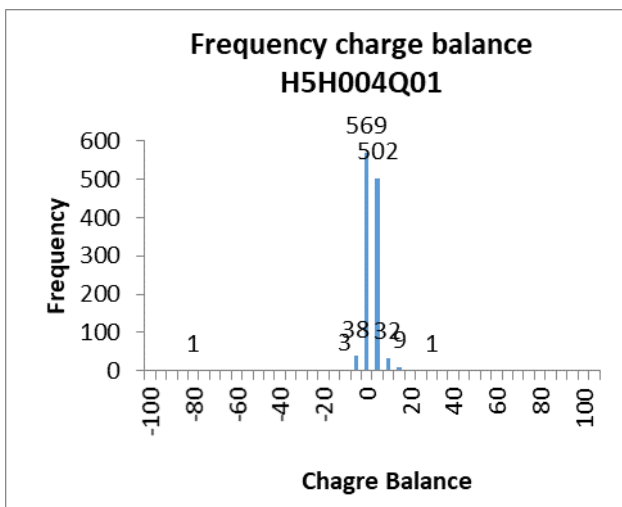
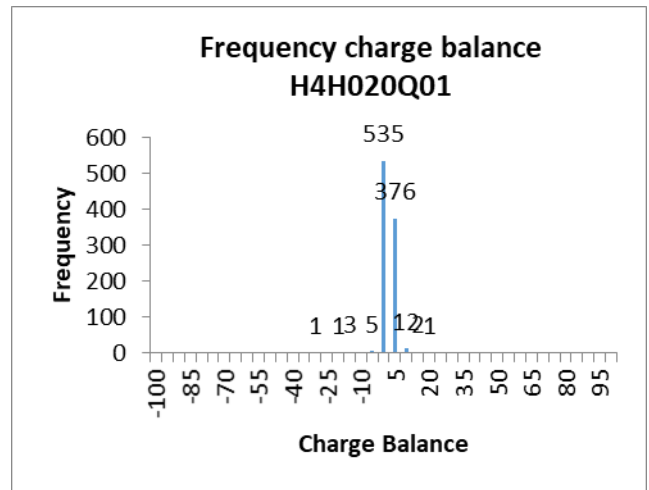
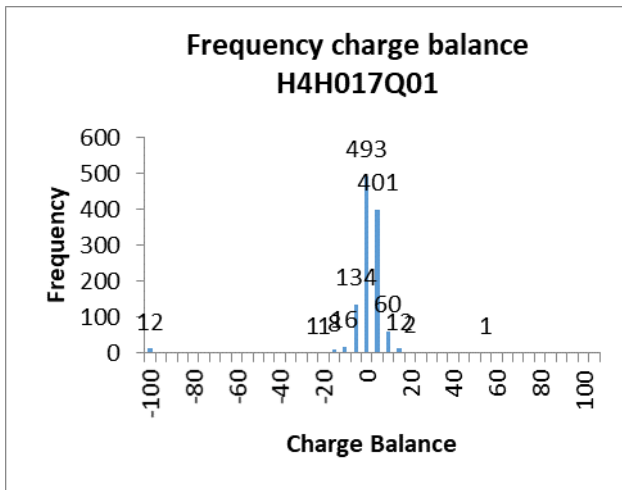
ANNEXURE D: HISTOGRAMS

UPPER BREEDE RIVER SECTION

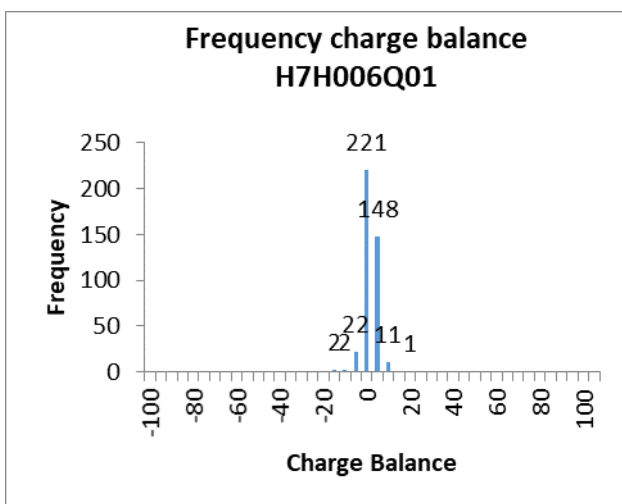


MIDDLE BREEDE RIVER SECTION

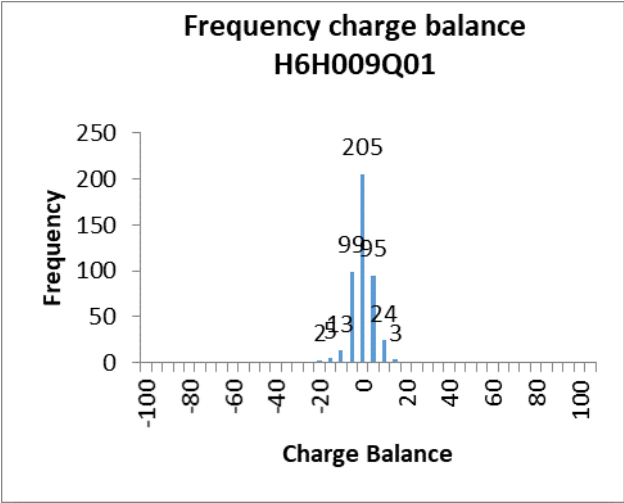




LOWER BREEDE RIVER SECTION



RIVIERSONDEREND SECTION



ANNEXURE E: DESCRIPTIVE STATISTICS OF WATER QUALITY DATA

	Site	Period	EC	TDS	pH	Na	Mg	Ca	K	NH ₄	F	Cl	NO ₃ +NO ₂	SO ₄	PO ₄	HCO ₃	SAR
			mS/m	mg/L		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
UPPER BREEDE SECTION	H1H003Q01	1970-1979	26,57	141,64	6,5	26,00	7,24	9,64	1,25	1,25	0,10	46,78	0,25	20,23	0,02	29,17	1,50
		1980-1989	23,03	120,58	6,5	22,31	6,16	8,10	1,50	0,07	0,09	41,98	0,34	17,26	0,02	21,51	1,42
		1990-1999	31,55	178,07	7,5	31,85	8,56	11,55	2,40	0,09	0,15	56,39	0,50	22,56	0,07	41,95	1,72
		2000-2009	29,31	170,35	7,5	30,19	5,81	11,42	4,04	0,11	0,10	41,60	0,66	18,70	0,17	54,72	1,82
		2010-2018	41,52	279,07	7,9	54,48	6,76	15,96	7,29	0,12	0,23	55,23	1,56	23,89	0,48	104,98	2,08
	H1H015Q01	1970-1979	12,49	66,27	6,3	12,56	3,14	4,29	1,03	0,07	0,07	23,13	0,10	7,18	0,02	14,31	1,15
		1980-1989	13,66	67,20	5,8	13,23	3,36	3,95	1,22	0,07	0,04	26,26	0,37	6,92	0,01	10,45	1,13
		1990-1999	13,43	71,83	7,1	12,00	3,59	4,74	1,46	0,04	0,14	21,58	0,55	9,52	0,02	16,28	0,99
		2000-2009	9,81	51,44	7,1	7,83	2,54	3,92	1,10	0,04	0,09	15,41	0,49	7,14	0,03	11,08	0,76
		2010-2018	12,74	66,64	6,8	11,48	3,32	4,38	1,33	0,05	0,10	21,51	0,49	8,39	0,02	13,81	0,98

Continue

	Site	Period	EC mS/m	TDS mg/L	pH	Na mg/L	Mg mg/L	Ca mg/L	K mg/L	NH ₄ mg/L	F mg/L	Cl mg/L	NO ₃ +NO ₂ mg/L	SO ₄ mg/L	PO ₄ mg/L	HCO ₃ mg/L	SAR
MIDDLE BREEDE SECTION	H2H010Q01	1970-1979	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		1980-1989	324,28	2105,02	8,0	451,31	109,69	99,17	9,80	0,09	0,58	644,30	0,91	545,95	0,03	236,00	7,30
		1990-1999	255,09	1683,32	8,3	359,46	82,29	77,40	9,05	0,07	0,54	507,34	1,25	356,97	0,05	277,44	6,63
		2000-2009	238,77	1502,24	8,2	323,82	70,33	68,26	7,97	0,06	0,58	442,31	0,76	285,23	0,07	294,10	6,43
		2010-2018	214,36	1431,07	8,5	299,97	68,83	68,99	9,00	0,05	0,70	417,70	0,77	238,53	0,09	312,36	5,97
	H3H011Q01	1970-1979	310,42	1899,33	7,8	466,02	90,53	69,32	4,97	0,02	0,61	766,62	0,13	197,07	0,01	301,81	8,64
		1980-1989	288,68	1747,86	7,9	424,27	80,67	64,26	6,96	0,07	0,54	700,81	0,45	201,38	0,04	263,26	8,11
		1990-1999	330,69	2069,50	8,3	508,36	90,43	72,32	9,43	0,07	0,50	837,57	0,64	219,44	0,09	321,50	9,33
		2000-2009	324,24	1919,11	8,2	469,42	84,01	69,60	8,44	0,09	0,45	769,48	1,03	204,03	0,66	302,02	8,82
		2010-2018	270,77	1640,64	8,3	411,80	73,36	60,28	9,79	0,03	0,33	641,12	0,90	178,67	0,28	255,56	8,41
	H4H017Q01	1970-1979	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		1980-1989	27,54	142,87	6,4	31,26	6,89	6,94	1,49	0,05	0,11	53,12	0,28	21,21	0,01	20,52	1,96
		1990-1999	27,39	146,83	7,4	30,57	6,90	7,28	1,78	0,04	0,16	51,68	0,34	20,37	0,02	26,38	1,91
		2000-2009	27,20	137,12	7,4	28,89	6,21	7,22	1,59	0,05	0,11	50,08	0,37	18,73	0,05	22,41	1,84
		2010-2018	26,40	136,17	7,5	29,54	5,44	6,89	2,13	0,04	0,12	51,16	0,27	19,44	0,03	16,56	2,10

Site	Period	EC	TDS	pH	Na	Mg	Ca	K	NH ₄	F	Cl	NO ₃ +NO ₂	SO ₄	PO ₄	HCO ₃	SAR
		mS/m	mg/L		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
	H4H020Q01	1970-1979	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		1980-1989	322,46	2027,93	8,0	446,22	103,22	96,10	13,11	0,09	0,70	732,42	0,47	366,32	0,04	264,10
		1990-1999	367,66	2358,42	8,2	521,55	119,10	109,50	15,30	0,07	0,65	920,58	0,52	352,85	0,05	310,04
		2000-2009	444,93	2746,80	8,2	627,27	134,01	125,28	17,06	0,06	0,74	1087,53	0,30	419,32	0,08	328,39
		2010-2018	455,73	2853,23	8,3	658,76	156,44	118,83	15,27	0,08	0,65	1178,65	0,13	415,38	0,08	194,97
	H5H004Q01	1970-1979	59,94	335,52	6,9	77,07	14,66	14,80	2,48	0,06	0,19	119,17	0,17	38,76	0,01	67,50
		1980-1989	76,24	426,37	7,0	101,76	19,60	16,92	2,80	0,05	0,18	164,35	0,27	51,91	0,01	67,35
		1990-1999	94,64	555,47	7,9	132,08	24,62	20,74	3,43	0,04	0,24	216,32	0,35	62,56	0,03	92,26
		2000-2009	116,11	654,38	7,9	158,40	28,81	24,43	3,69	0,05	0,23	259,44	0,43	71,98	0,06	103,58
		2010-2018	97,82	563,92	8,0	132,45	23,06	21,08	4,03	0,04	0,27	232,62	0,19	63,39	0,05	103,58
	H5H005Q01	1970-1979	65,21	378,75	6,9	89,79	15,91	13,95	2,88	0,06	0,21	133,92	0,13	43,42	0,01	77,76
		1980-1989	84,13	484,60	7,1	117,31	21,03	17,67	3,27	0,06	0,27	180,66	0,27	55,43	0,02	87,32
		1990-1999	100,73	597,08	8,0	141,75	25,86	21,30	3,86	0,04	0,31	220,10	0,28	67,34	0,02	113,28
		2000-2009	112,18	632,58	7,9	151,50	27,45	23,39	3,80	0,04	0,27	240,47	0,29	68,00	0,04	113,83
		2010-2018	91,07	544,68	7,8	121,87	22,23	20,57	3,62	0,05	0,28	218,56	0,10	59,63	0,01	N/A

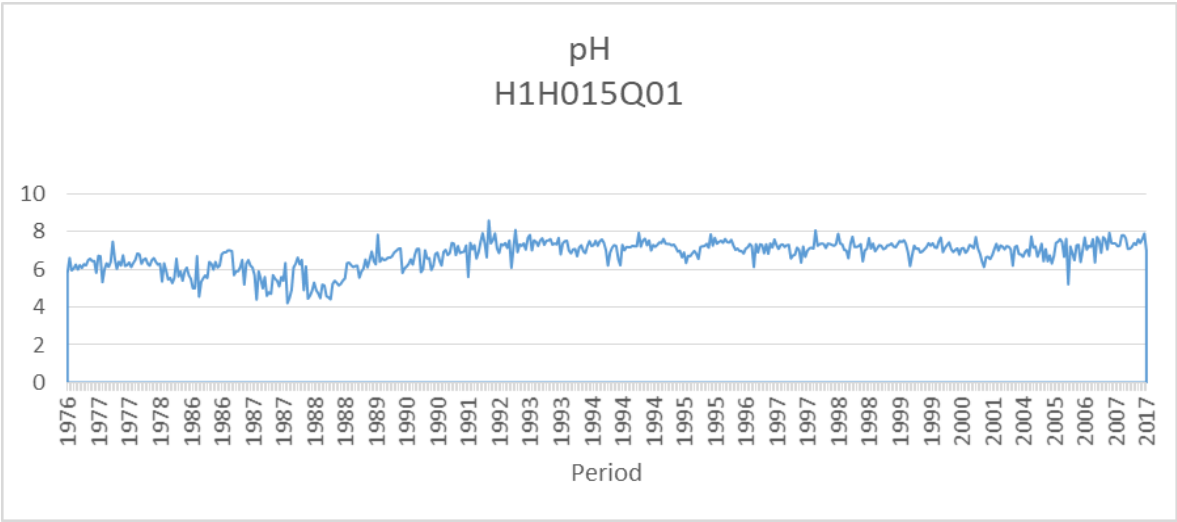
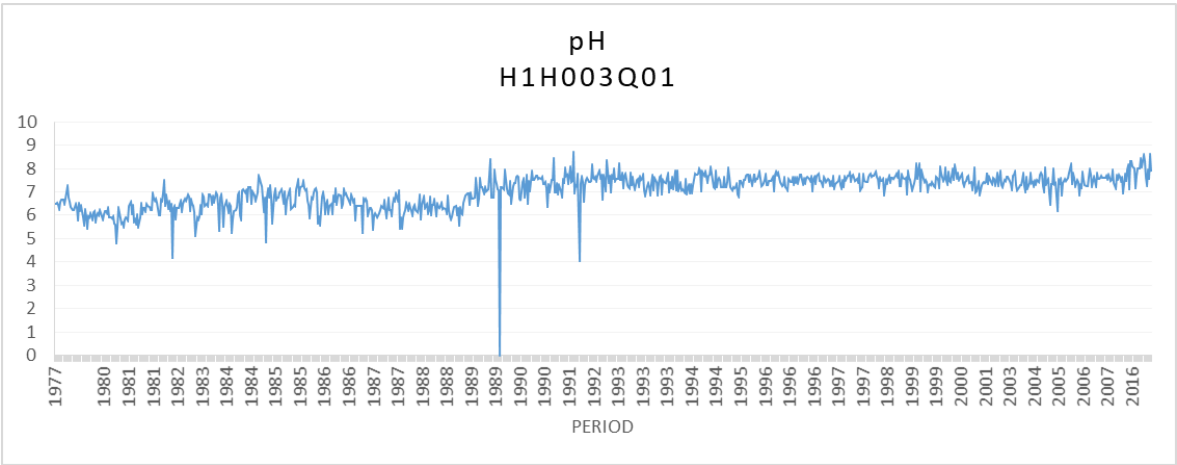
Continue

	Site	Period	EC mS/m	TDS mg/L	pH	Na mg/L	Mg mg/L	Ca mg/L	K mg/L	NH ₄ mg/L	F mg/L	Cl mg/L	NO ₃ +NO ₂ mg/L	SO ₄ mg/L	PO ₄ mg/L	HCO ₃ mg/L	SAR
LOWER BREEDER SECTION	H7H006Q01	1970-1979	62,97	352,24	7,0	86,70	14,45	12,65	2,14	0,06	0,19	134,49	0,09	35,44	0,01	65,52	3,81
		1980-1989	54,32	299,61	6,7	74,61	12,88	9,99	2,27	0,05	0,15	116,87	0,16	32,32	0,01	49,61	3,45
		1990-1999	69,96	406,10	7,7	98,95	16,93	13,34	2,81	0,04	0,23	157,52	0,25	43,23	0,02	71,19	4,04
		2000-2009	82,91	469,37	7,7	115,02	19,57	16,18	3,08	0,06	0,20	187,69	0,29	47,55	0,03	78,11	4,39
		2010-2018	60,34	338,82	7,8	81,85	14,64	12,32	2,94	0,03	0,16	133,25	0,19	32,33	0,01	60,00	3,69
RIVIERSONDEREND SECTION	H6H009Q01	1970-1979	33,55	169,99	6,5	45,15	6,17	5,39	1,28	0,05	0,09	76,55	0,15	9,63	0,02	24,98	3,14
		1980-1989	24,51	125,32	5,9	33,88	4,95	3,15	1,15	0,05	0,06	58,81	0,14	8,80	0,04	13,69	2,64
		1990-1999	35,37	187,73	7,2	49,60	7,10	4,65	1,54	0,03	0,15	84,34	0,20	16,26	0,02	23,04	3,13
		2000-2009	43,62	229,05	7,4	61,34	8,40	5,74	1,78	0,06	0,11	103,22	0,22	20,66	0,03	26,59	3,56
		2010-2018	43,66	239,21	7,2	65,28	8,92	4,95	2,37	0,04	0,21	116,71	0,17	14,86	0,01	7,62	2,84

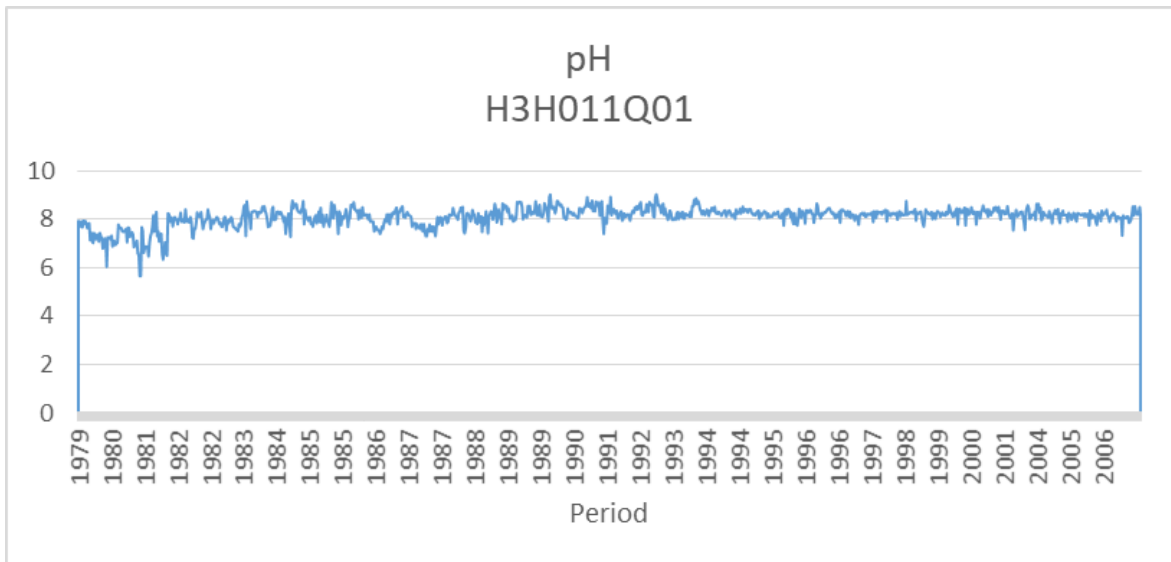
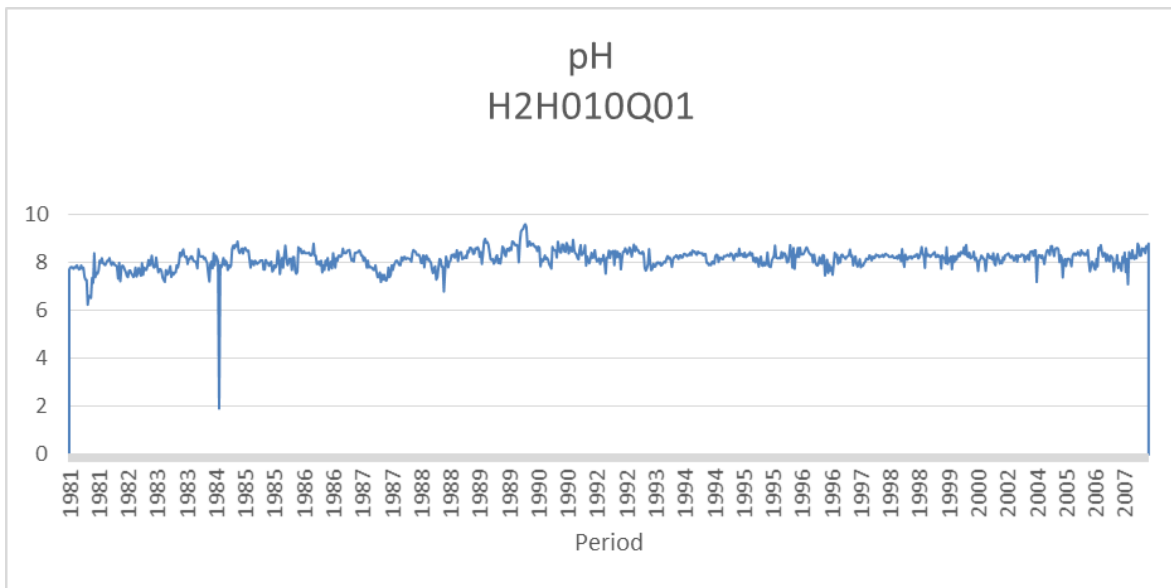
ANNEXURE F: TIME SERIES PLOTS FOR ANORGANIC WATER QUALITY

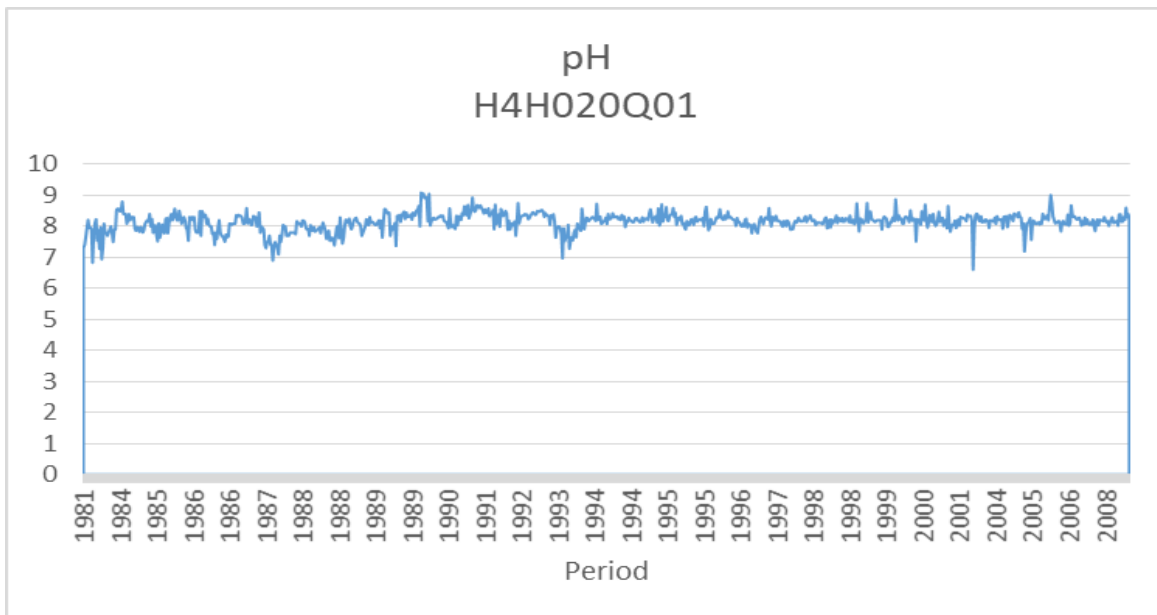
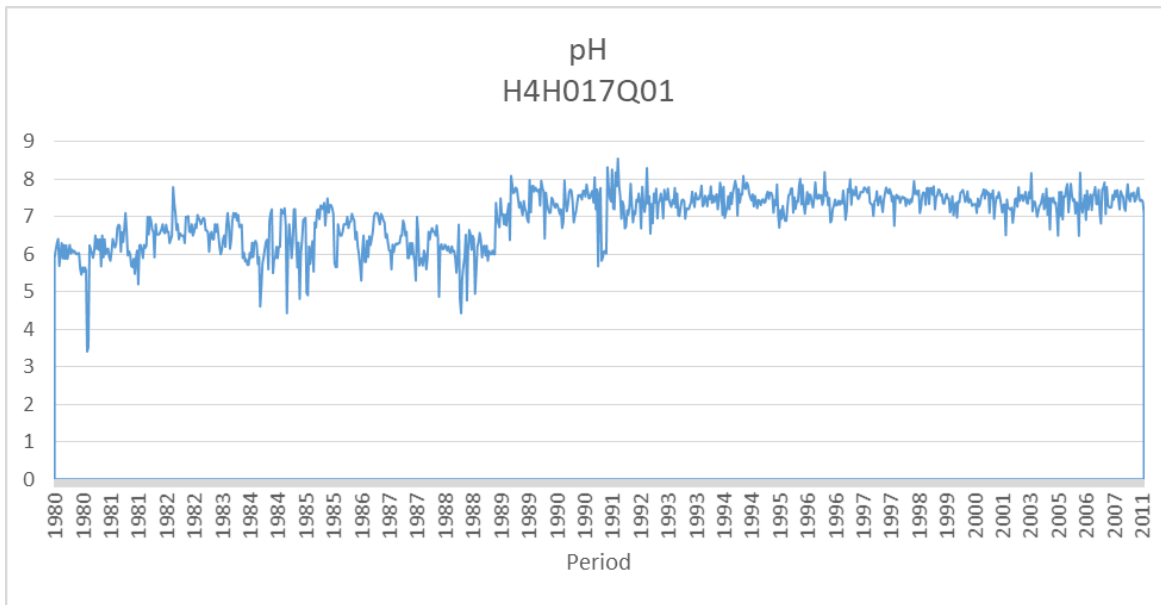
Time series for pH

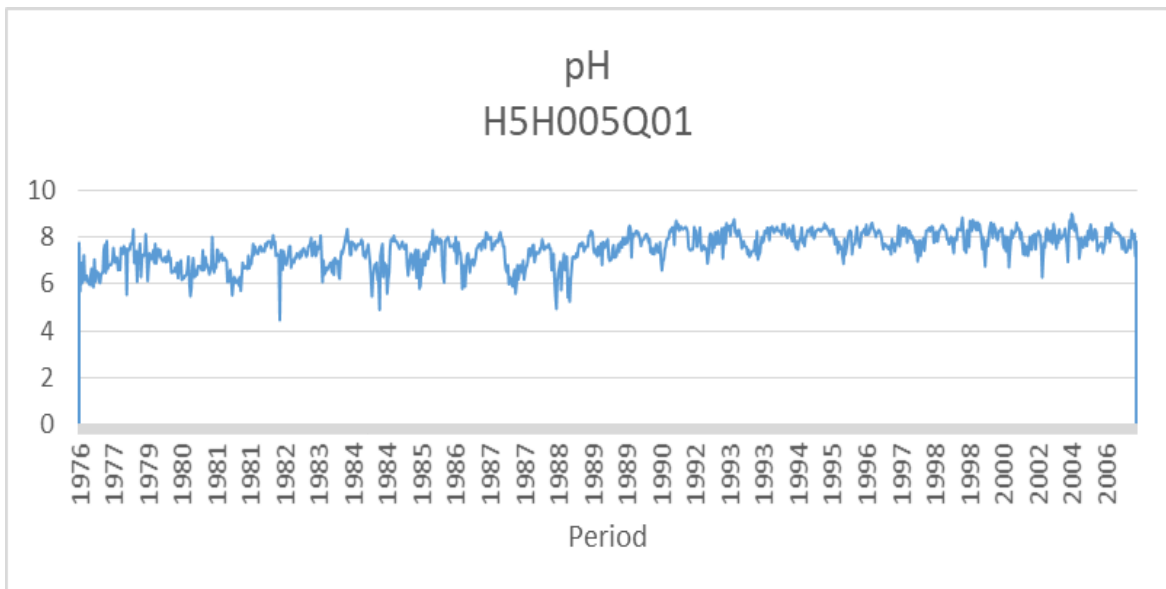
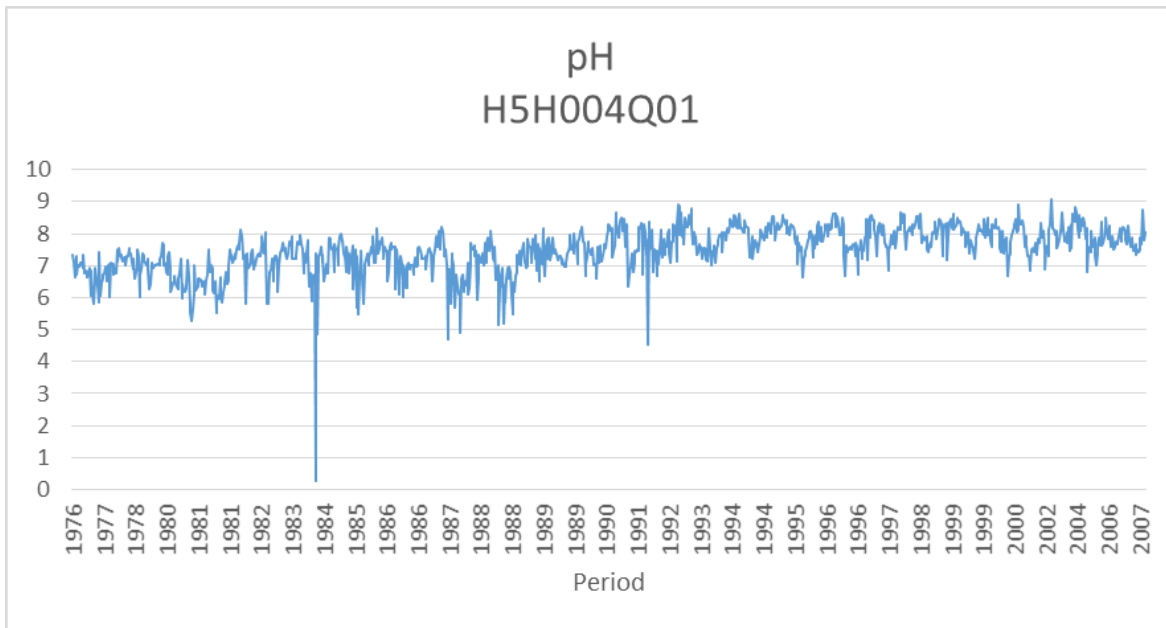
UPPER BREEDE SECTION



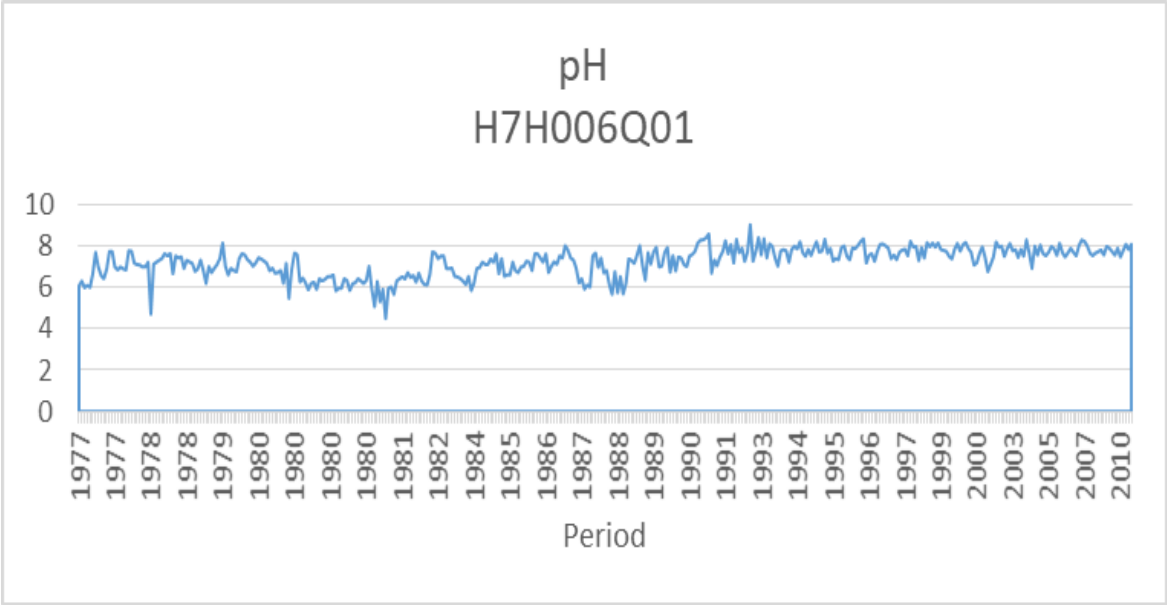
MIDDLE BREEDE SECTION



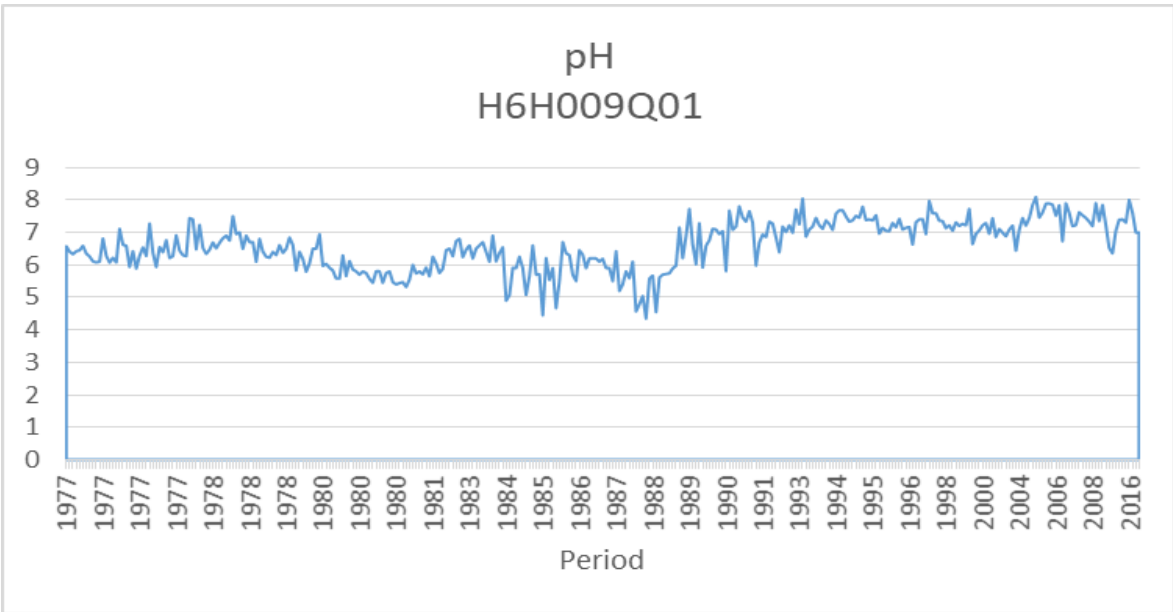




LOWER BREEDE SECTION

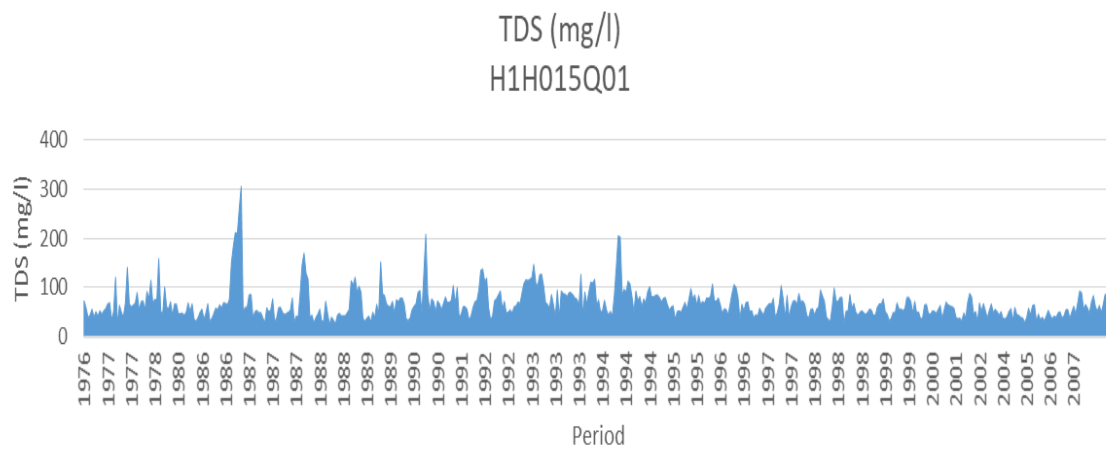
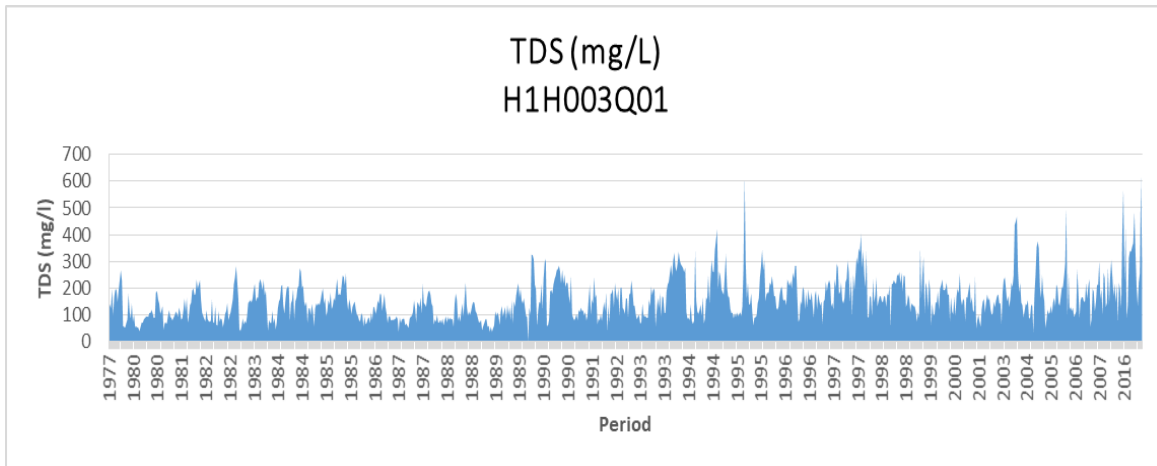


RIVIERSONDEREND SECTION

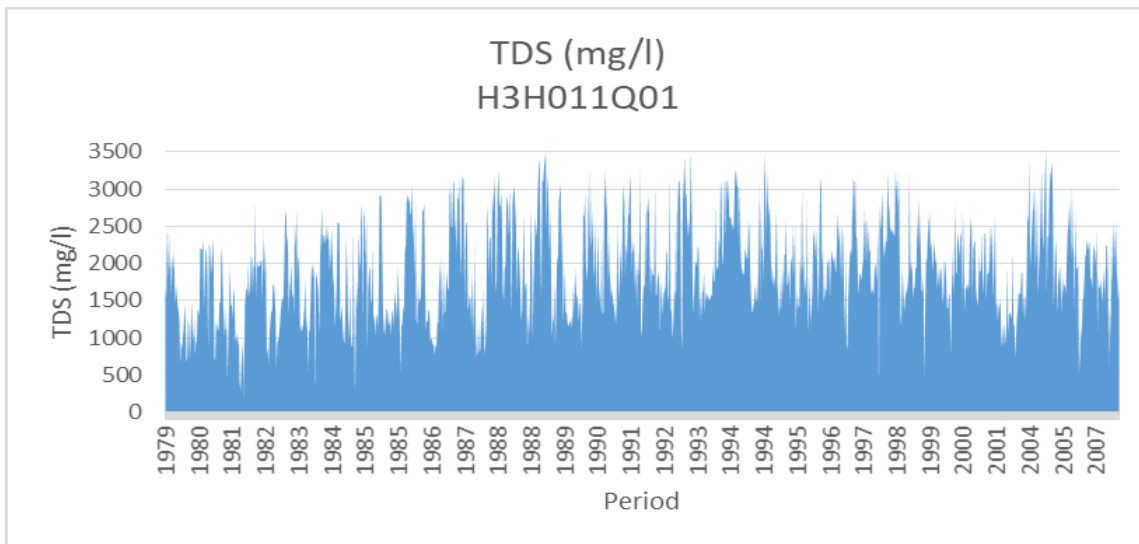
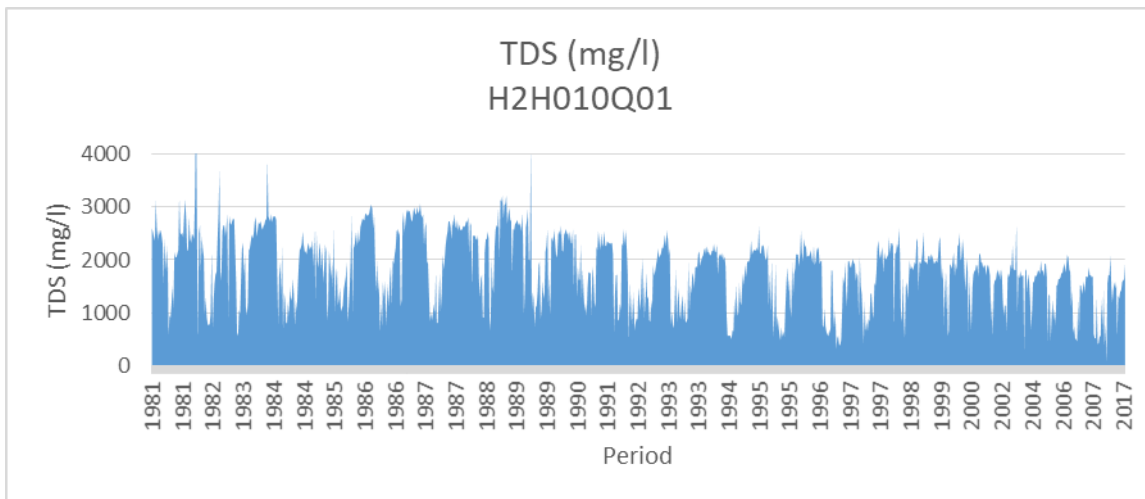


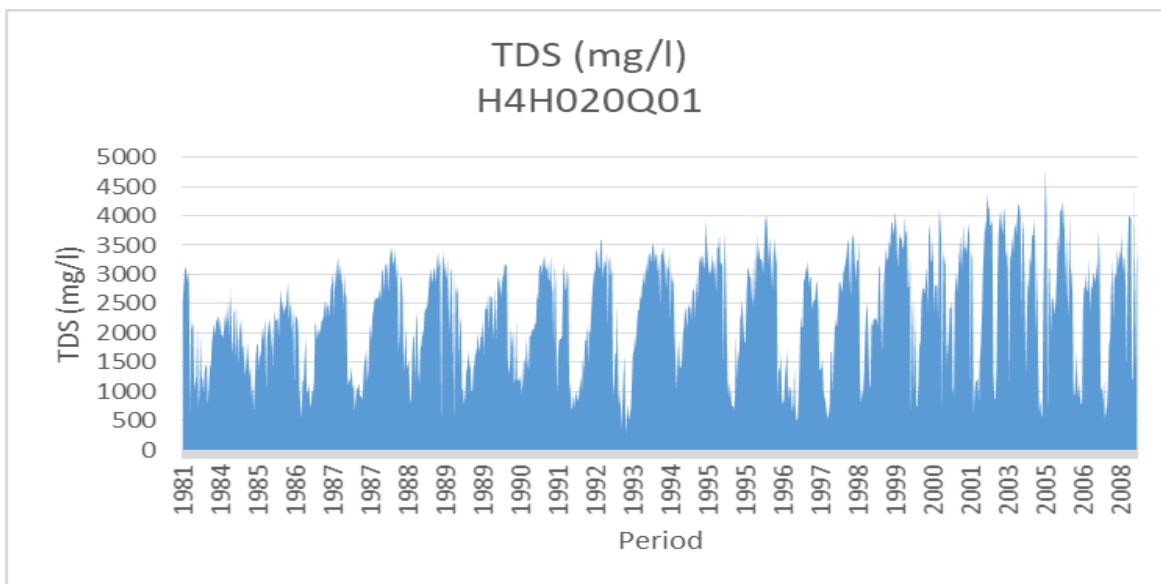
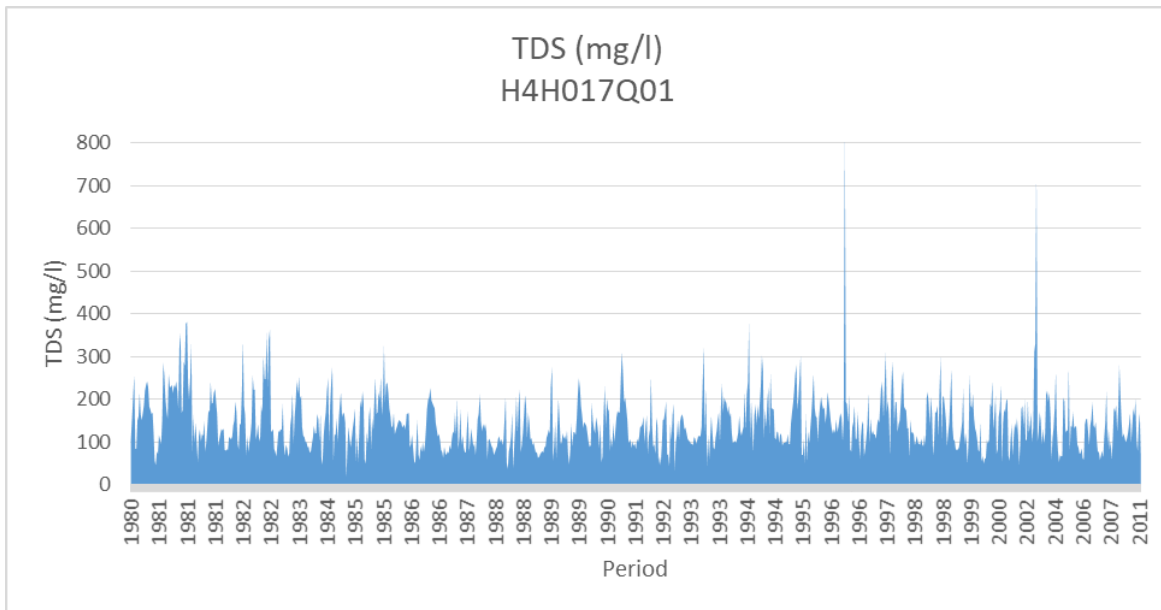
Time series for TDS

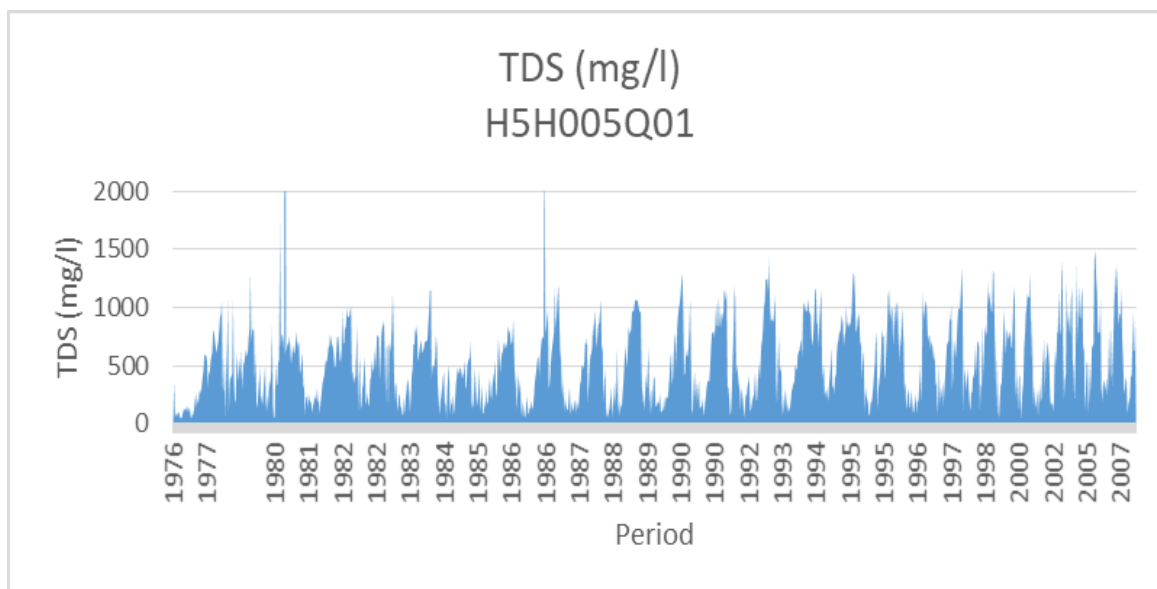
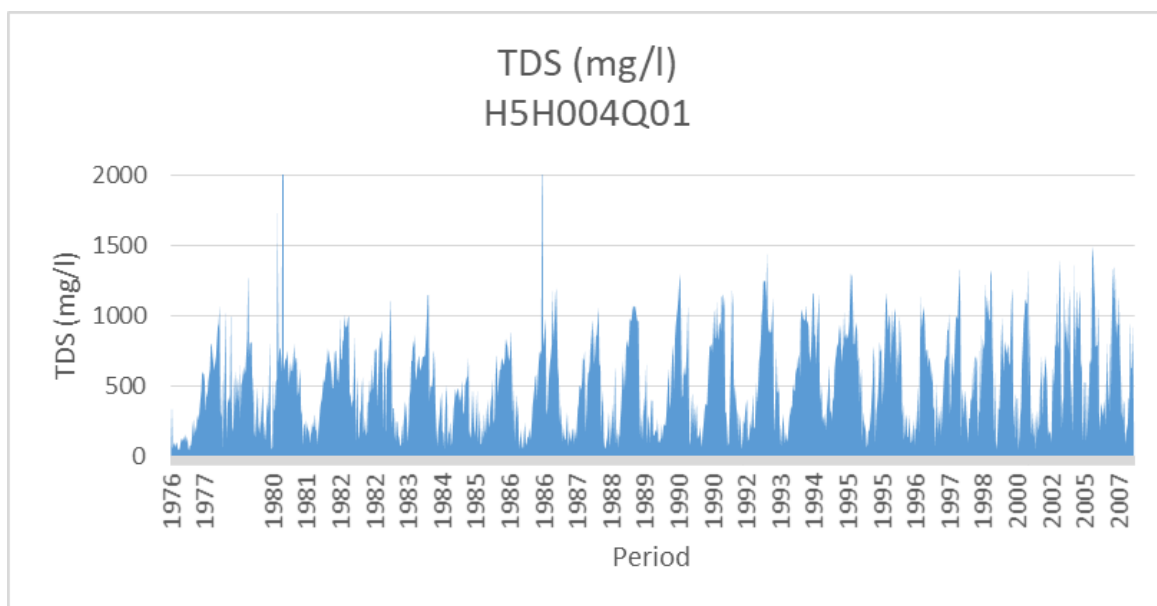
UPPER BREEDE SECTION



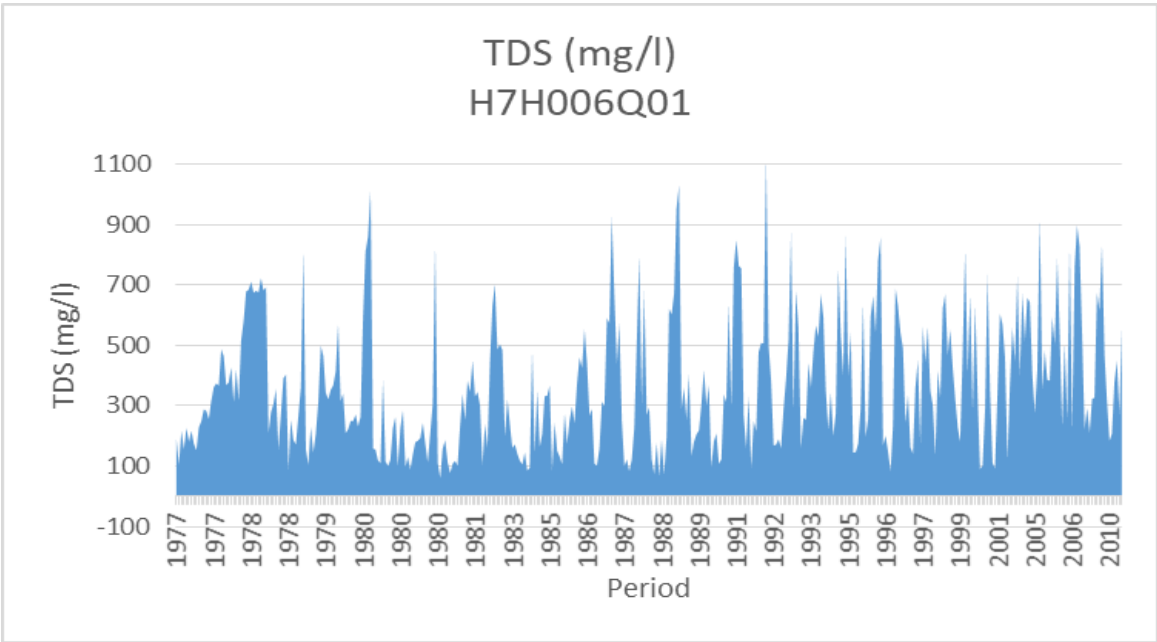
MIDDLE BREEDE SECTION



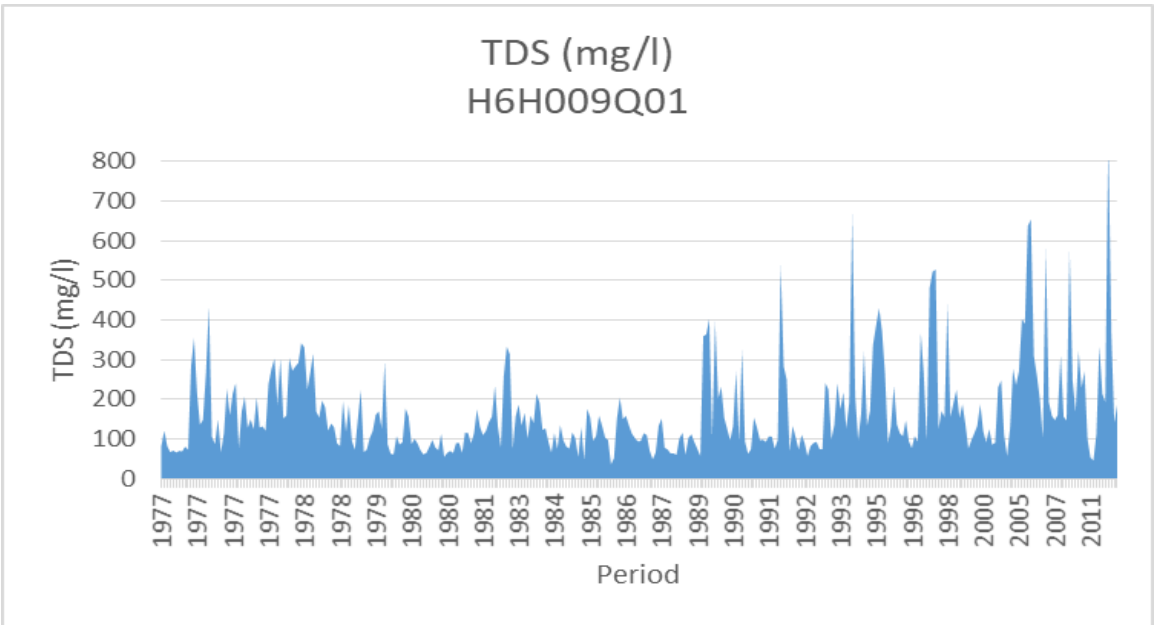




LOWER BREEDE SECTION

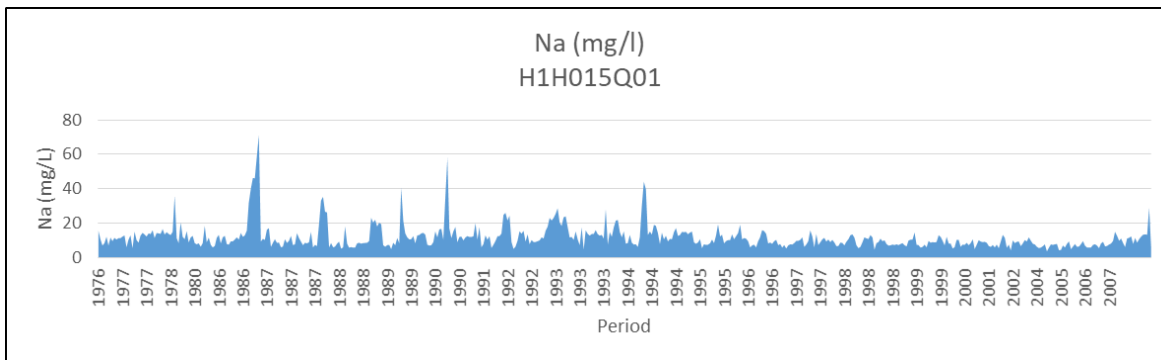
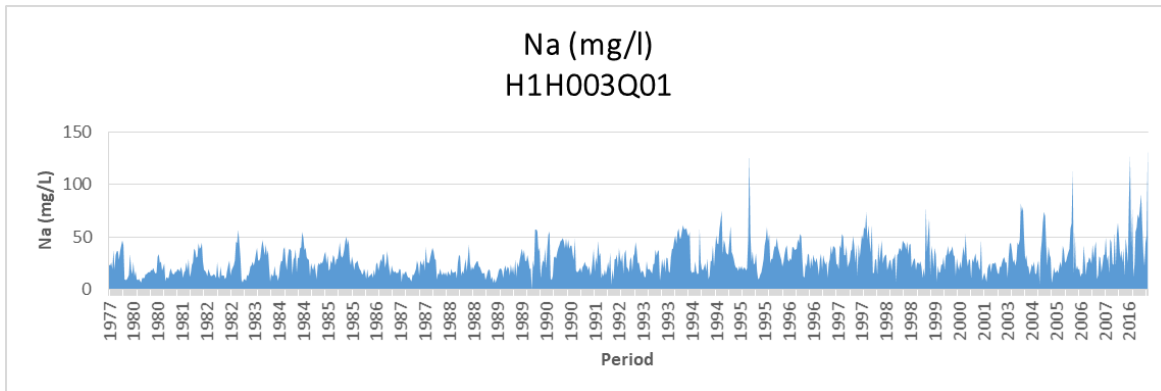


RIVIERSONDEREND SECTION

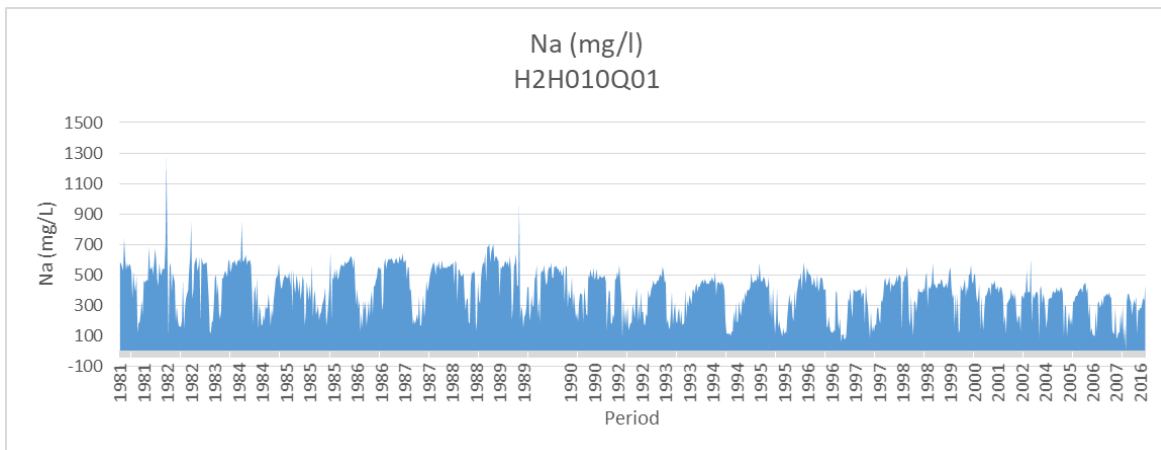


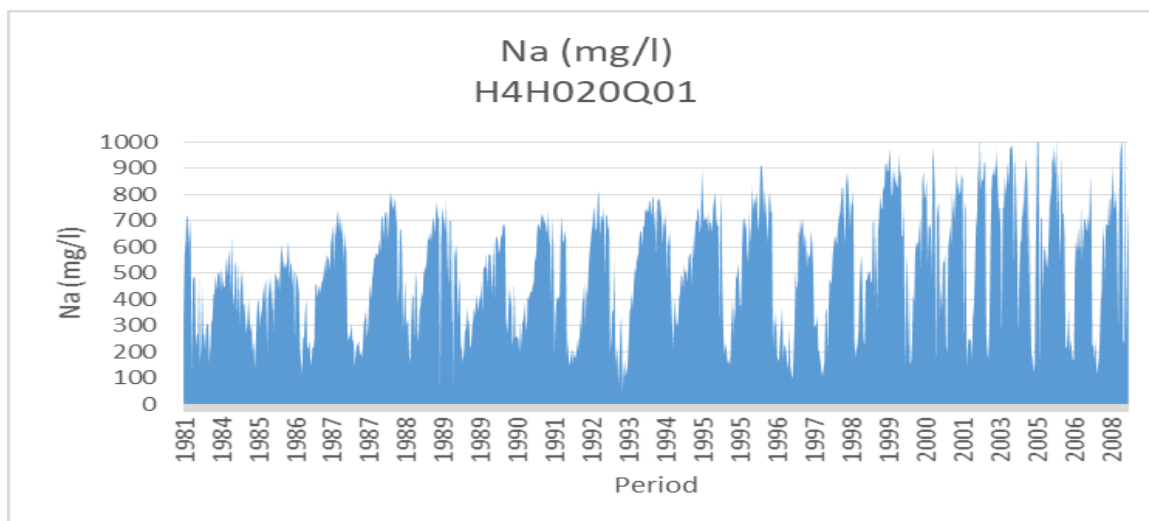
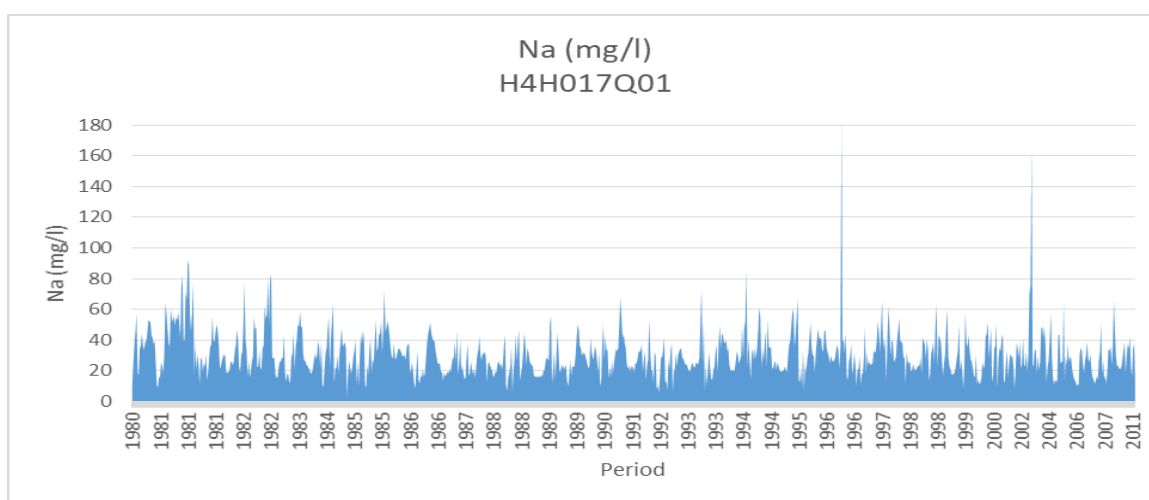
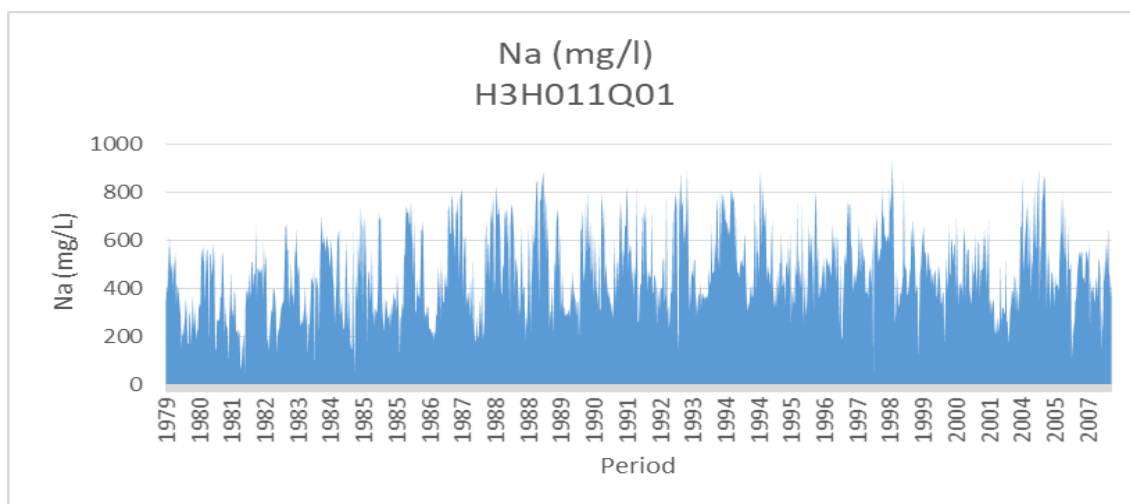
Na (mg/l) time series

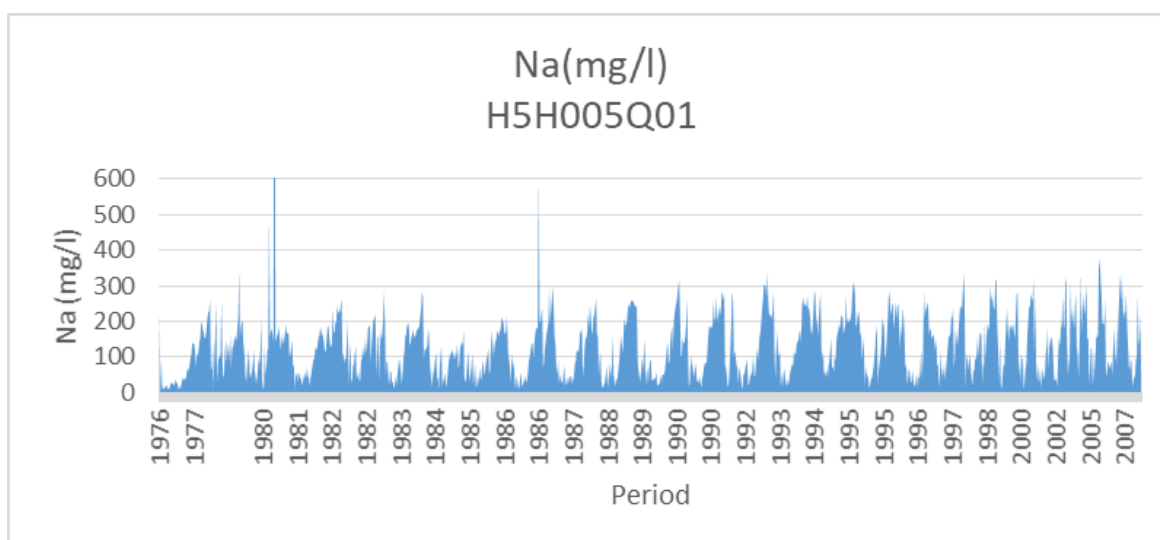
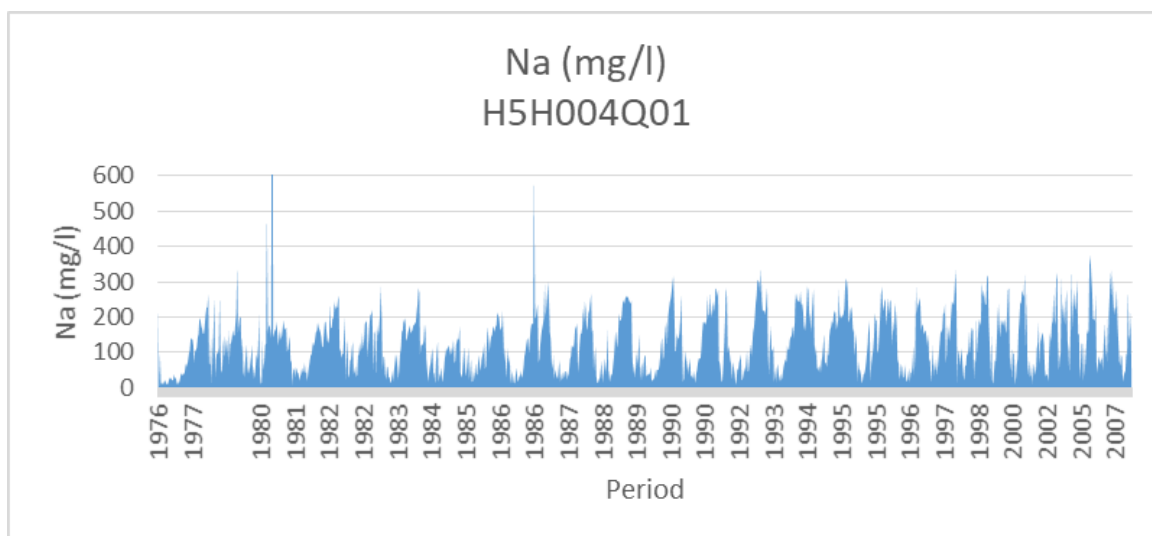
UPPER BREEDE SECTION



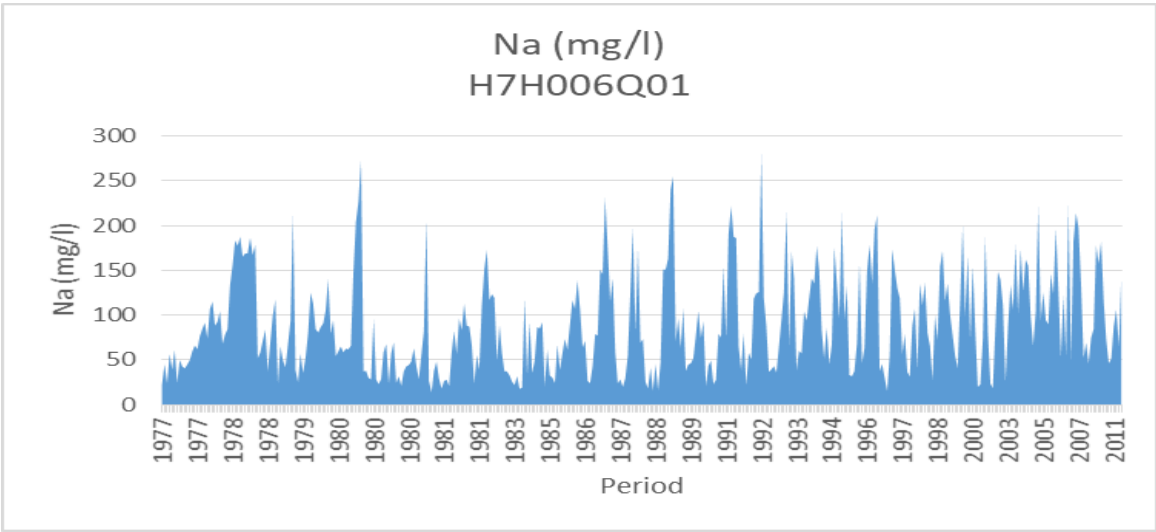
MIDDLE BREEDE SECTION



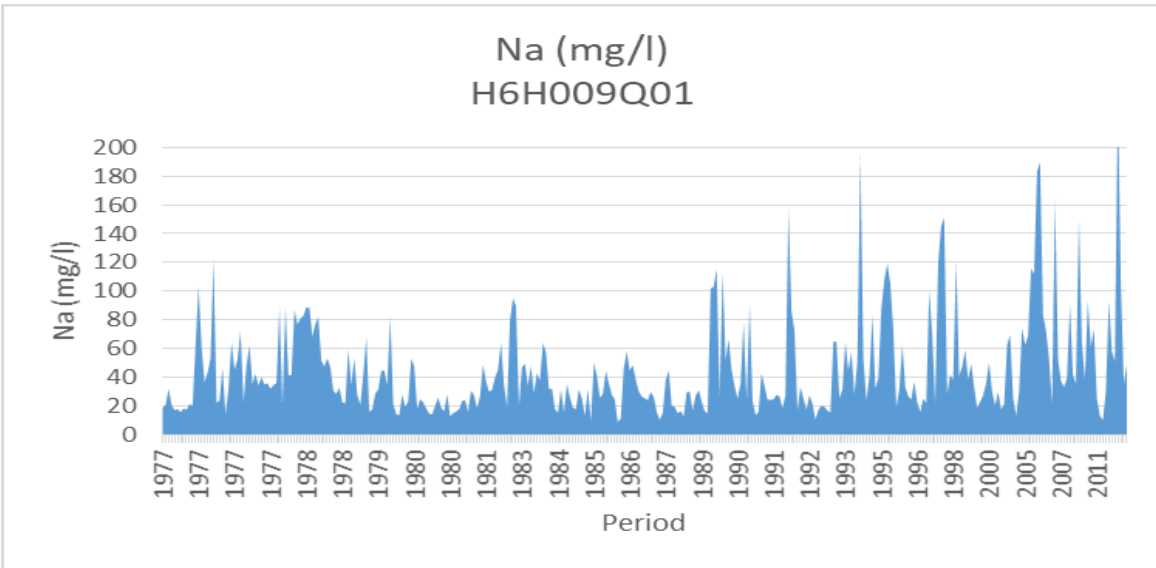




LOWER BREEDE SECTION

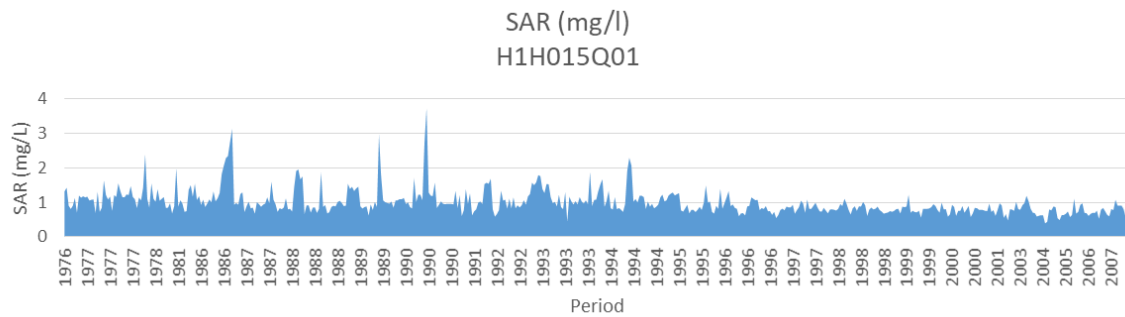
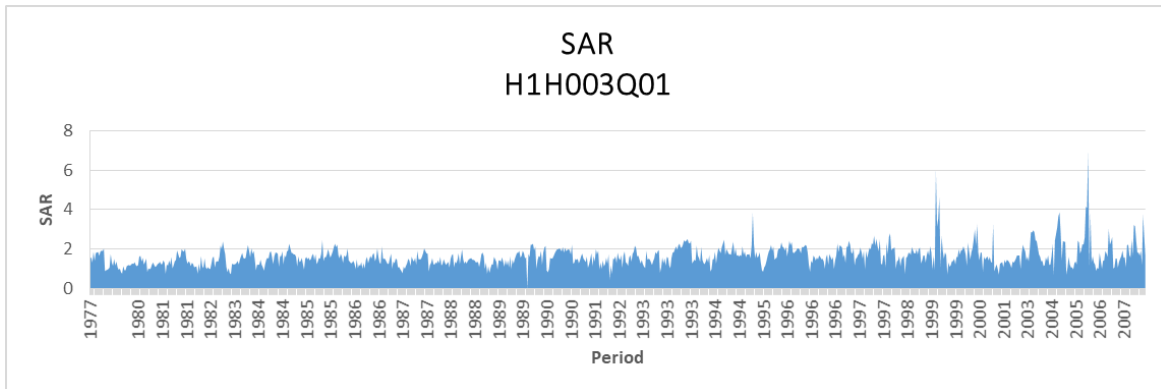


RIVIERSONDEREND SECTION

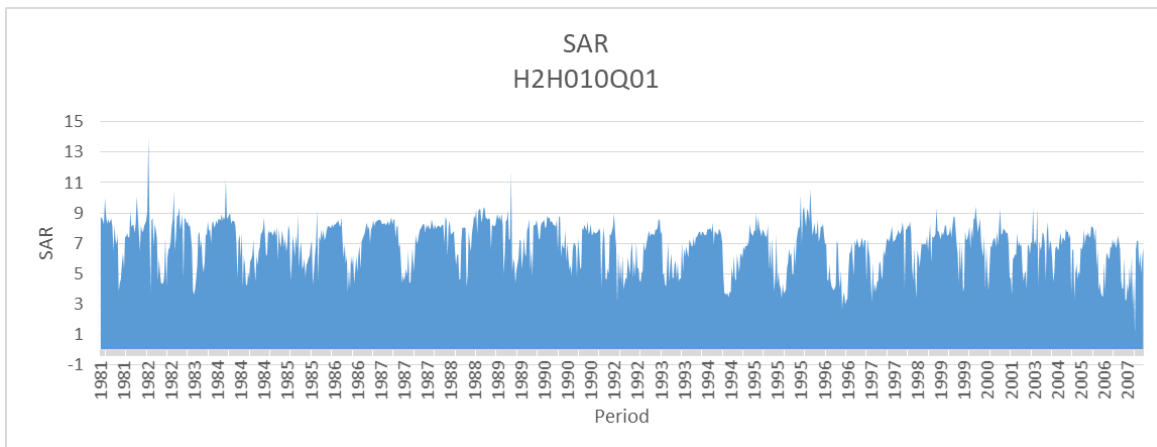


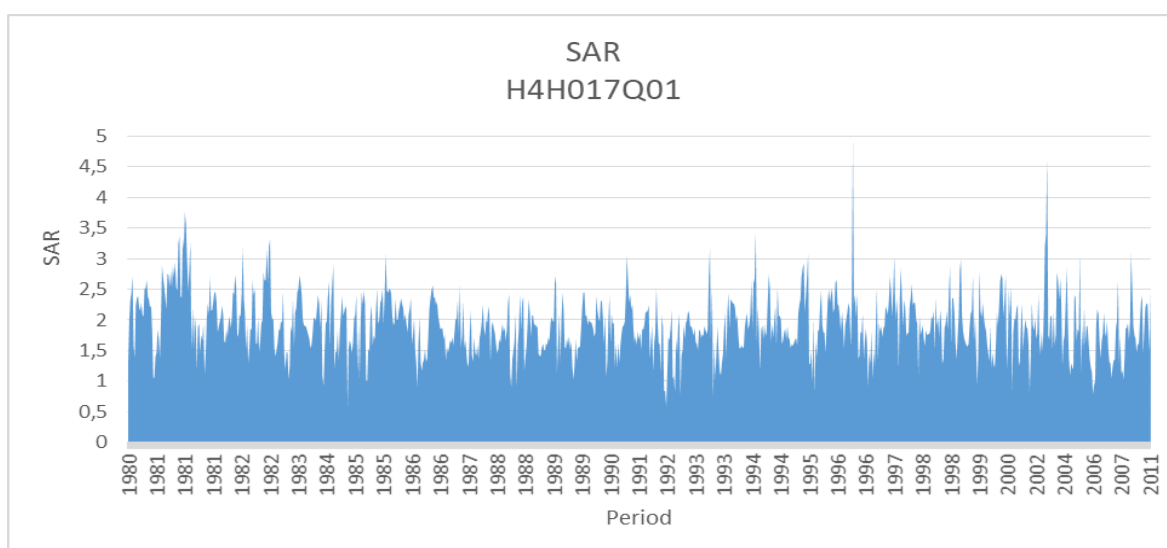
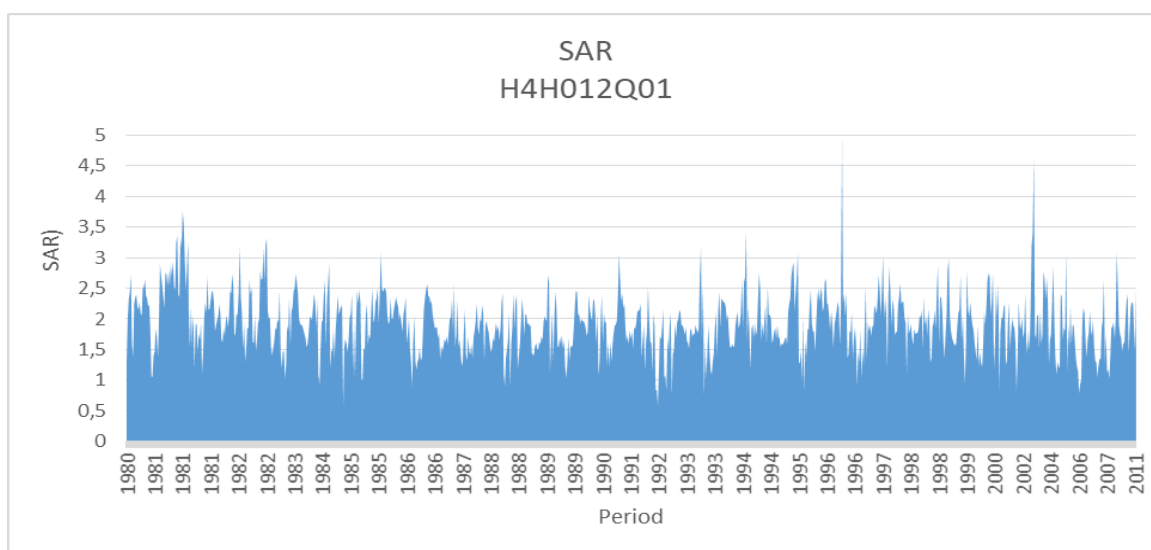
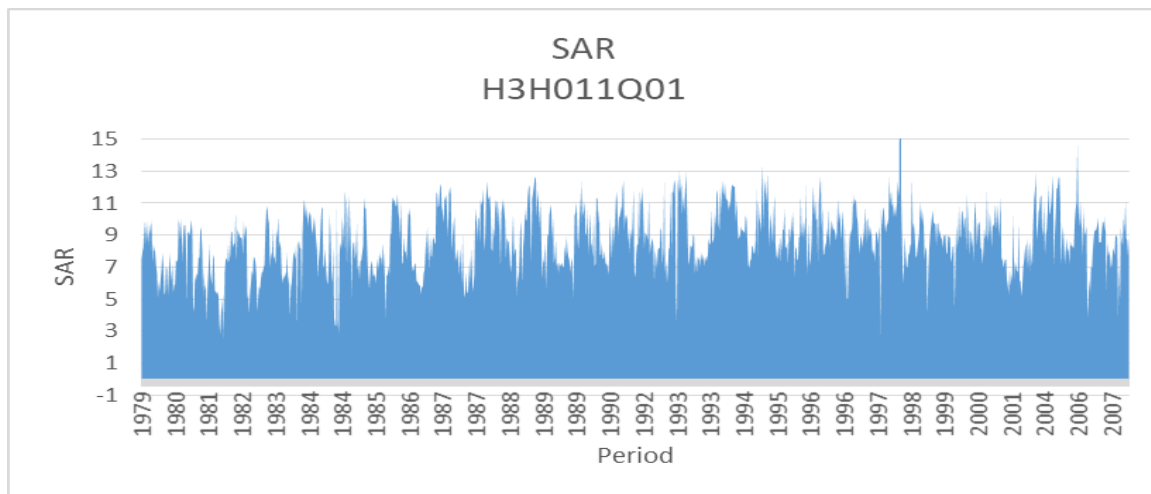
SAR time series

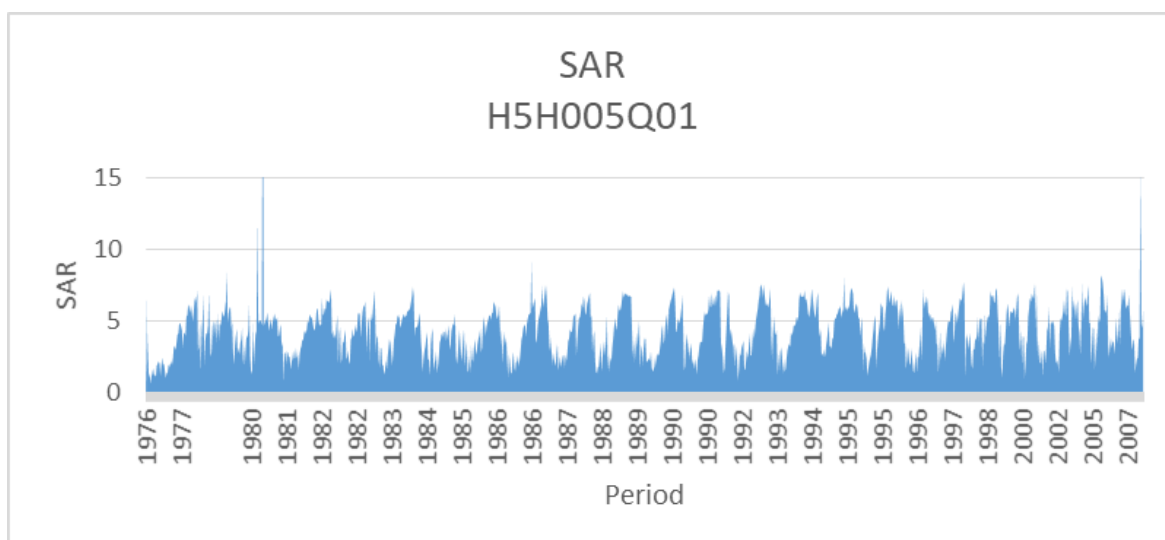
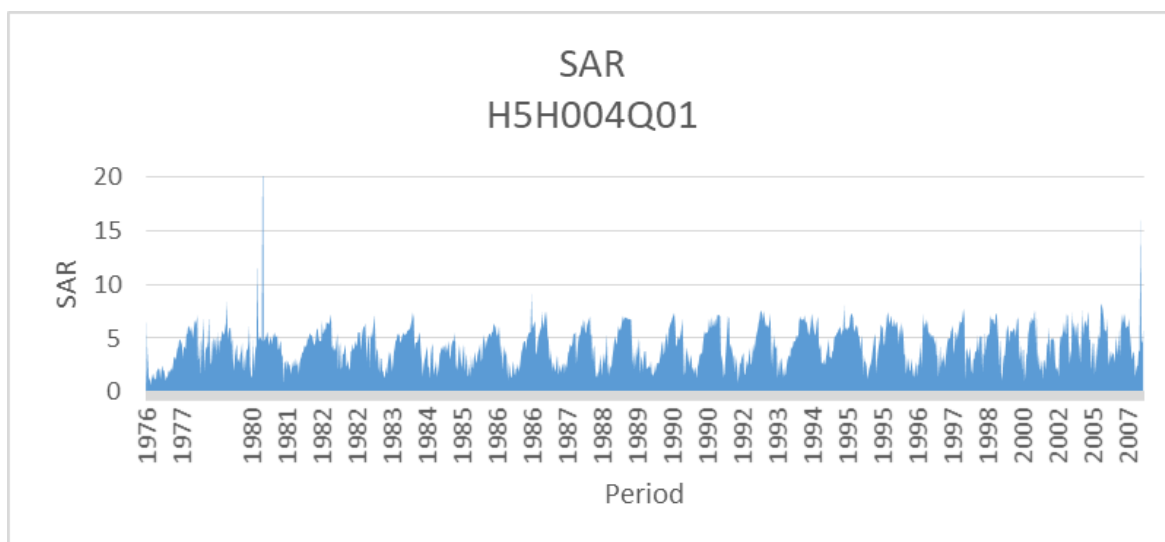
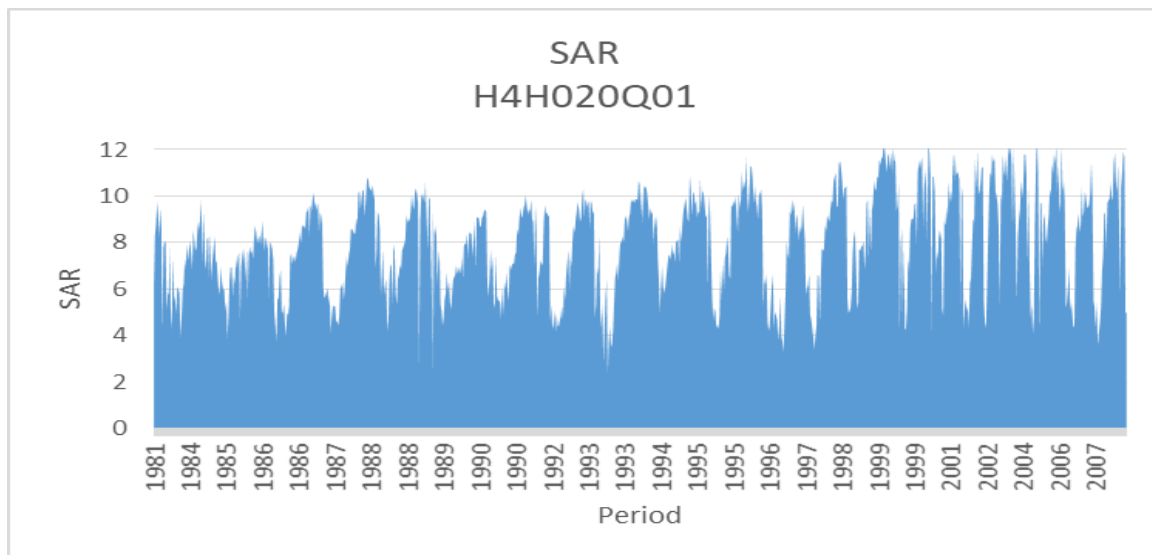
UPPER BREEDE SECTION



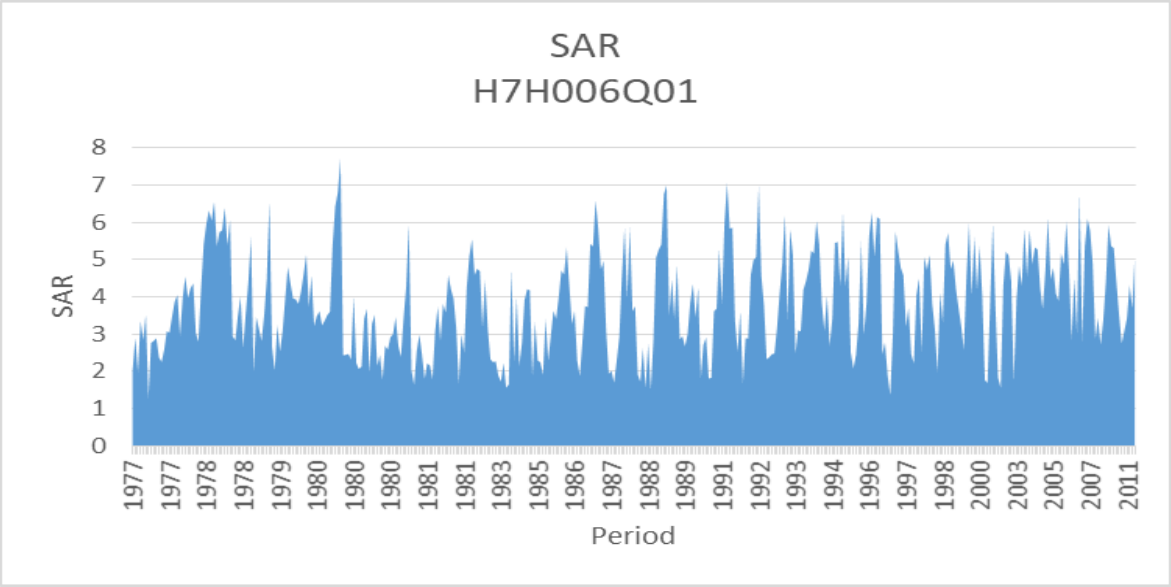
MIDDLE BREEDE SECTION



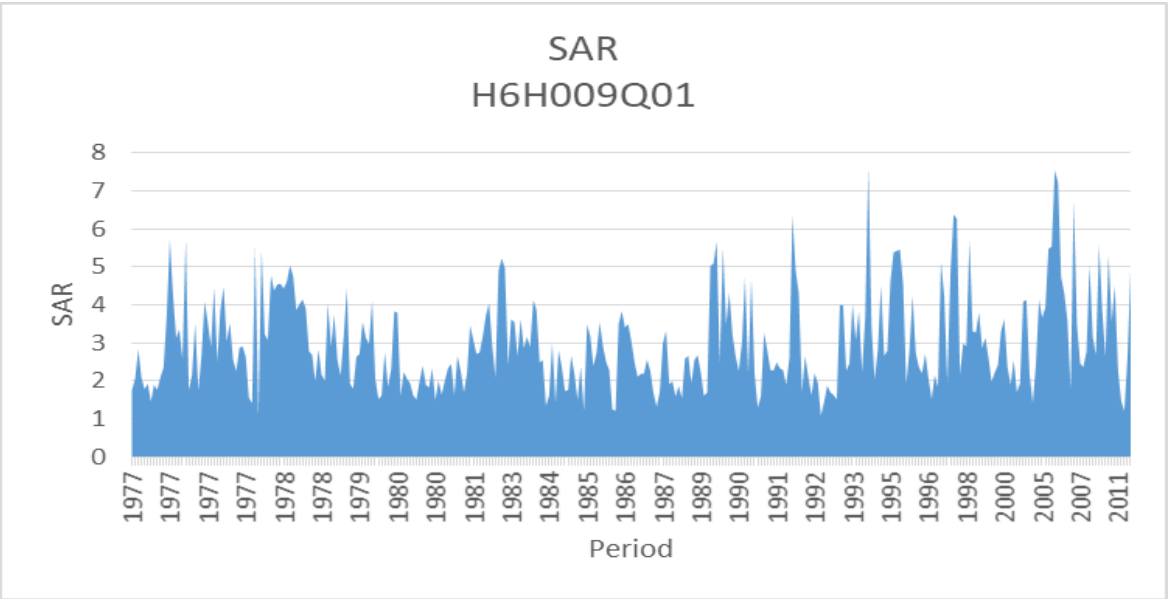




LOWER BREEDE SECTION

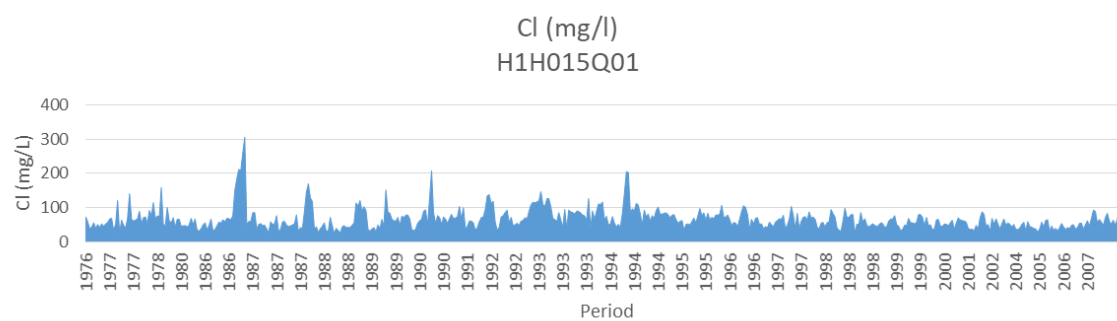
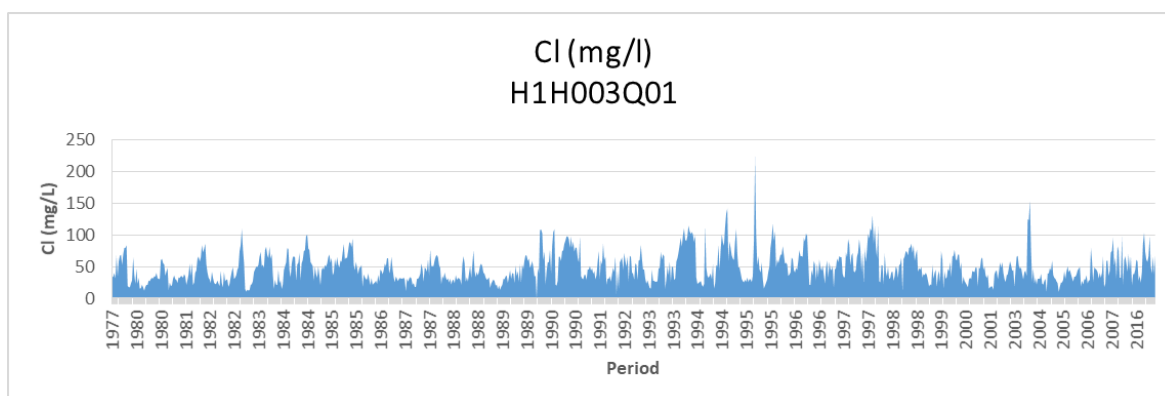


RIVIERSONDEREND SECTION

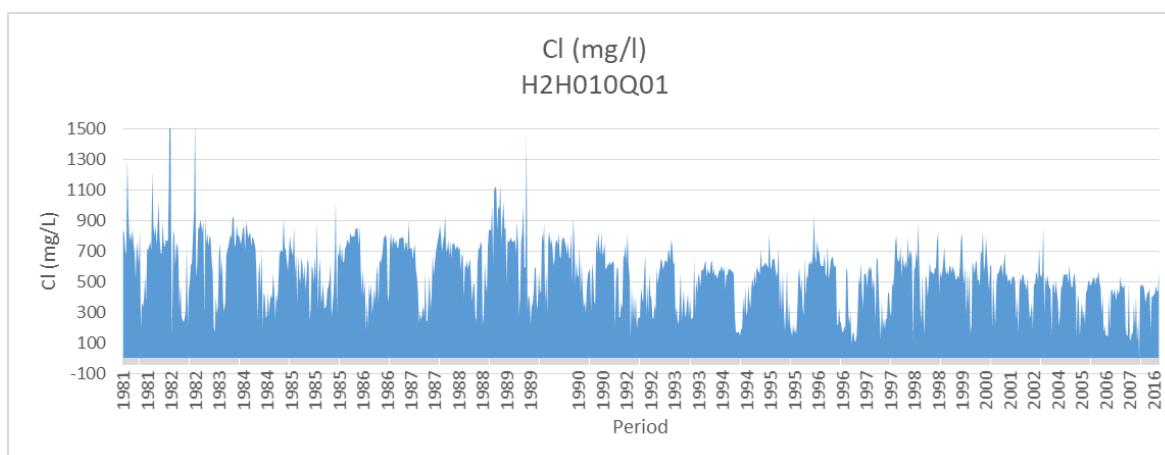


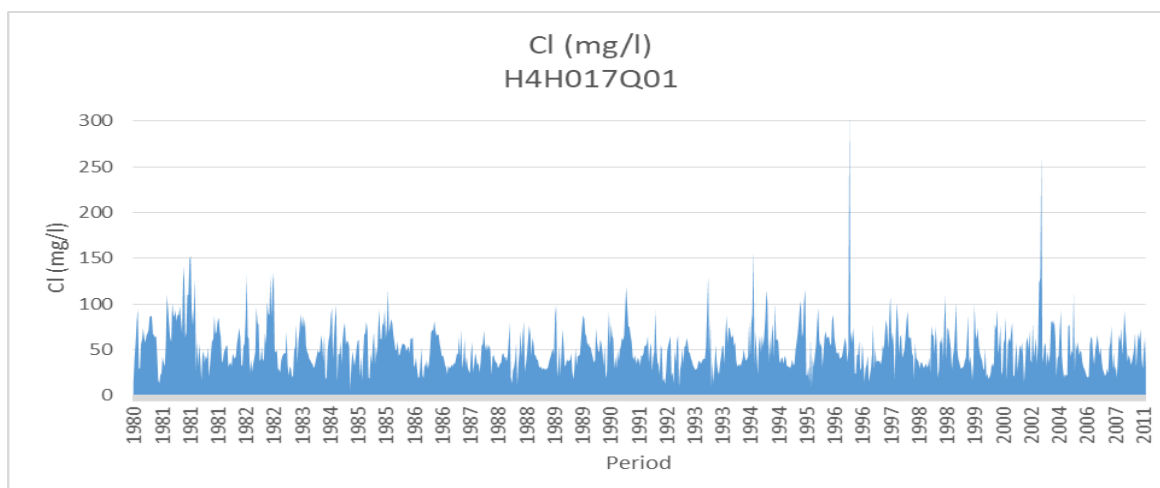
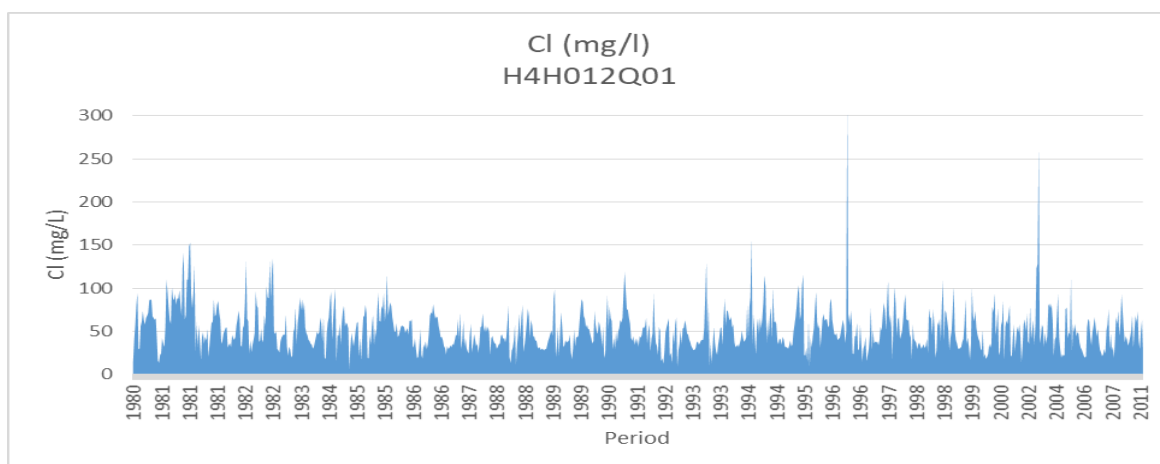
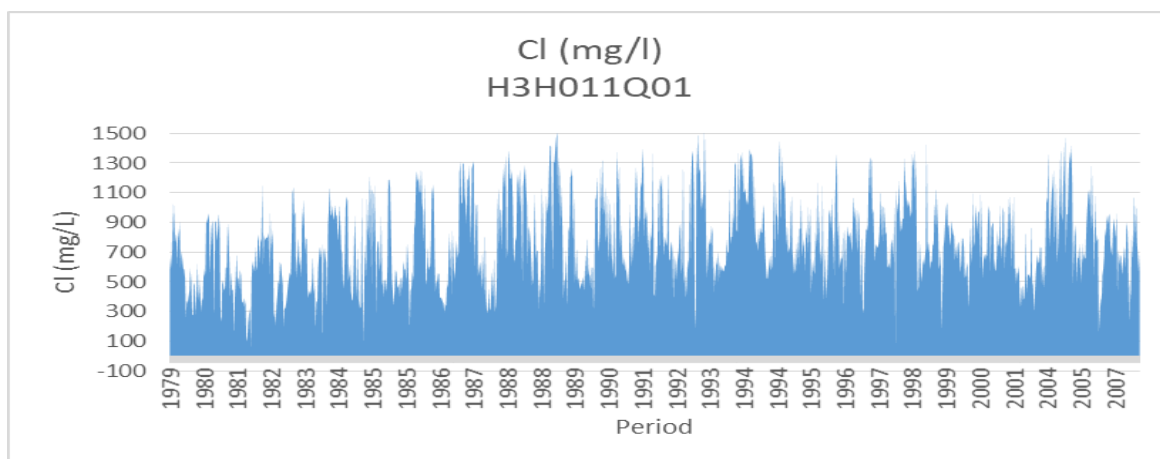
Cl (mg/l) time series

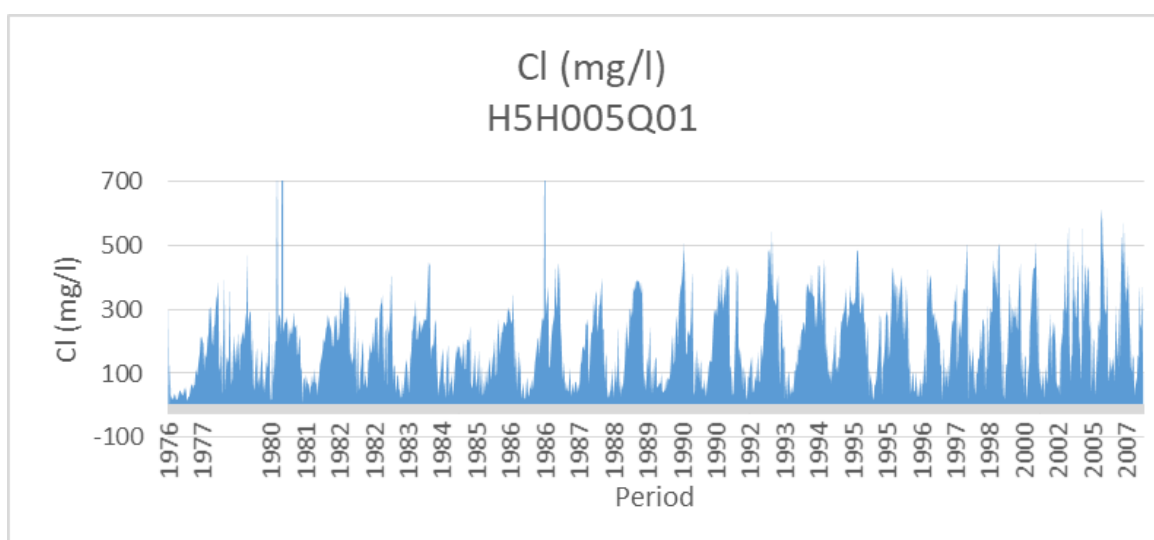
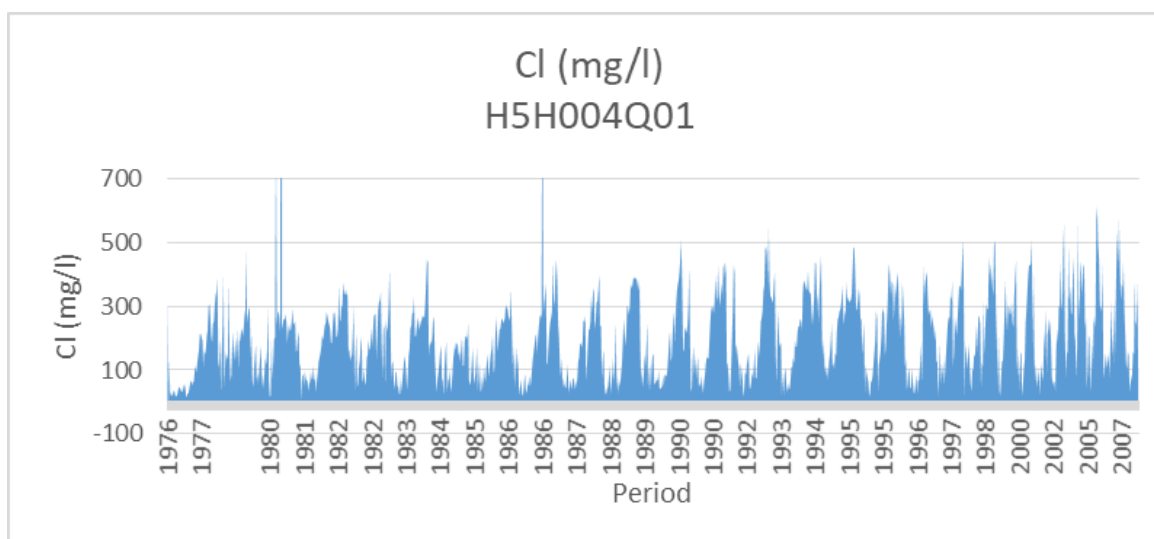
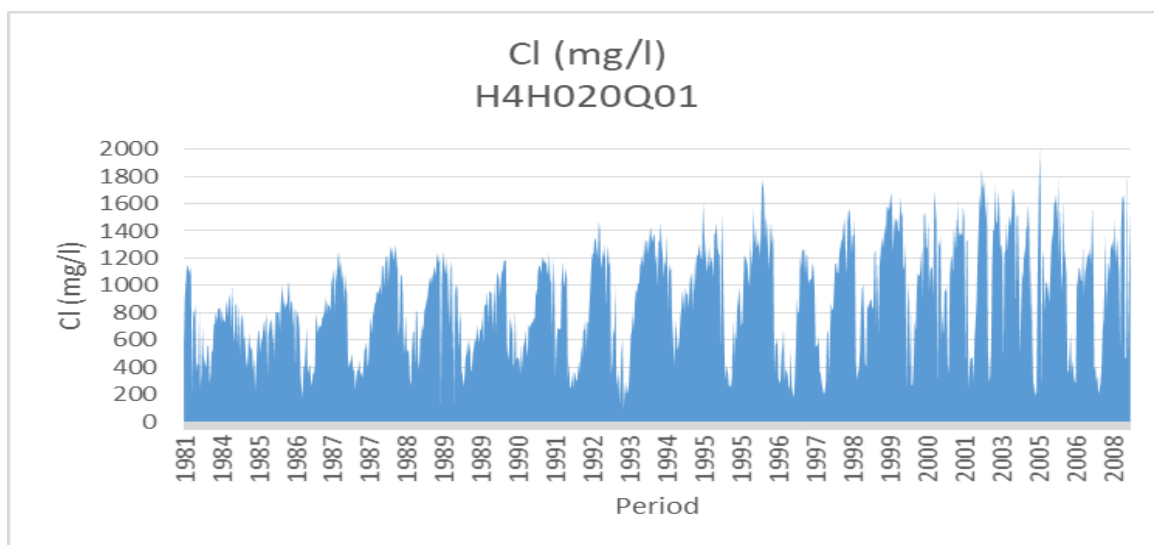
UPPER BREEDE SECTION



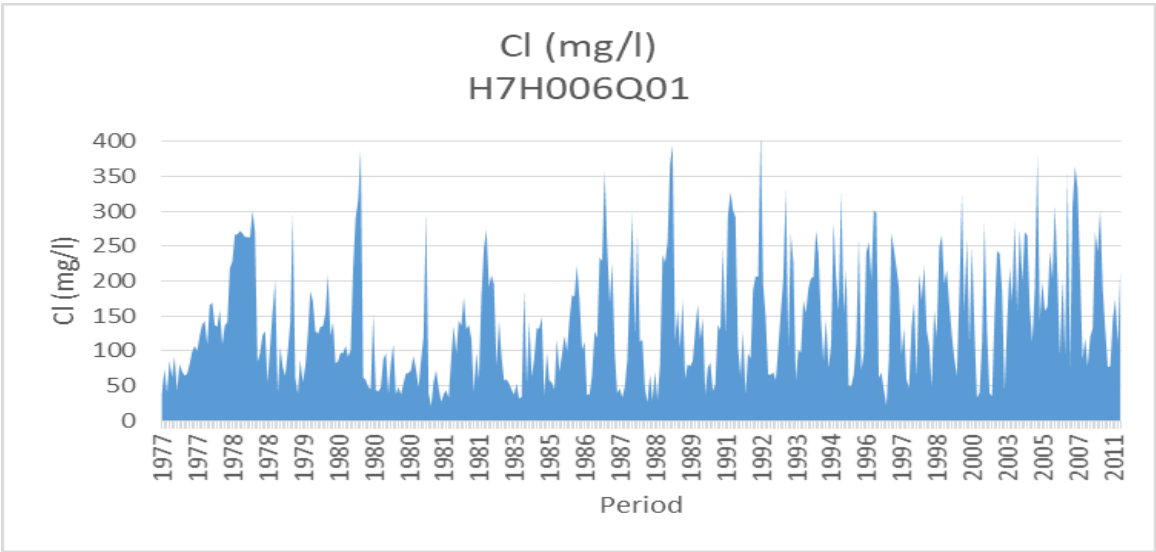
MIDDLE BREEDE SECTION



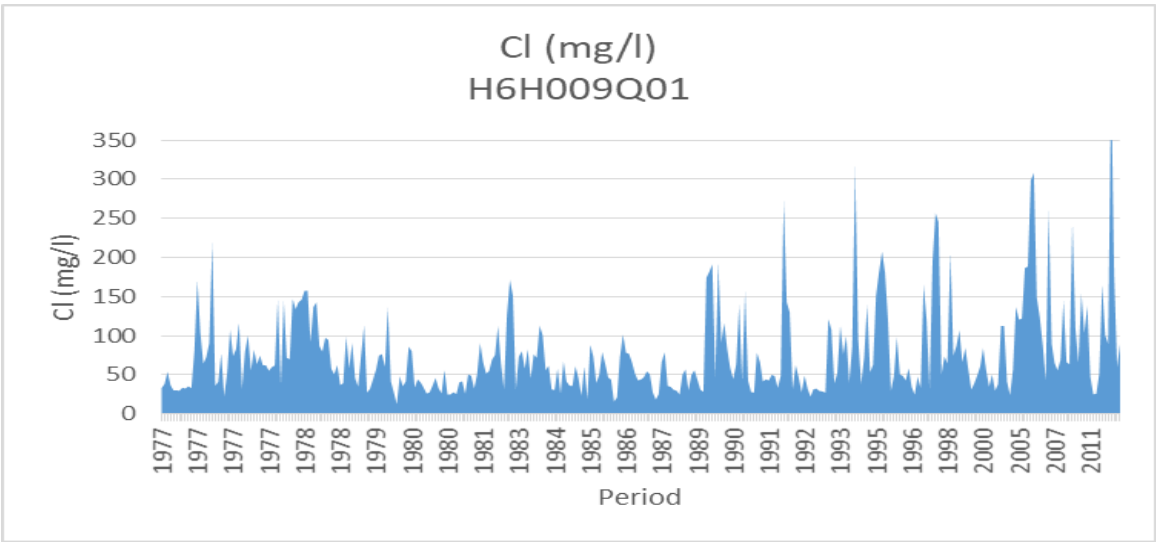




LOWER BREEDE SECTION

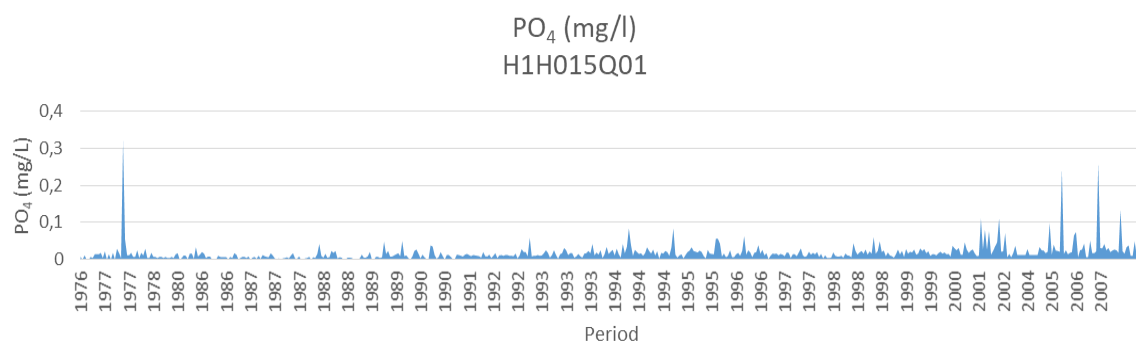
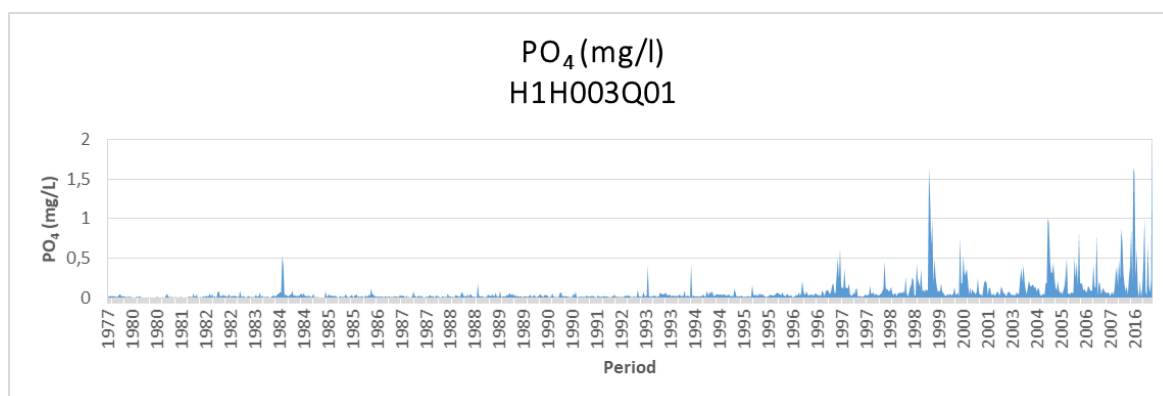


RIVIERSONDEREND SECTION

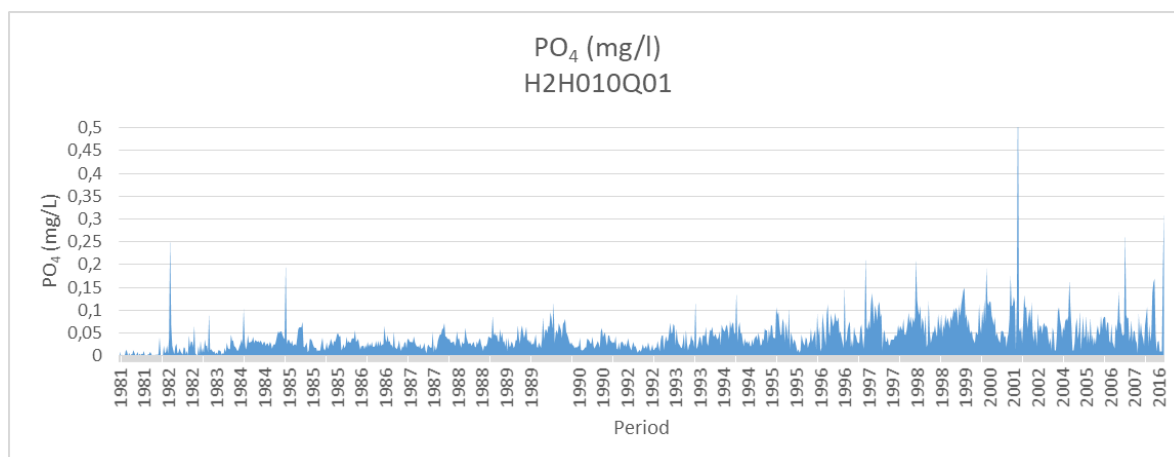


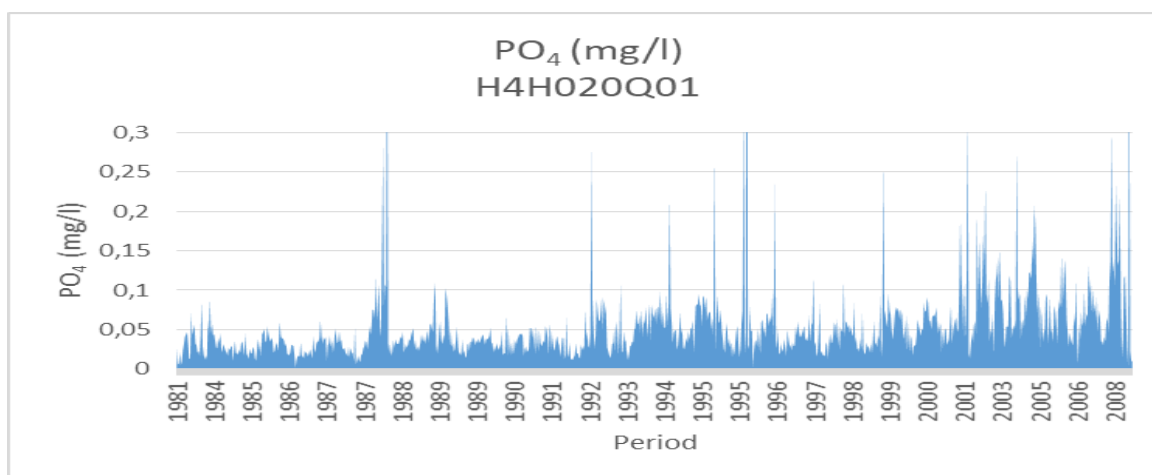
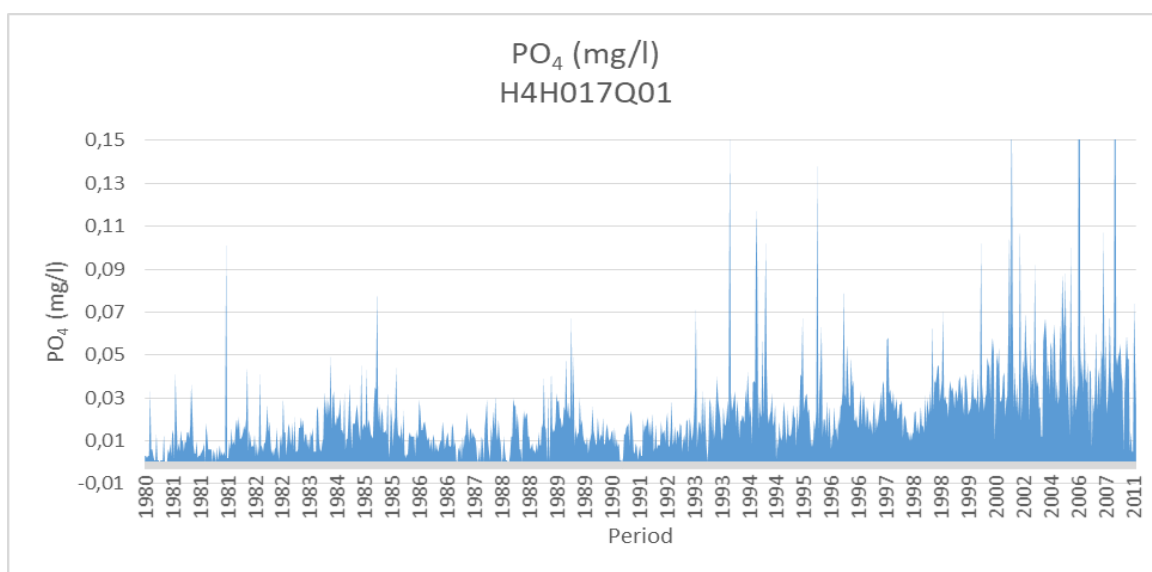
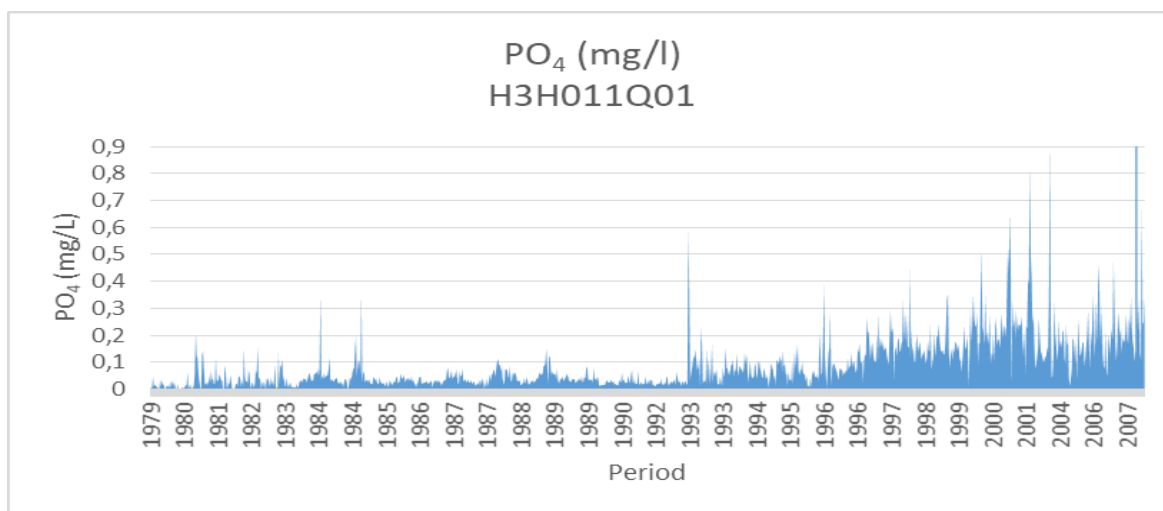
PO₄ (mg/l) time series

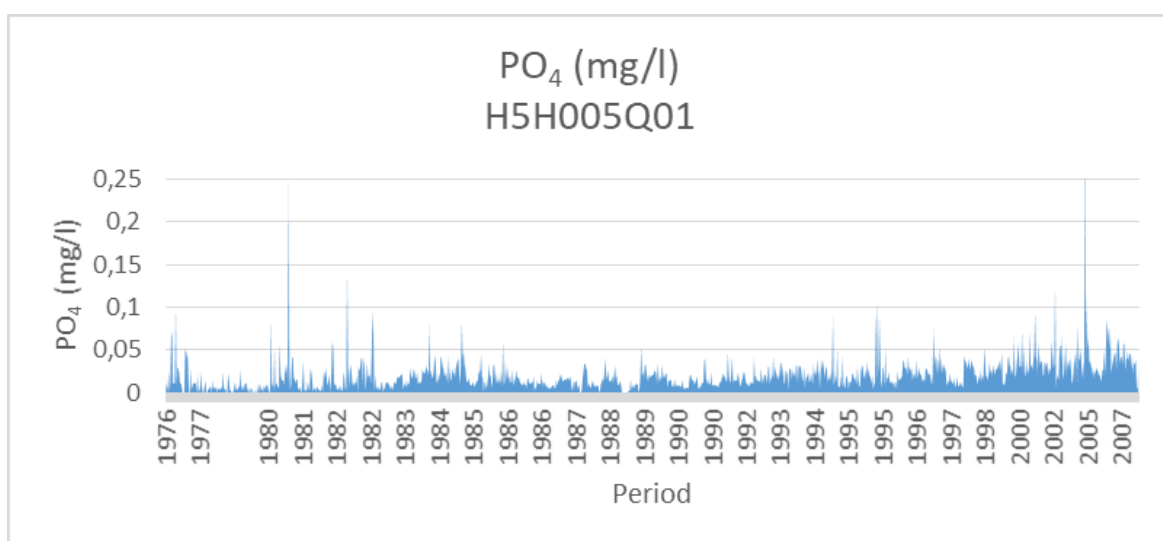
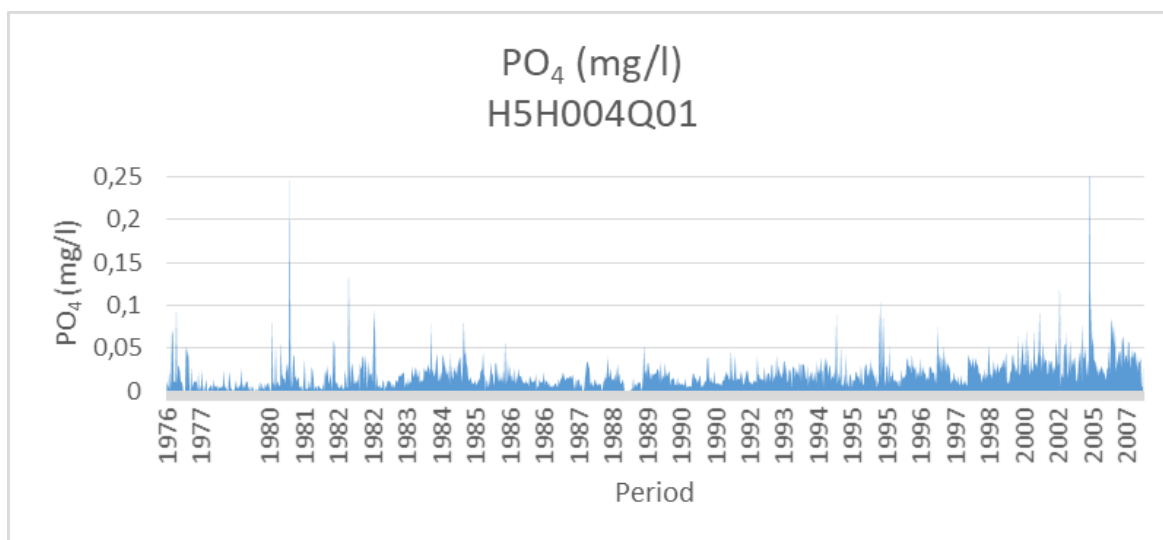
UPPER BREEDE SECTION



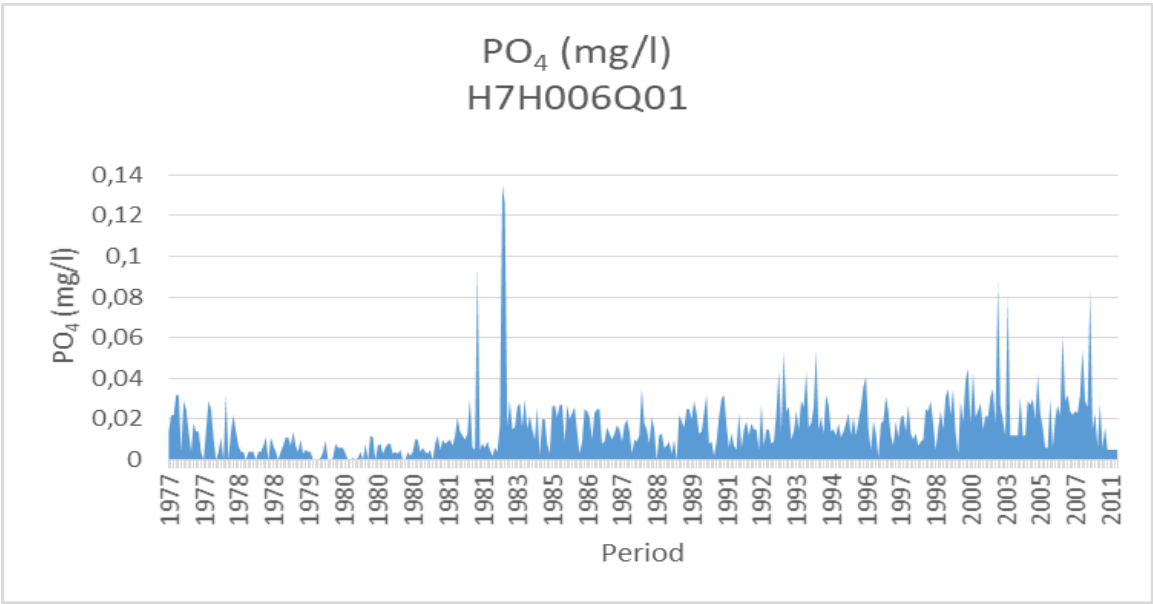
MIDDLE BREEDE SECTION



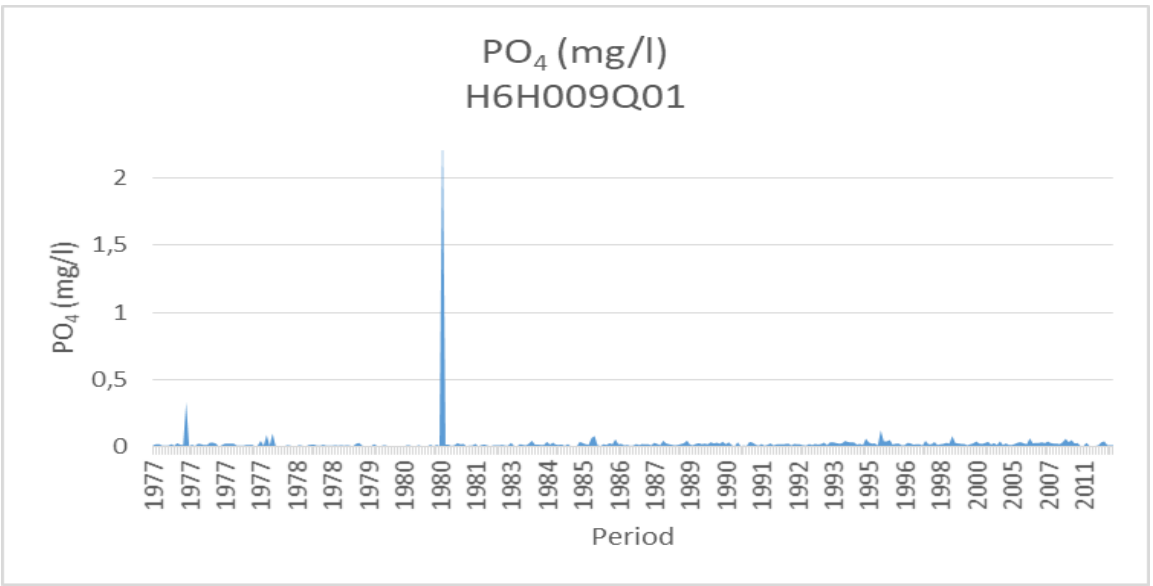




LOWER BREEDE SECTION

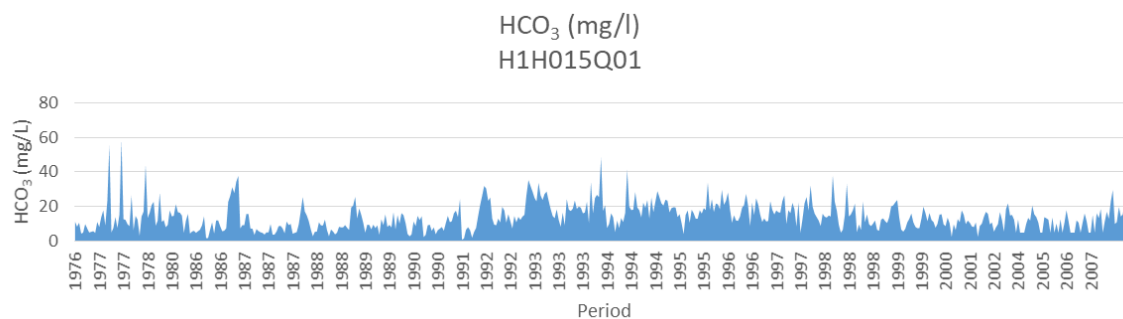
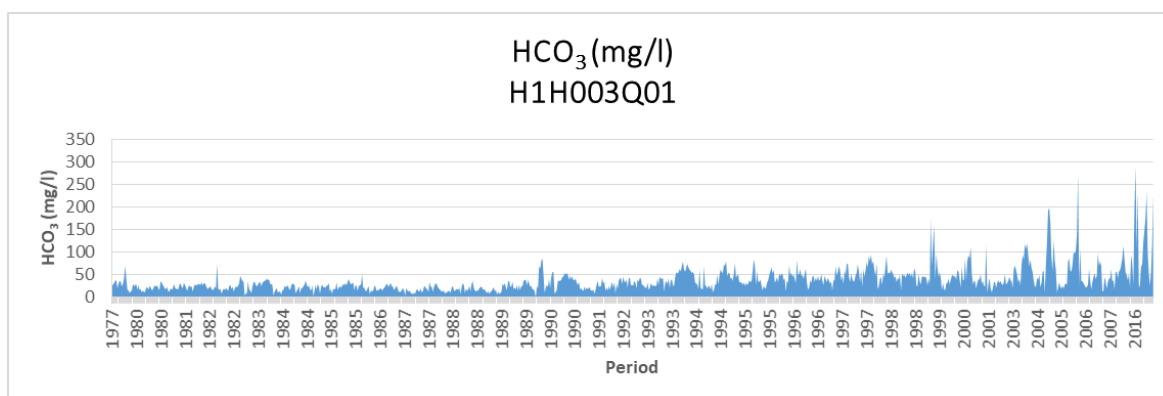


RIVIERSONDEREND SECTION

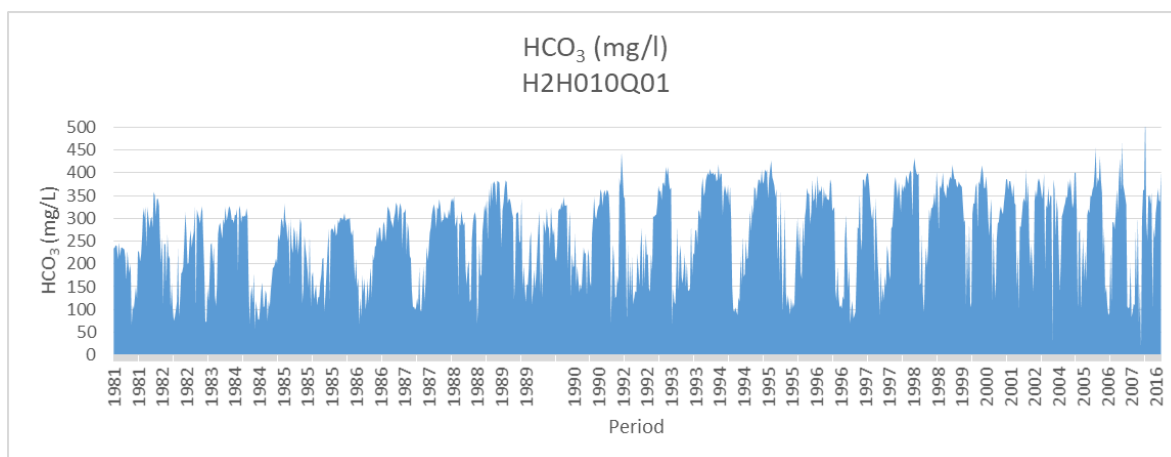


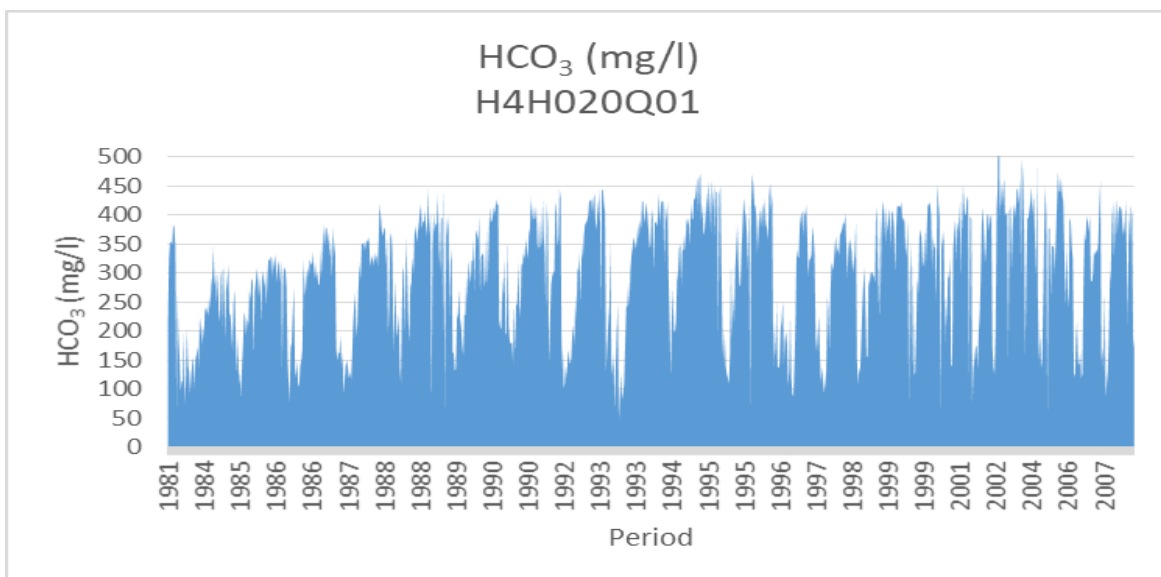
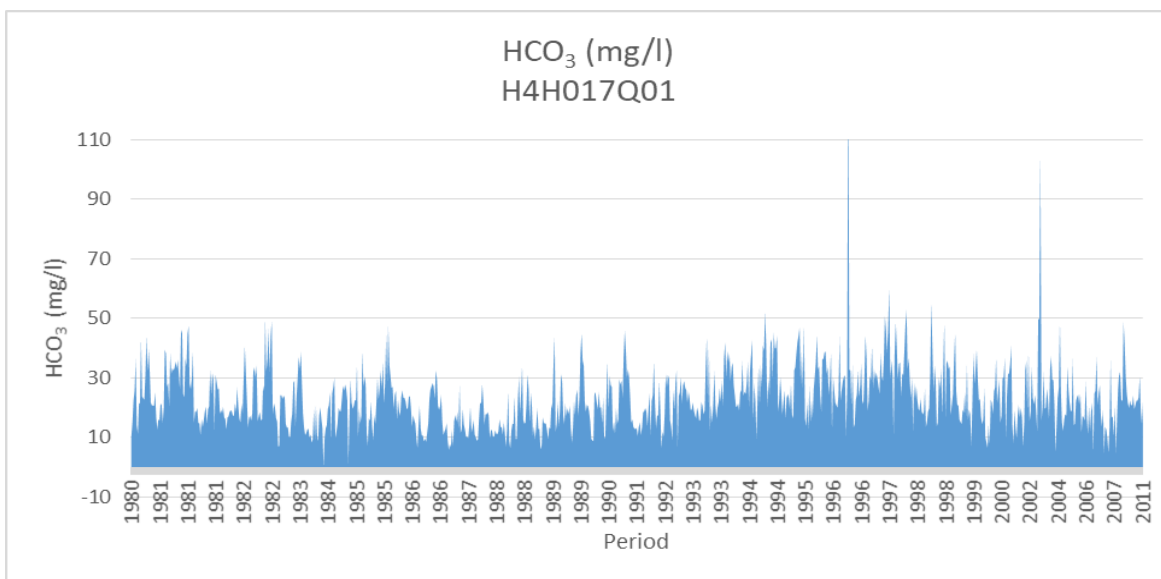
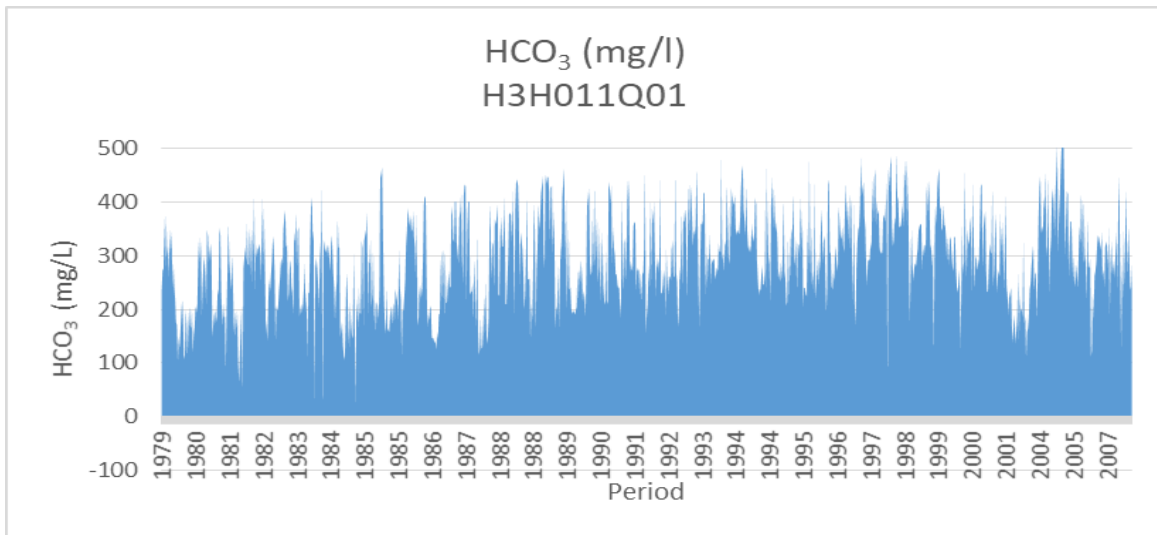
HCO₃ (mg/l) time series

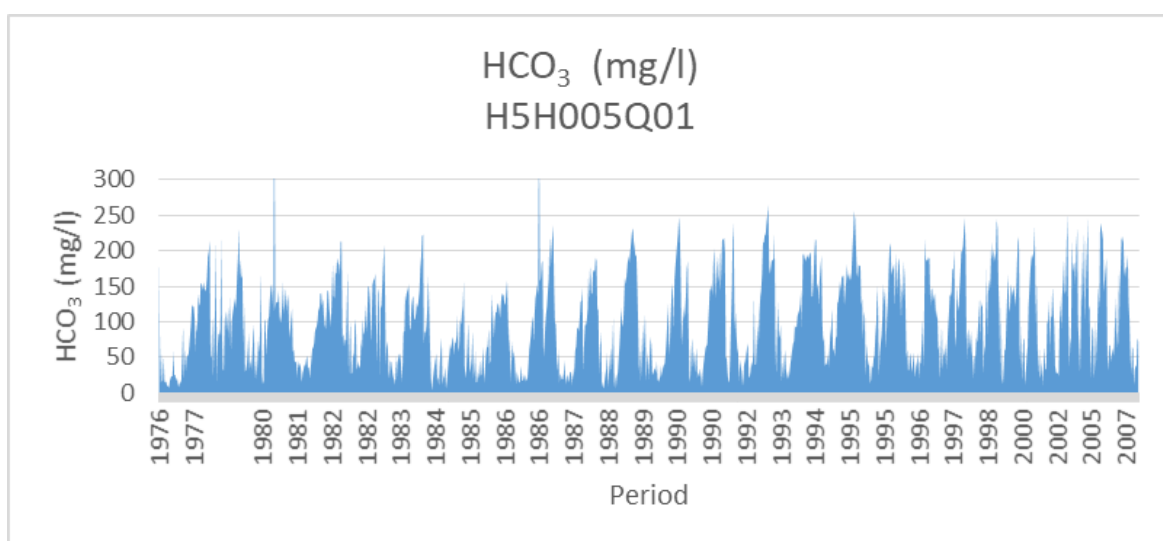
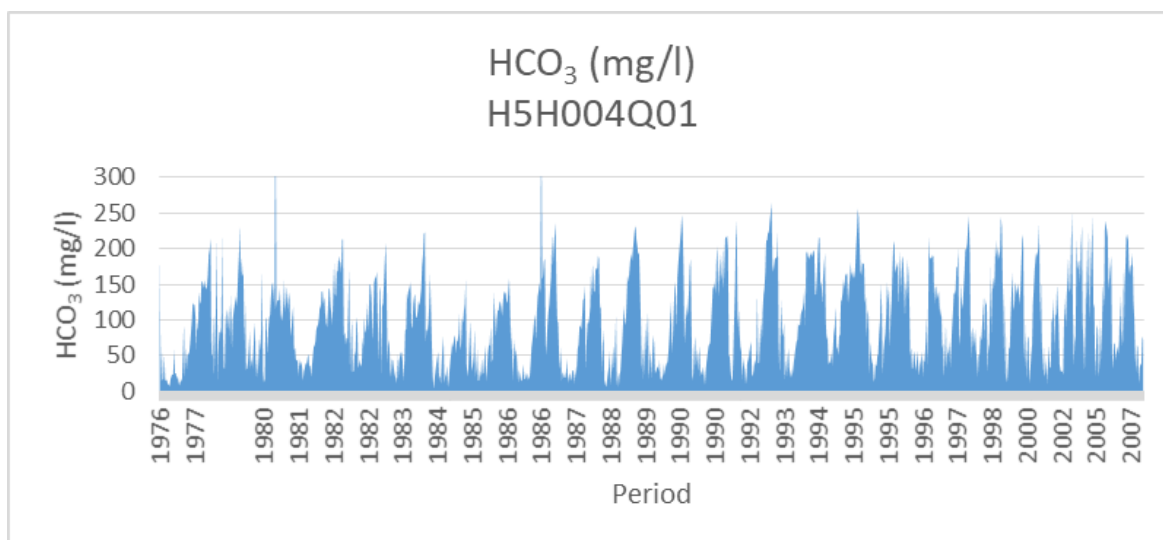
UPPER BREEDE SECTION



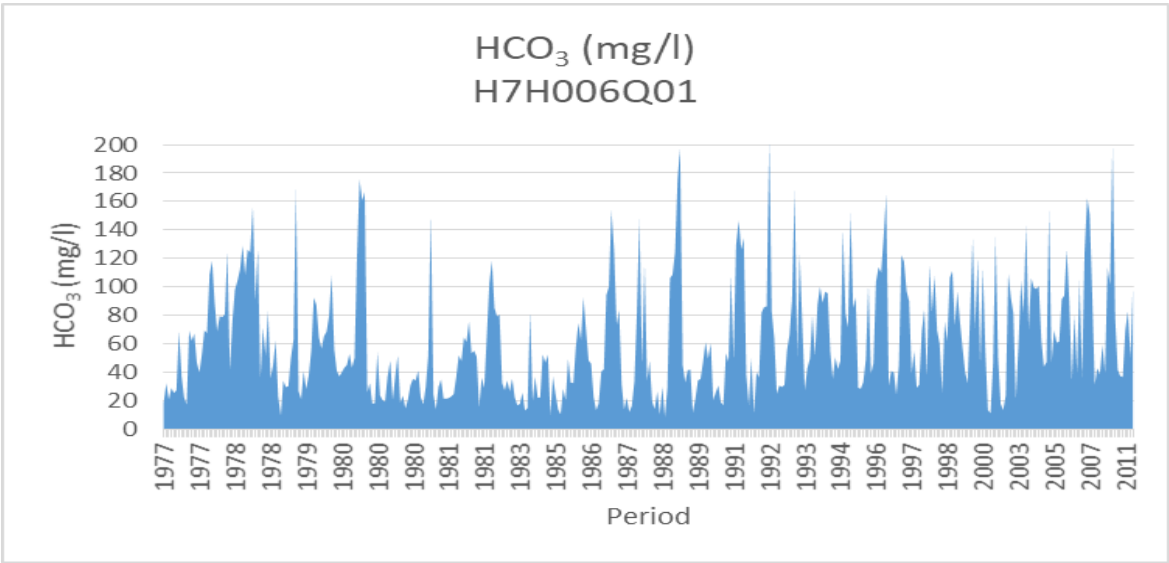
MIDDLE BREEDE SECTION



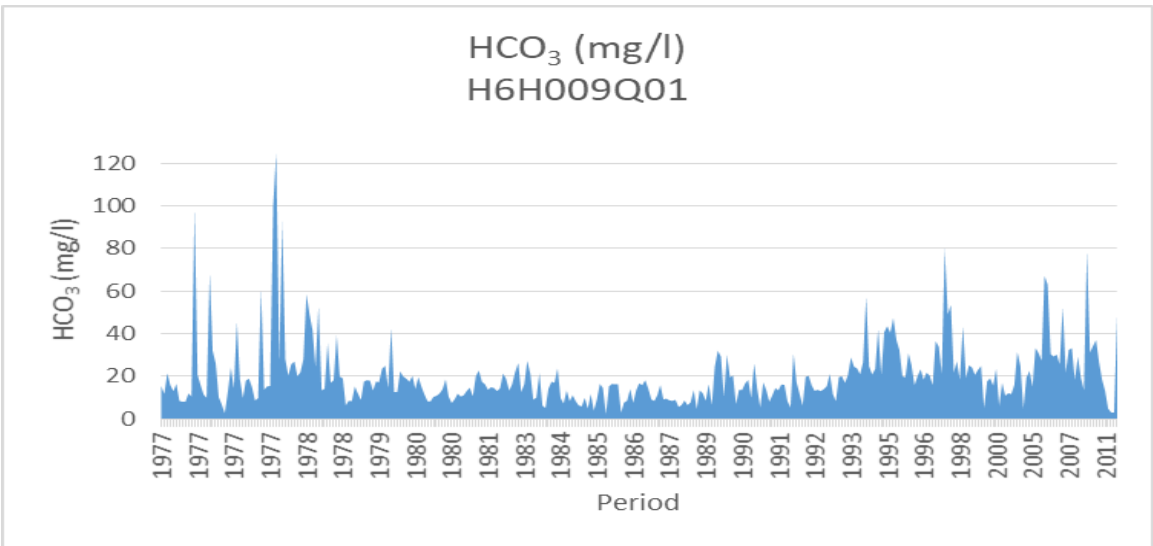




LOWER BREEDE SECTION

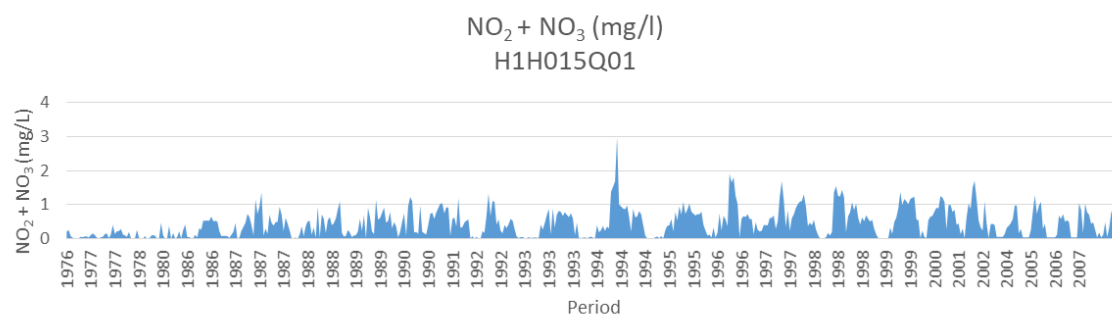
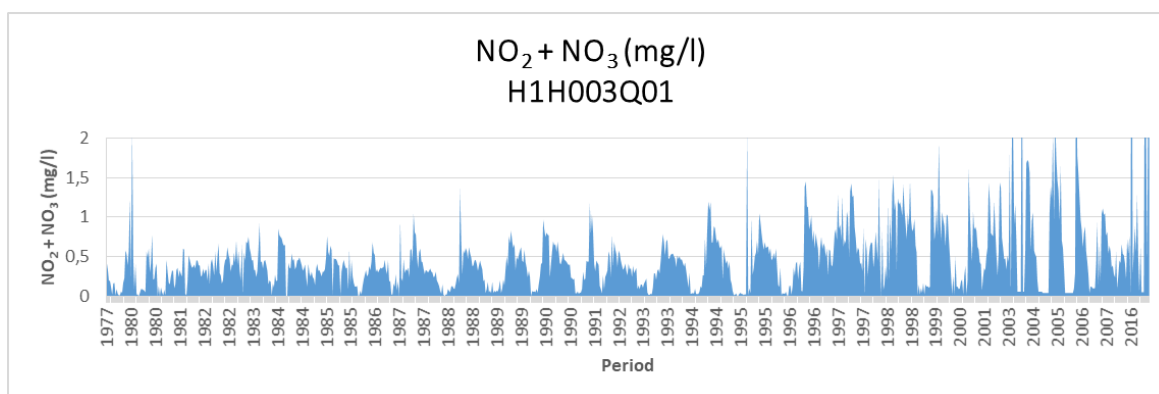


RIVIERSONDEREND SECTION

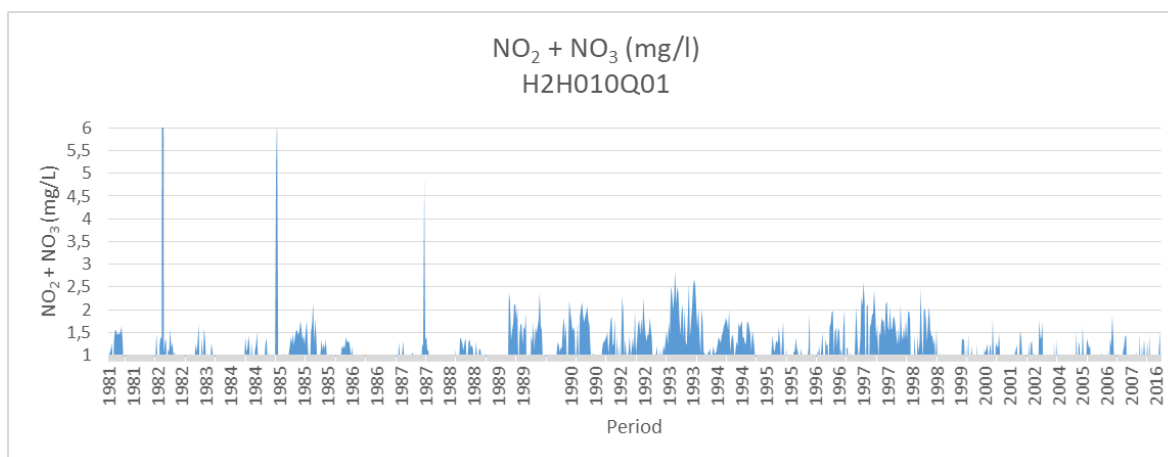


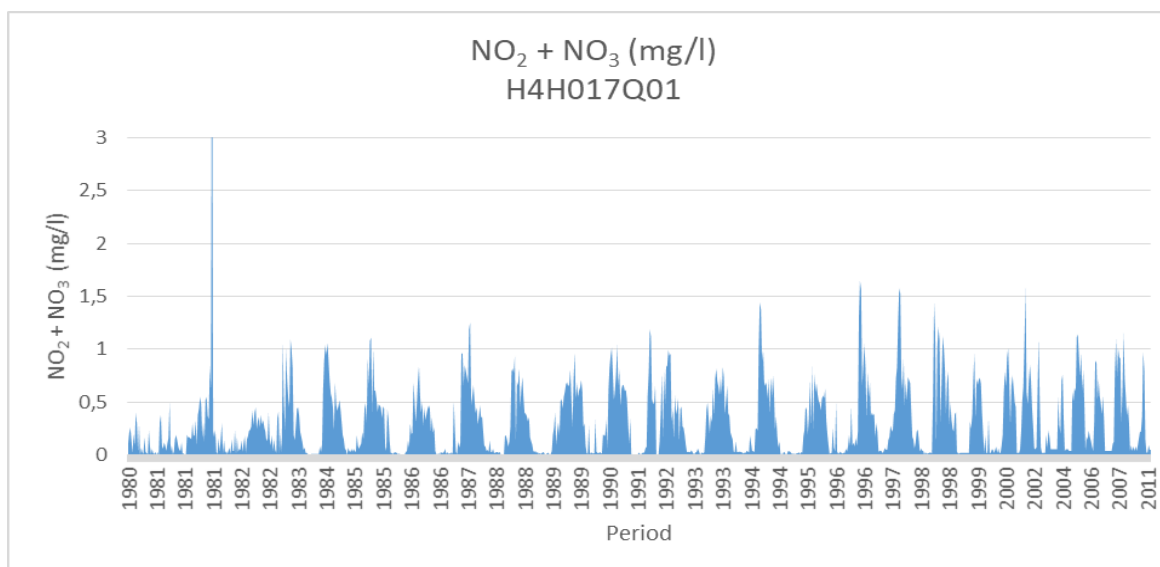
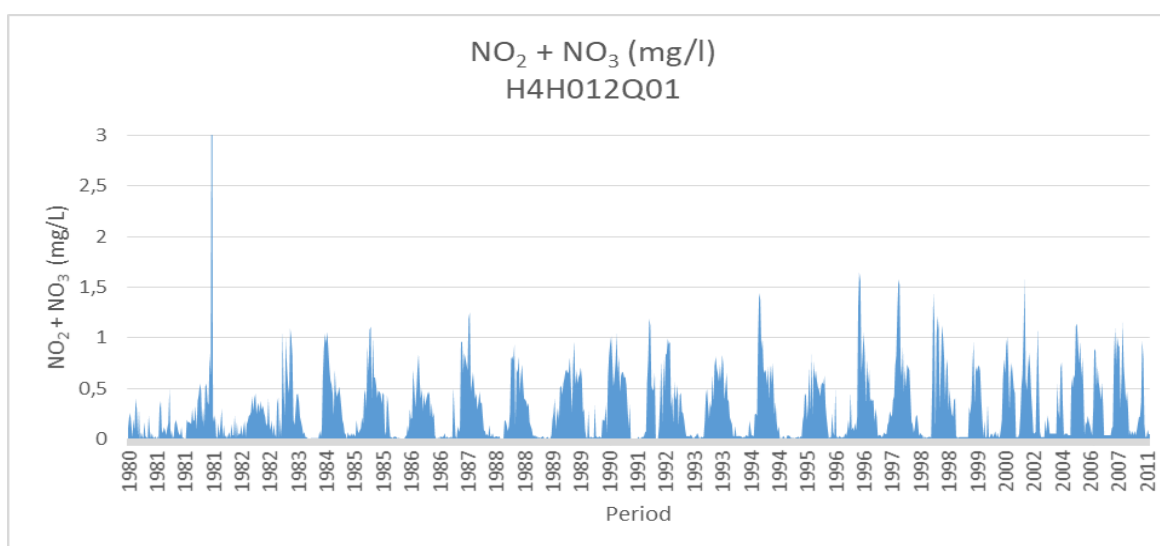
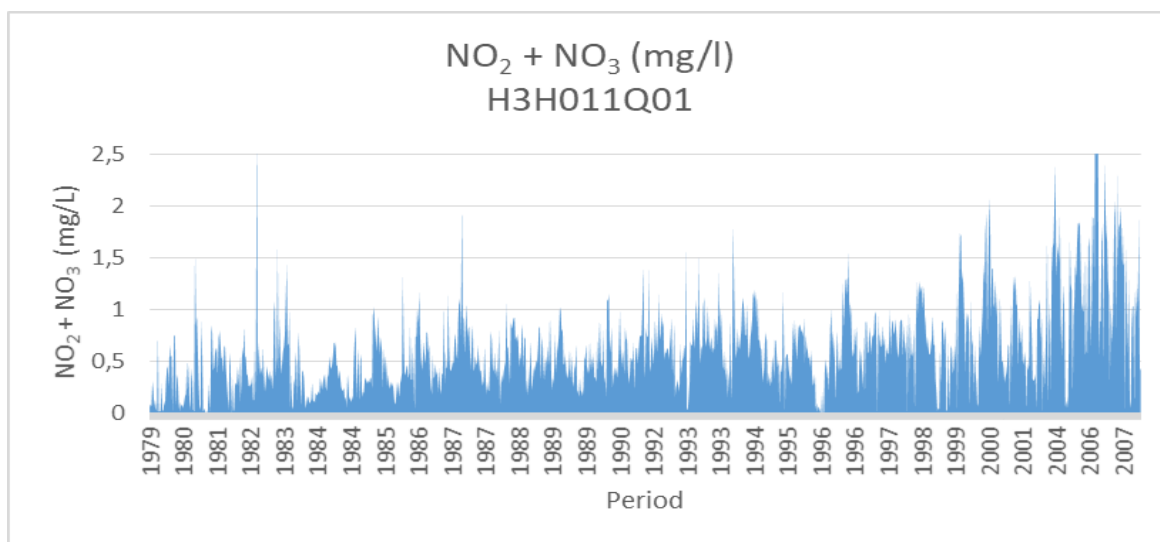
NO₂ + NO₃ (mg/l) time series

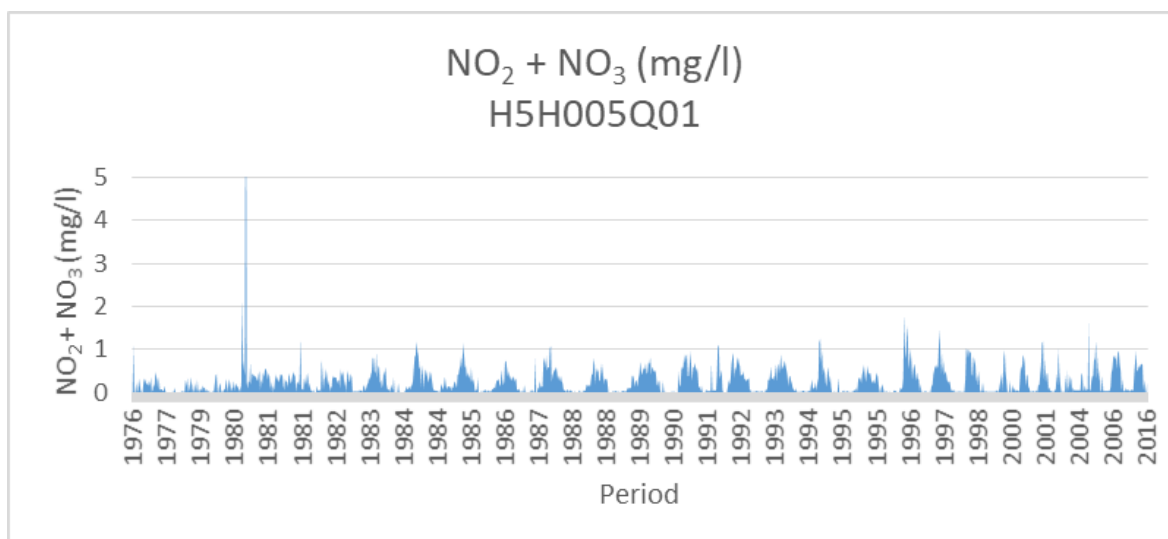
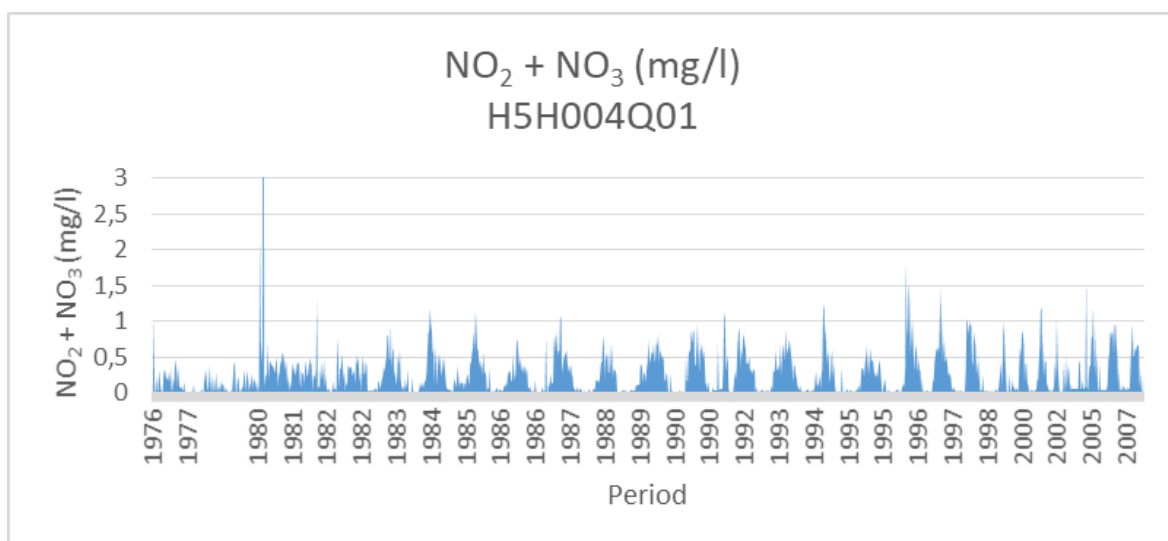
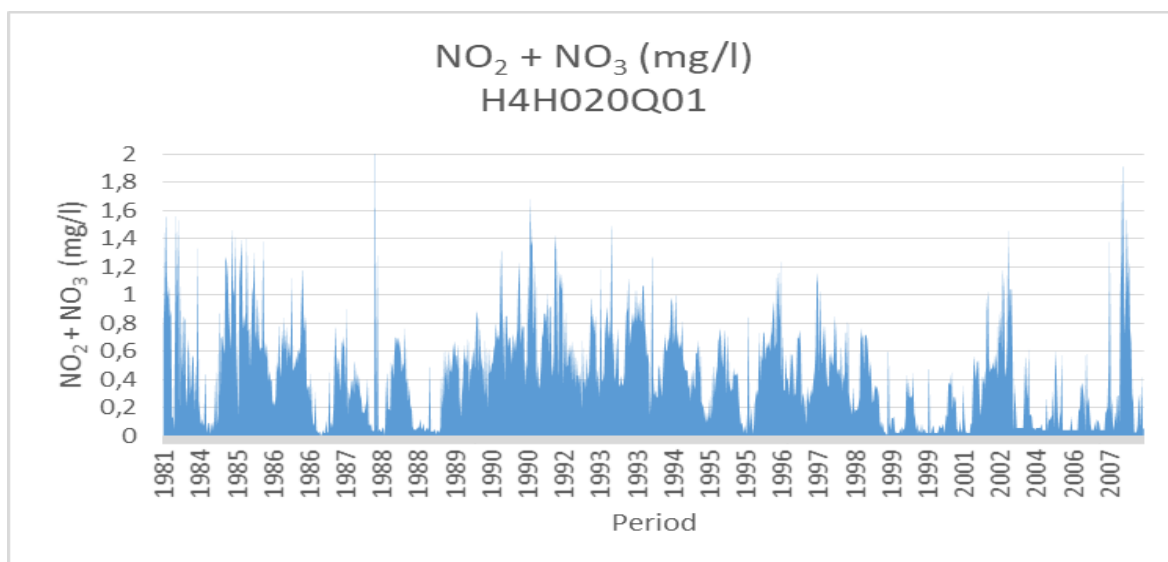
UPPER BREEDE SECTION



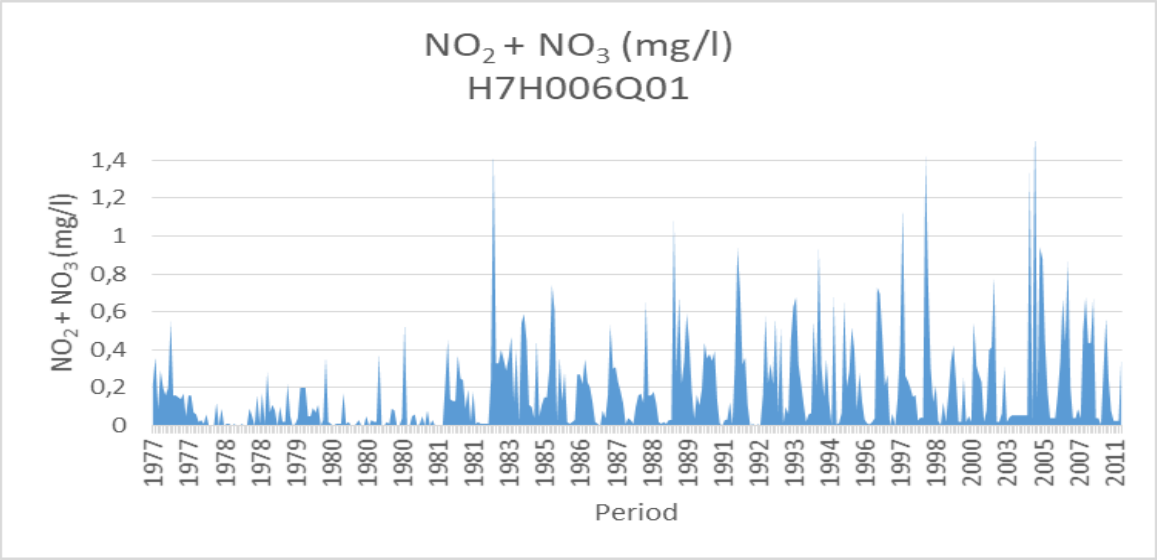
MIDDLE BREEDE SECTION



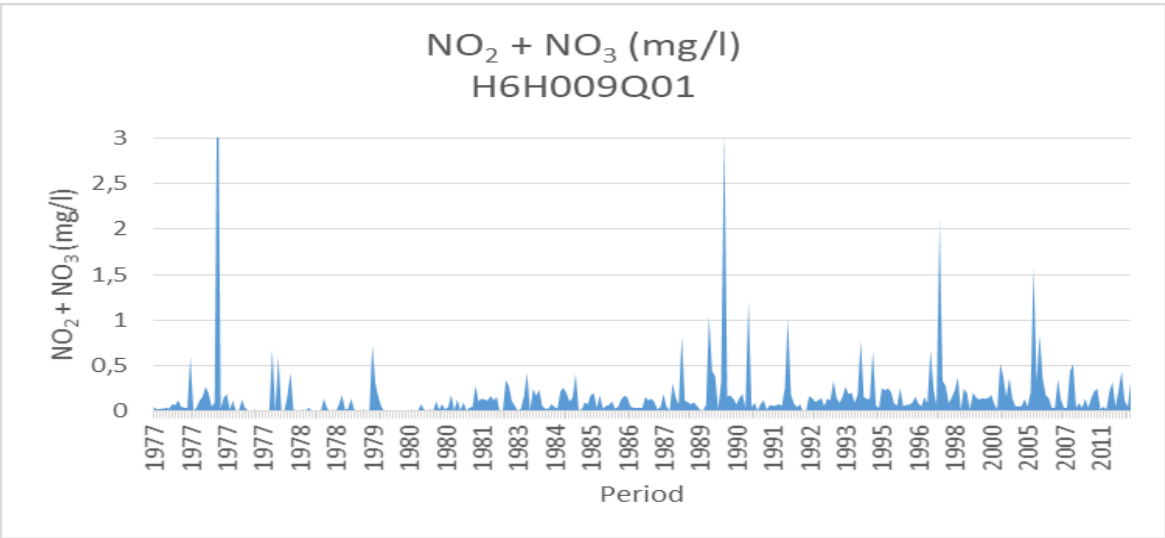




LOWER BREEDE SECTION

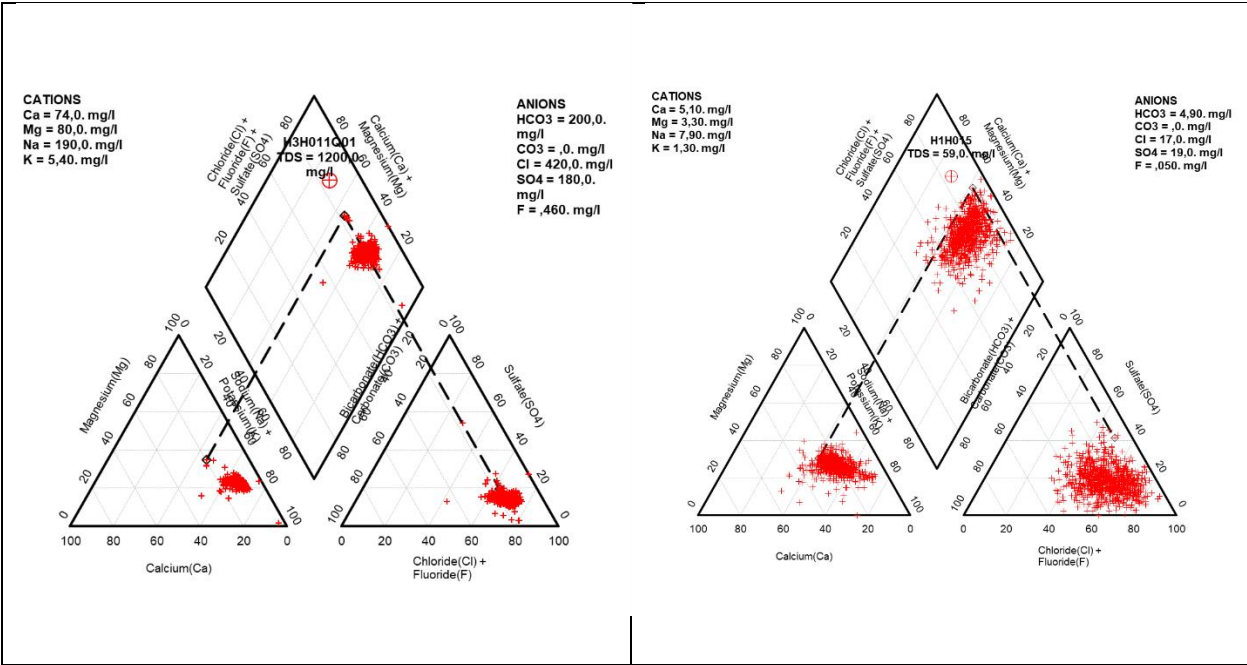


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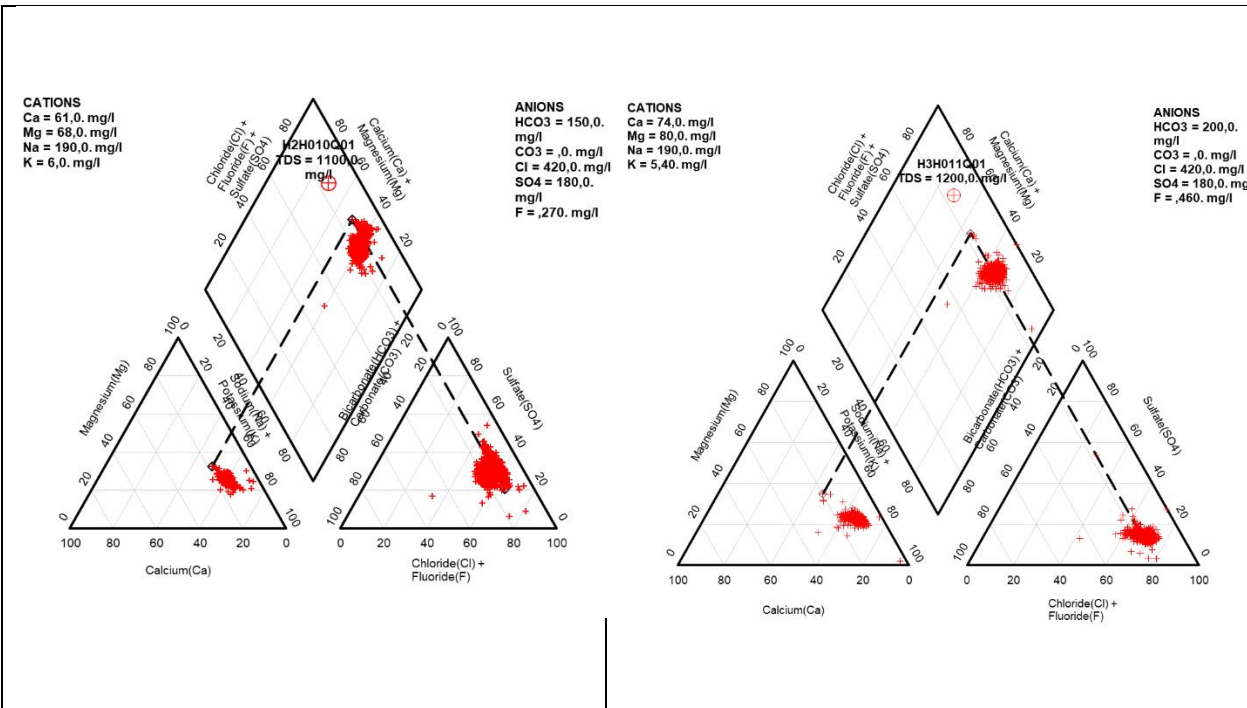


ANNEXURE G: PIPER DIAGRAMS

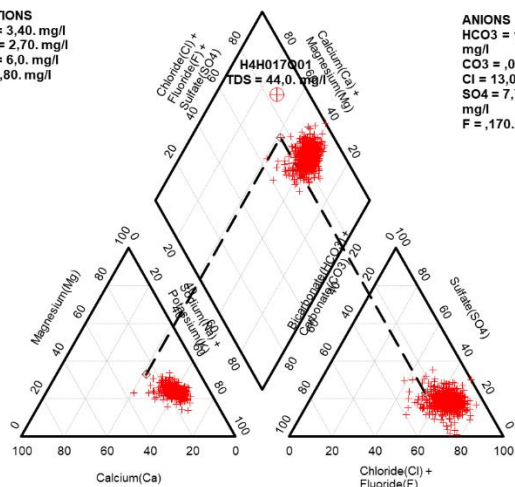
UPPER BREEDE RIVER SECTION



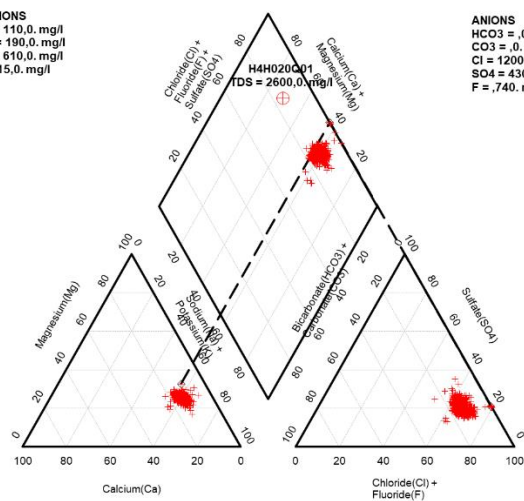
MIDDLE BREEDE RIVER SECTION



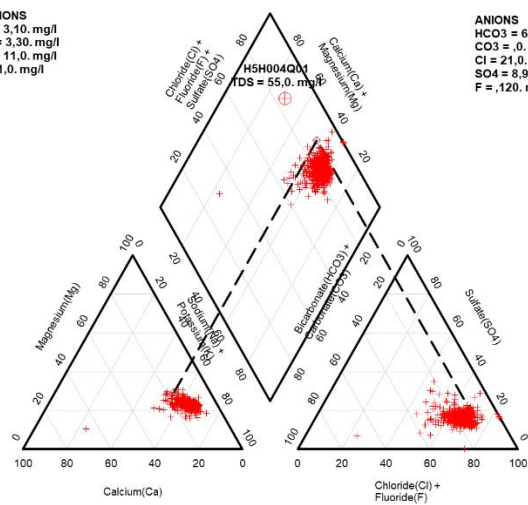
CATIONS
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 Mg = 2,70. mg/l
 Na = 6,0. mg/l
 K = ,80. mg/l



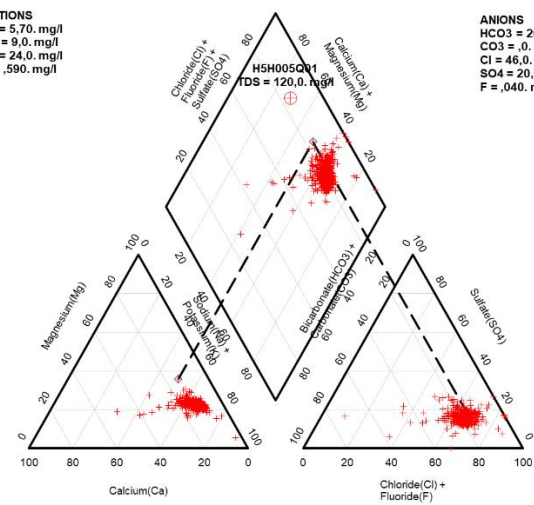
CATIONS
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 Mg = 190,0. mg/l
 Na = 610,0. mg/l
 K = 15,0. mg/l



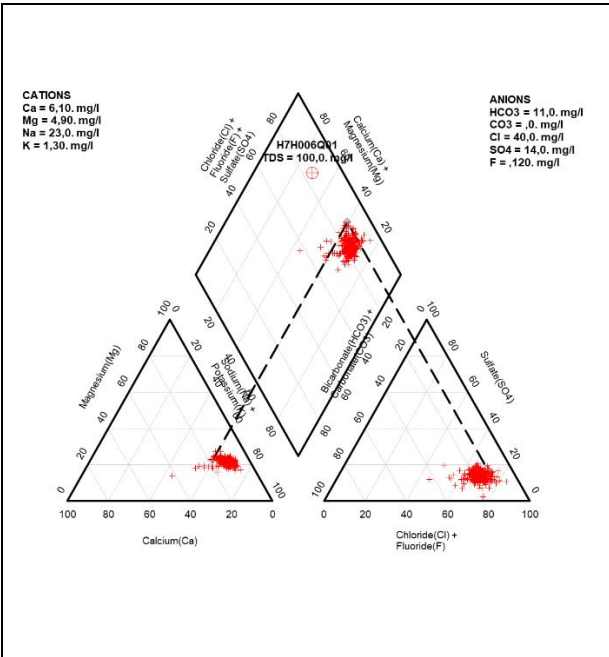
CATIONS
 Ca = 3,10. mg/l
 Mg = 3,30. mg/l
 Na = 11,0. mg/l
 K = 1,0. mg/l



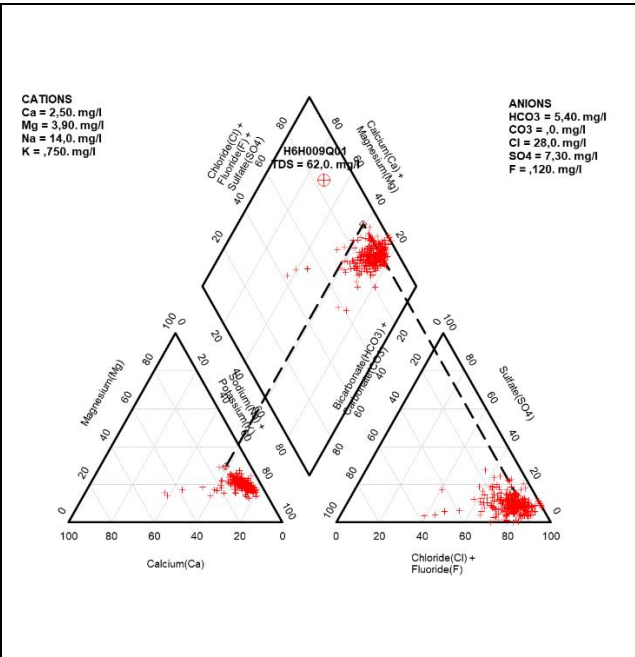
CATIONS
 Ca = 5,70. mg/l
 Mg = 9,0. mg/l
 Na = 24,0. mg/l
 K = ,590. mg/l



LOWER BREEDE RIVER SECTION

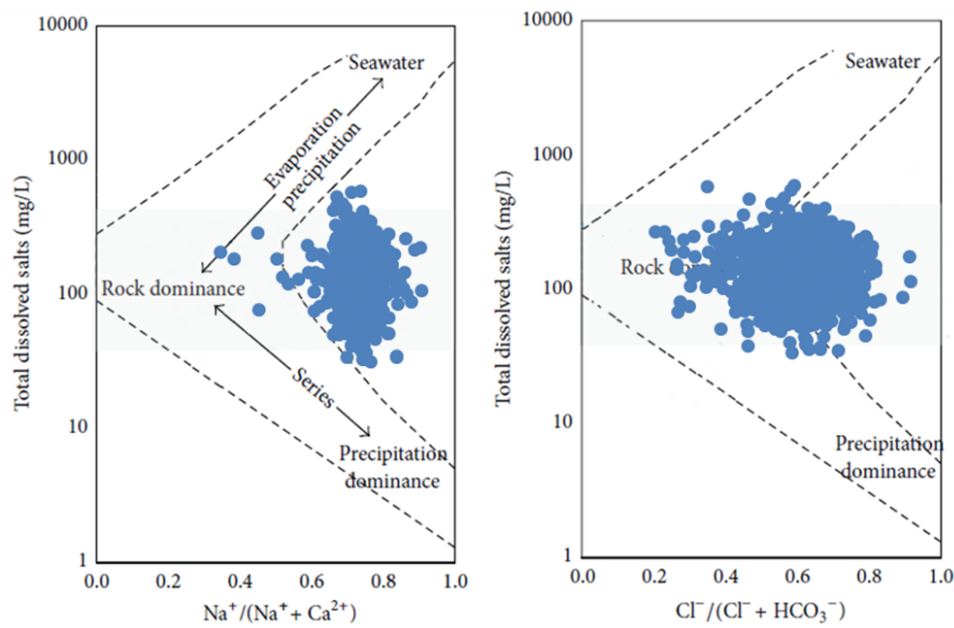


RIVIERSONDEREND SECTION

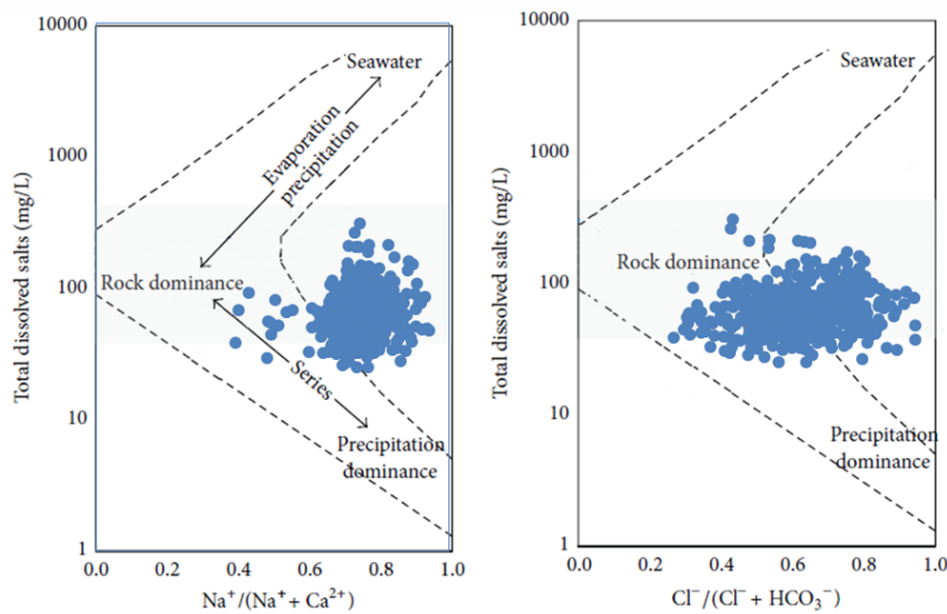


ANNEXURE H: GIBBS DIAGRAMS

UPPER BREEDE SECTION

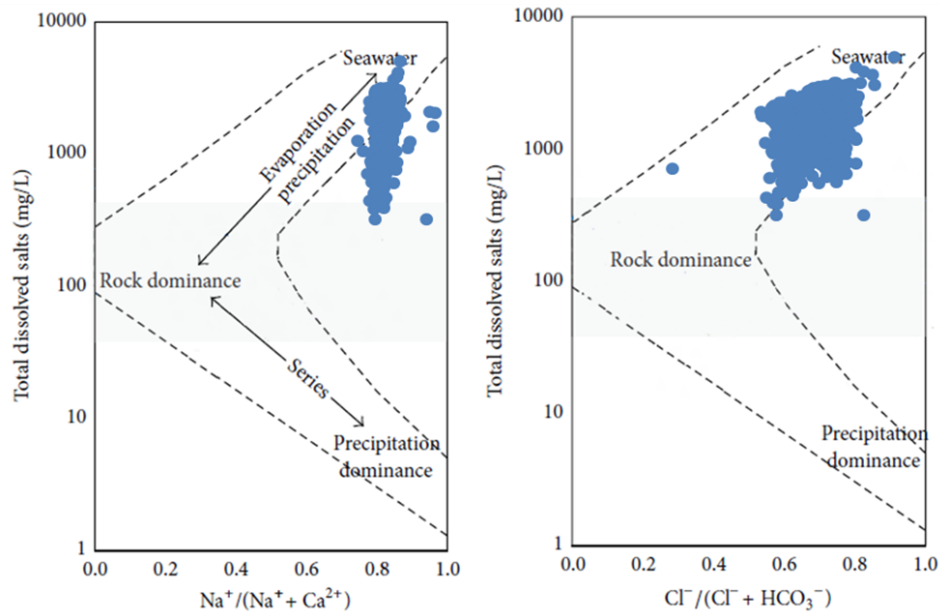


Gibbs diagram for sample locality H1H003Q01.

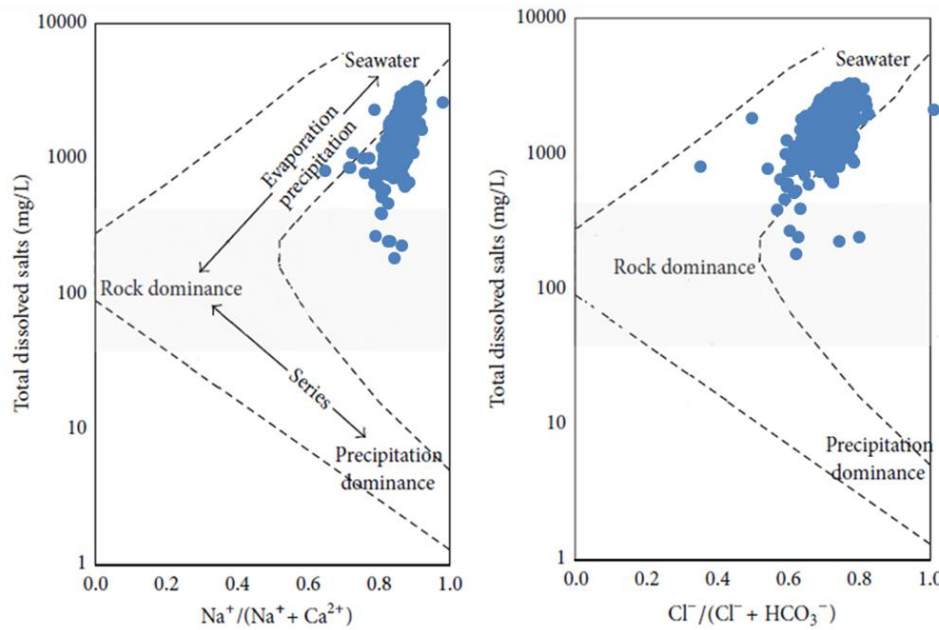


Gibbs diagram for sample locality H1H015Q01

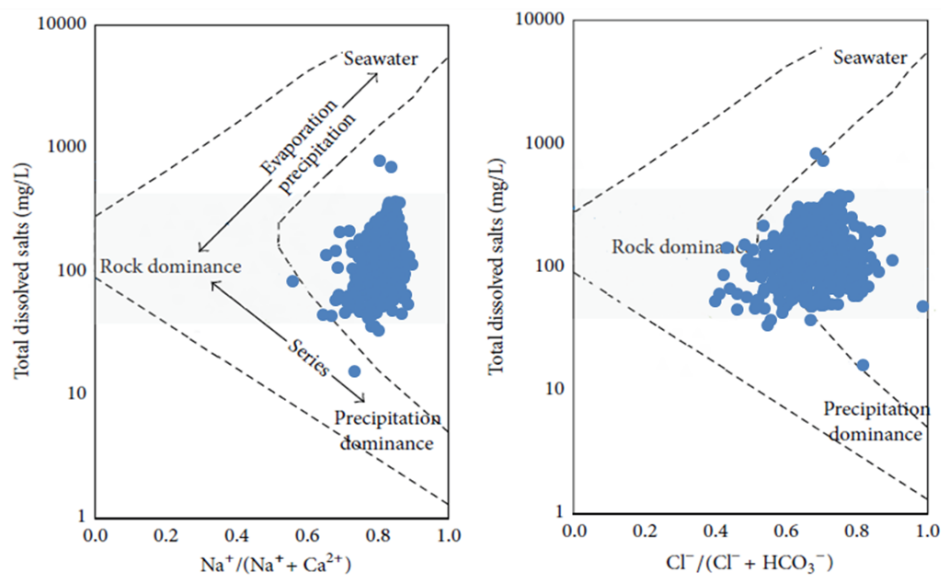
MIDDLE BREEDE SECTION



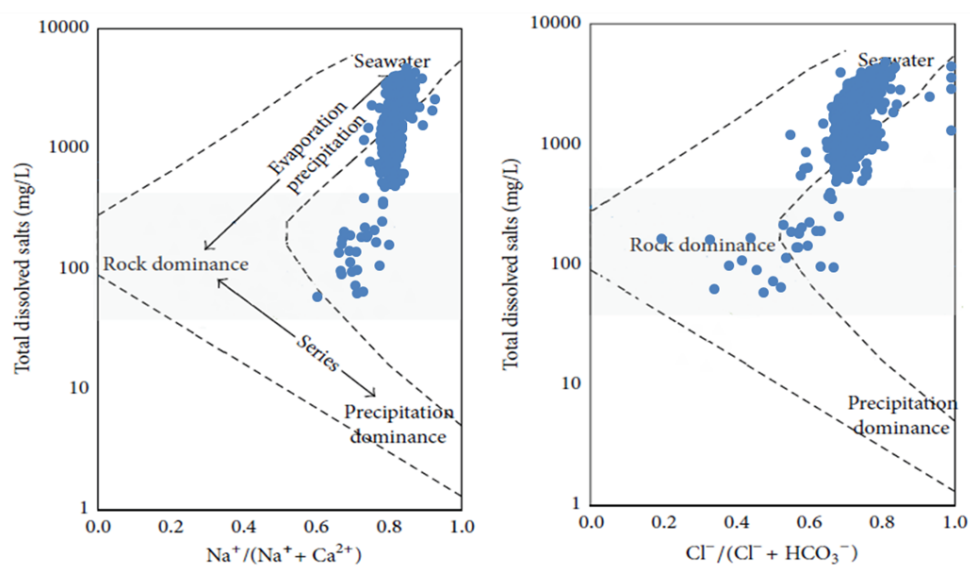
Gibbs diagram for sample locality H2H010Q01



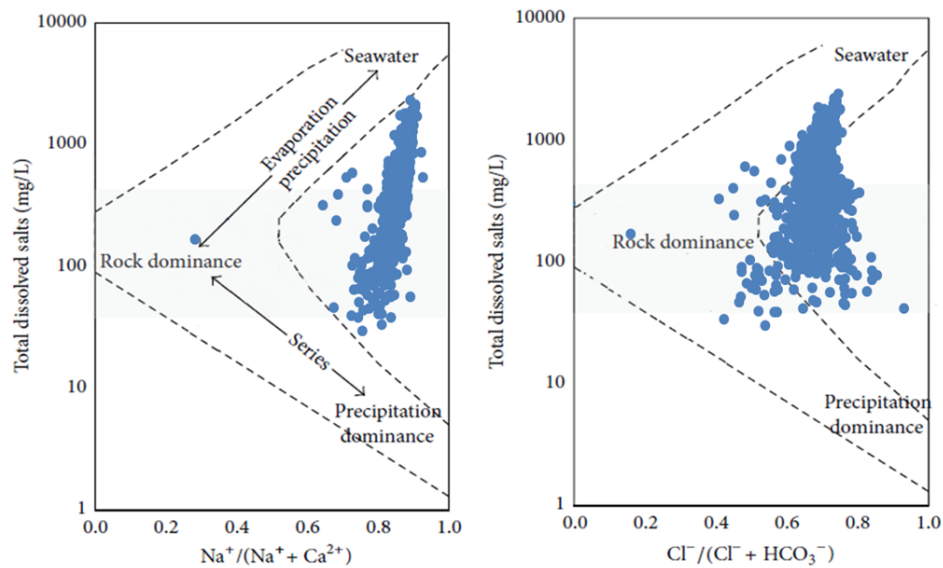
Gibbs diagram for sample locality H3H011Q01



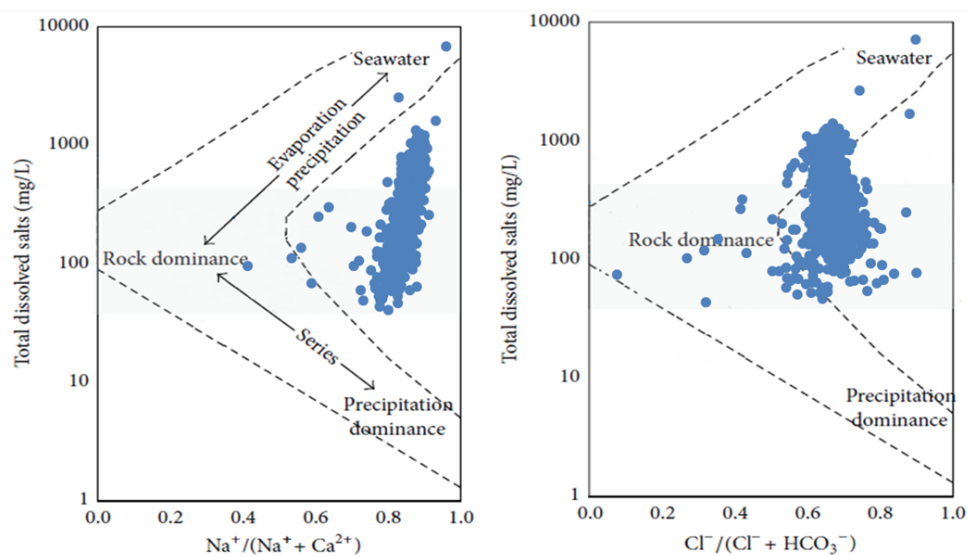
Gibbs diagram for sample locality H4H017Q01



Gibbs diagram for sample locality H4H020Q01

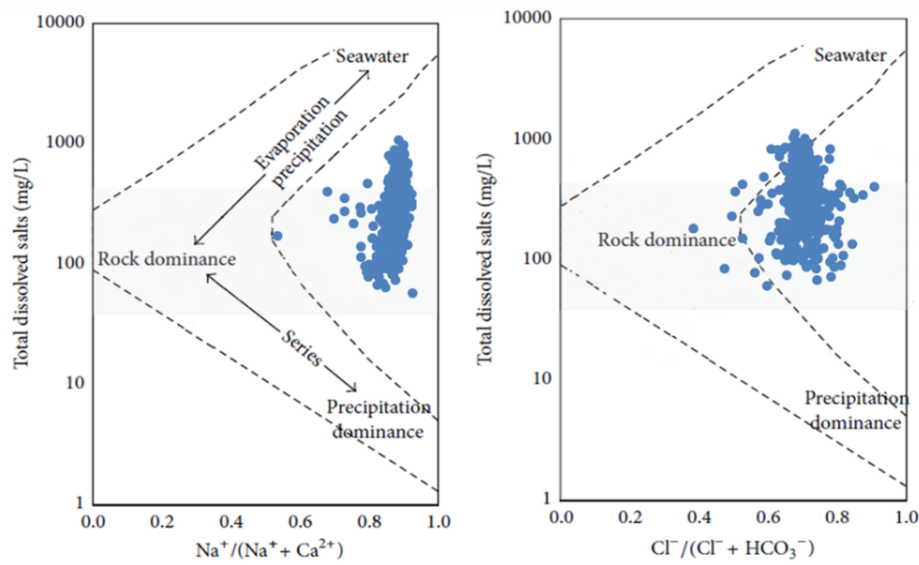


Gibbs diagram for sample locality H5H004Q01



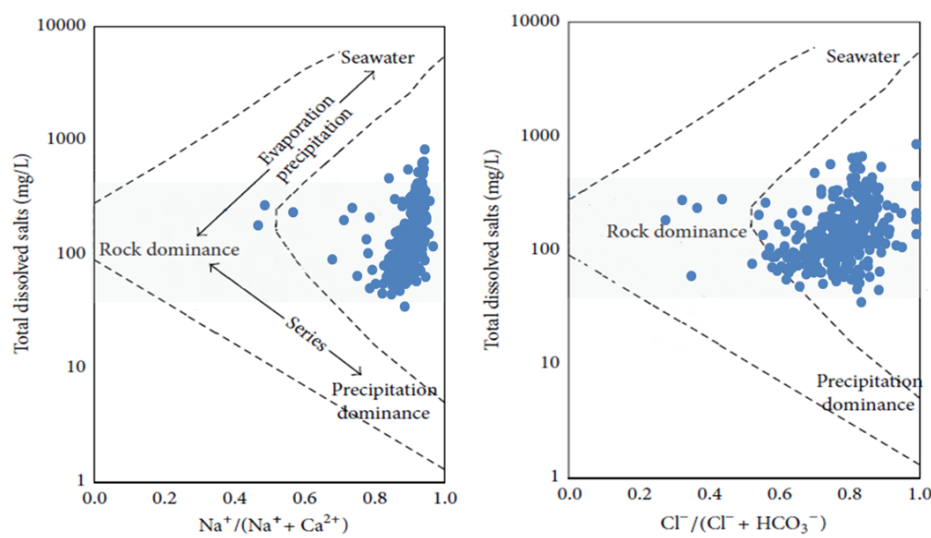
Gibbs diagram for sample locality H5H005Q01

LOWER BREEDE SECTION



Gibbs diagram for sample locality H7H006Q01.

RIVIERSONDEREND SECTION



Gibbs diagram for sample locality H6H009Q01

ANNEXURE I: MICROBIOLOGICAL WATER QUALITY DATA

		Cer1				Cer2				Cer3			
		Mean	Median	Min	Max	Mean	Median	Min	Max	Mean	Median	Min	Max
Fecal Coliforms (c/100ml)	2008	202,82	74,00	9,00	1100,00	2757,82	600,00	36,00	17200,00	15853,82	2900,00	92,00	110000,00
E.Coli (c/100ml)		191,09	73,00	9,00	1100,00	2611,45	240,00	0,00	16800,00	4625,64	400,00	35,00	30000,00
Fecal Coliforms (c/100ml)	2009	322,25	175,00	23,00	1300,00	20990,25	950,00	43,00	240000,00	12192,92	1400,00	85,00	110000,00
E.Coli (c/100ml)		280,83	142,50	4,00	1100,00	10042,42	605,00	36,00	110000,00	5834,83	425,00	4,00	46000,00
Fecal Coliforms (c/100ml)	2010	744,40	128,00	44,00	3200,00	2579,00	920,00	85,00	7700,00	3292,00	1900,00	440,00	7900,00
E.Coli (c/100ml)		677,80	123,00	0,00	3100,00	2399,00	800,00	85,00	7200,00	3232,00	1870,00	380,00	7900,00
Fecal Coliforms (c/100ml)	2011	400,18	151,00	0,00	2200,00	1254,55	1000,00	0,00	6100,00	1924,36	1000,00	8,00	10200,00
Fecal Coliforms (c/100ml)	2012	74,33	27,00	6,00	306,00	85,56	50,00	0,00	228,00	126,50	112,50	0,00	435,00
E.Coli (c/100ml)		26,25	16,50	0,00	91,00	78,13	46,50	0,00	205,00	76,25	23,50	0,00	435,00
Fecal Coliforms (c/100ml)	2013	527,78	140,00	40,00	1900,00	841,22	418,00	28,00	2500,00	868,89	300,00	43,00	3600,00
E.Coli (c/100ml)		302,89	47,00	1,00	1900,00	423,33	73,00	27,00	2100,00	952,00	41,00	0,00	5200,00
Fecal Coliforms (c/100ml)	2014	116,00	116,00	62,00	170,00	224,50	224,50	49,00	400,00	1639,00	320,00	35,00	5300,00
E.Coli (c/100ml)		116,00	116,00	62,00	170,00	24,50	24,50	0,00	49,00	515,00	35,00	0,00	2300,00
Fecal Coliforms (c/100ml)	2016	14,67	12,00	0,00	32,00	362,33	49,00	38,00	1000,00	818,83	27,50	2,00	4000,00
E.Coli (c/100ml)		12,67	12,00	0,00	26,00	27,67	34,00	0,00	49,00	816,33	20,00	2,00	4000,00
Fecal Coliforms (c/100ml)	2017	158,63	80,00	20,00	570,00	85,14	40,00	20,00	250,00	352,67	310,00	4,00	900,00
E.Coli (c/100ml)		151,25	80,00	0,00	570,00	64,57	38,00	16,00	250,00	252,67	160,00	0,00	590,00
Fecal Coliforms (c/100ml)	2019	484,64	200,00	32,00	1500,00	555,20	300,00	90,00	2500,00	3901,82	1600,00	160,00	21300,00
E.Coli (c/100ml)		515,36	140,00	0,00	1800,00	865,20	490,00	90,00	3300,00	6110,91	400,00	0,00	47200,00
Fecal Coliforms (c/100ml)	2020	412,00	166,00	70,00	1000,00	738,67	320,00	96,00	1800,00	1810,00	1480,00	350,00	3600,00
E.Coli (c/100ml)		412,00	166,00	70,00	1000,00	738,67	320,00	96,00	1800,00	1810,00	1480,00	350,00	3600,00

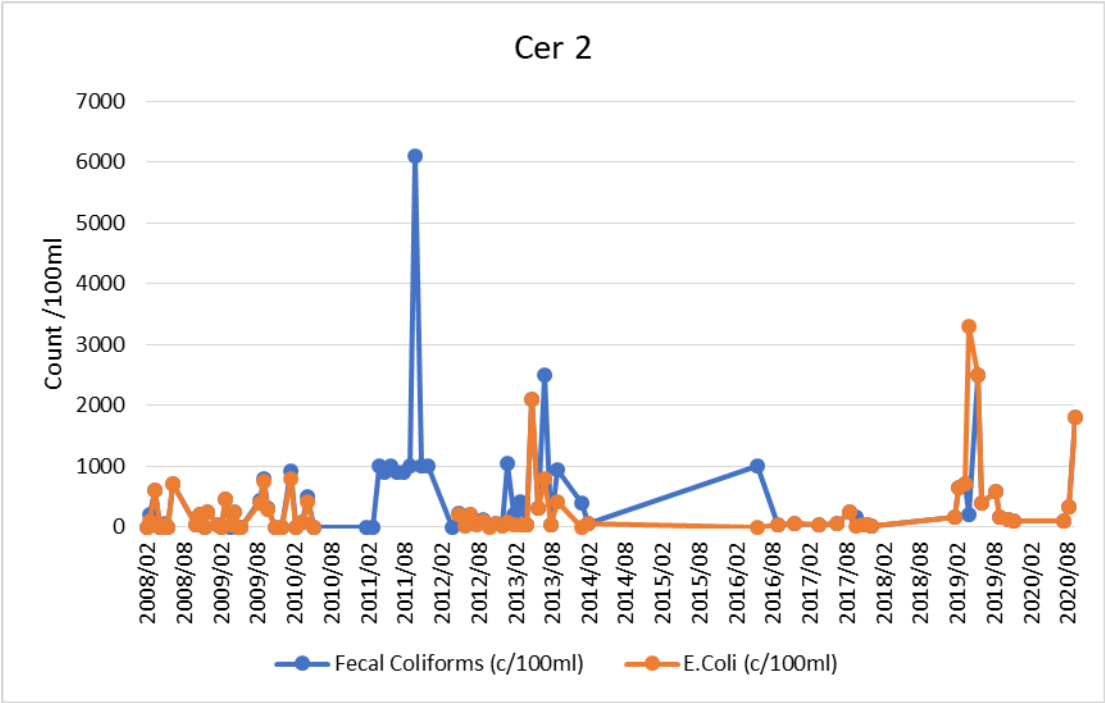
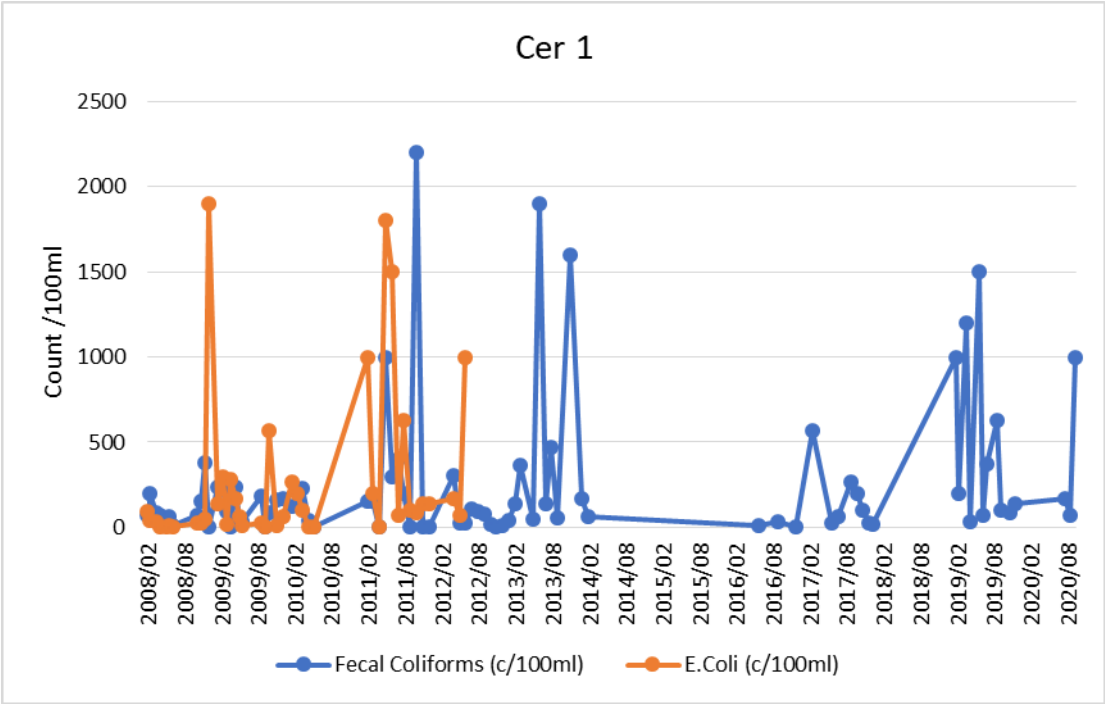
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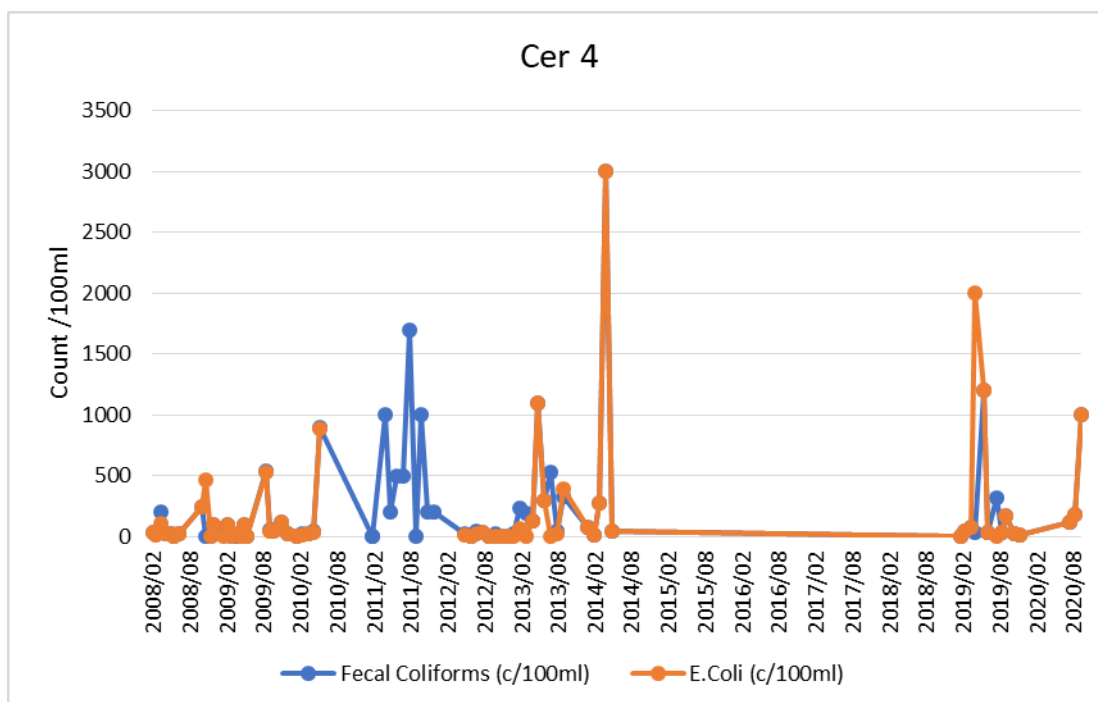
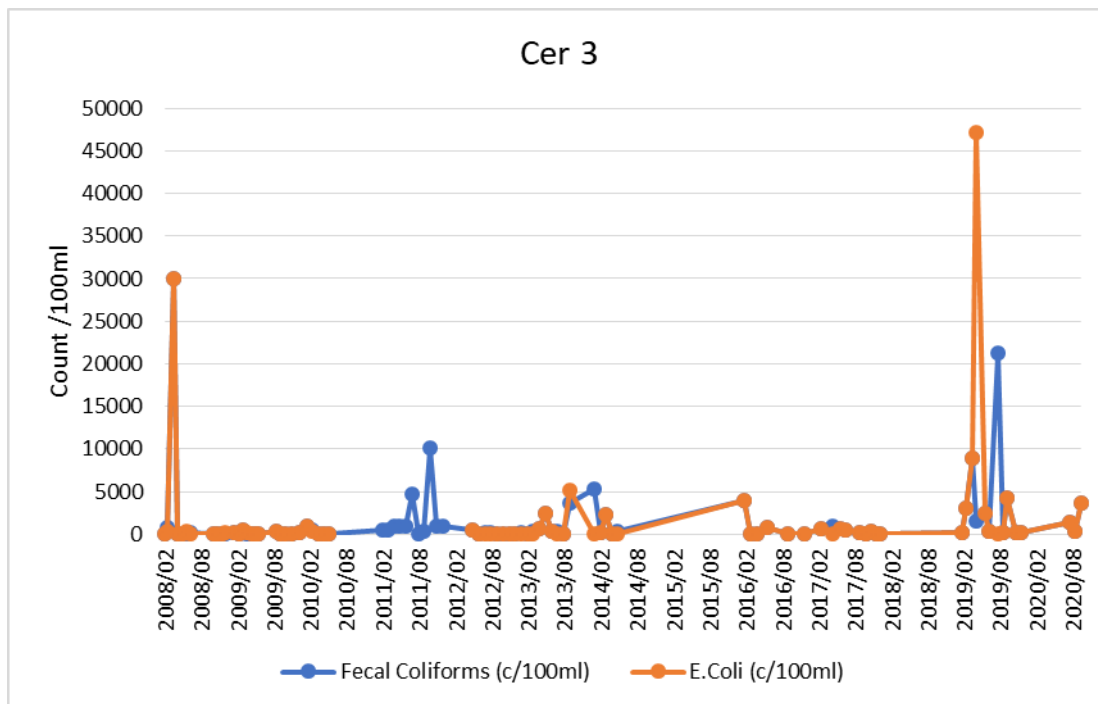
		Cer4				Cer5				Cer6			
		Mean	Median	Min	Max	Mean	Median	Min	Max	Mean	Median	Min	Max
Fecal Coliforms (c/100ml)	2008	1095,82	93,00	18,00	4700,00	126,09	34,00	0,00	460,00	113,91	83,00	20,00	460,00
E.Coli (c/100ml)		619,36	93,00	16,00	4700,00	121,91	27,00	0,00	460,00	100,09	43,00	0,00	460,00
Fecal Coliforms (c/100ml)	2009	560,75	71,50	4,00	4600,00	223,11	150,00	10,00	600,00	599,83	160,00	4,00	4600,00
E.Coli (c/100ml)		464,50	47,00	0,00	4600,00	164,56	75,00	0,00	580,00	564,92	65,50	3,00	4600,00
Fecal Coliforms (c/100ml)	2010	195,60	19,00	3,00	900,00	189,00	189,00	28,00	350,00	313,80	34,00	13,00	1300,00
E.Coli (c/100ml)		192,40	17,00	2,00	890,00	170,00	170,00	0,00	340,00	293,20	32,00	13,00	1200,00
Fecal Coliforms (c/100ml)	2011	481,82	200,00	0,00	1700,00	388,89	200,00	0,00	1000,00	503,40	400,00	34,00	1000,00
Fecal Coliforms (c/100ml)	2012	16,75	14,00	0,00	45,00	15,75	14,00	0,00	32,00	85,33	82,00	1,00	322,00
E.Coli (c/100ml)		9,88	4,00	0,00	36,00	9,25	5,00	0,00	25,00	71,25	33,50	0,00	294,00
Fecal Coliforms (c/100ml)	2013	319,22	236,00	19,00	1100,00	360,29	300,00	41,00	860,00	137,00	79,00	32,00	300,00
E.Coli (c/100ml)		222,67	60,00	0,00	1100,00	347,43	300,00	0,00	860,00	126,67	79,00	1,00	300,00
Fecal Coliforms (c/100ml)	2014	683,20	80,00	9,00	3000,00	36,67	25,00	15,00	70,00	216,71	100,00	45,00	550,00
E.Coli (c/100ml)		683,20	80,00	9,00	3000,00	36,67	25,00	15,00	70,00	292,71	100,00	27,00	1000,00
Fecal Coliforms (c/100ml)	2016					36,67	25,00	15,00	70,00	292,00	77,00	0,00	980,00
E.Coli (c/100ml)						36,67	25,00	15,00	70,00	205,80	77,00	0,00	689,00
Fecal Coliforms (c/100ml)	2017					206,80	100,00	12,00	800,00	121,20	49,00	12,00	400,00
E.Coli (c/100ml)						206,80	100,00	12,00	800,00	121,20	49,00	12,00	400,00
Fecal Coliforms (c/100ml)	2019	175,18	31,00	1,00	1200,00	103,00	80,00	14,00	280,00	108,14	45,00	6,00	270,00
E.Coli (c/100ml)		325,18	31,00	0,00	2000,00	74,43	42,00	0,00	280,00	69,57	38,00	0,00	250,00
Fecal Coliforms (c/100ml)	2020	433,33	180,00	120,00	1000,00	291,33	224,00	150,00	500,00	301,33	330,00	204,00	370,00
E.Coli (c/100ml)		433,33	180,00	120,00	1000,00	291,33	224,00	150,00	500,00	301,33	330,00	204,00	370,00

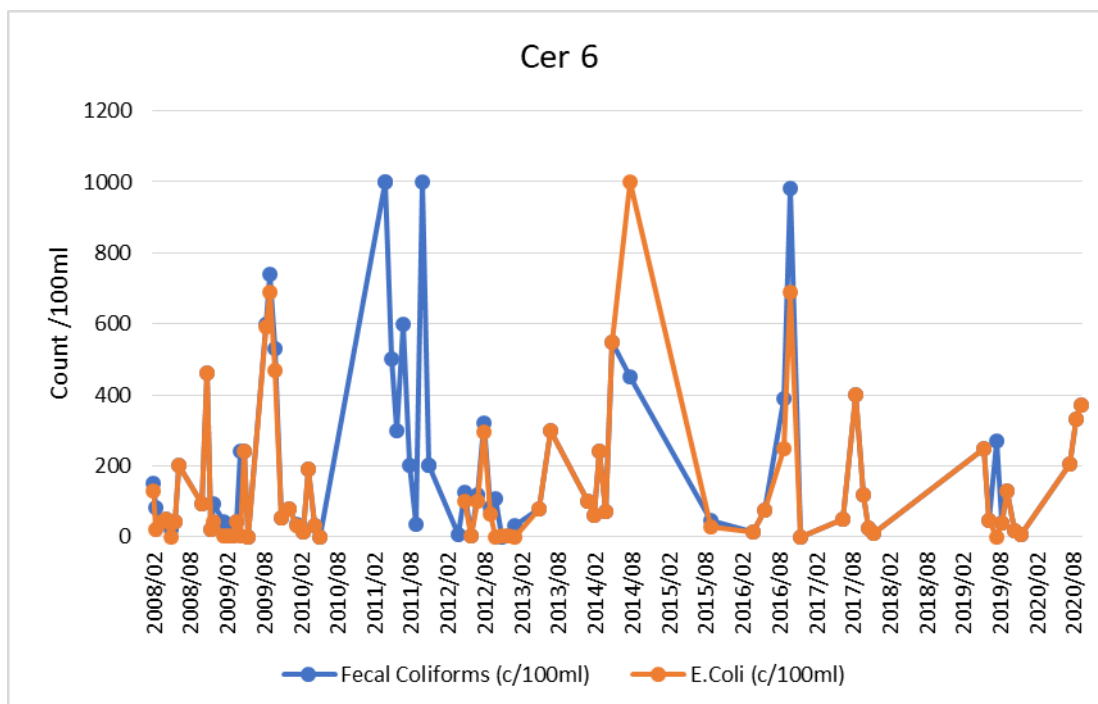
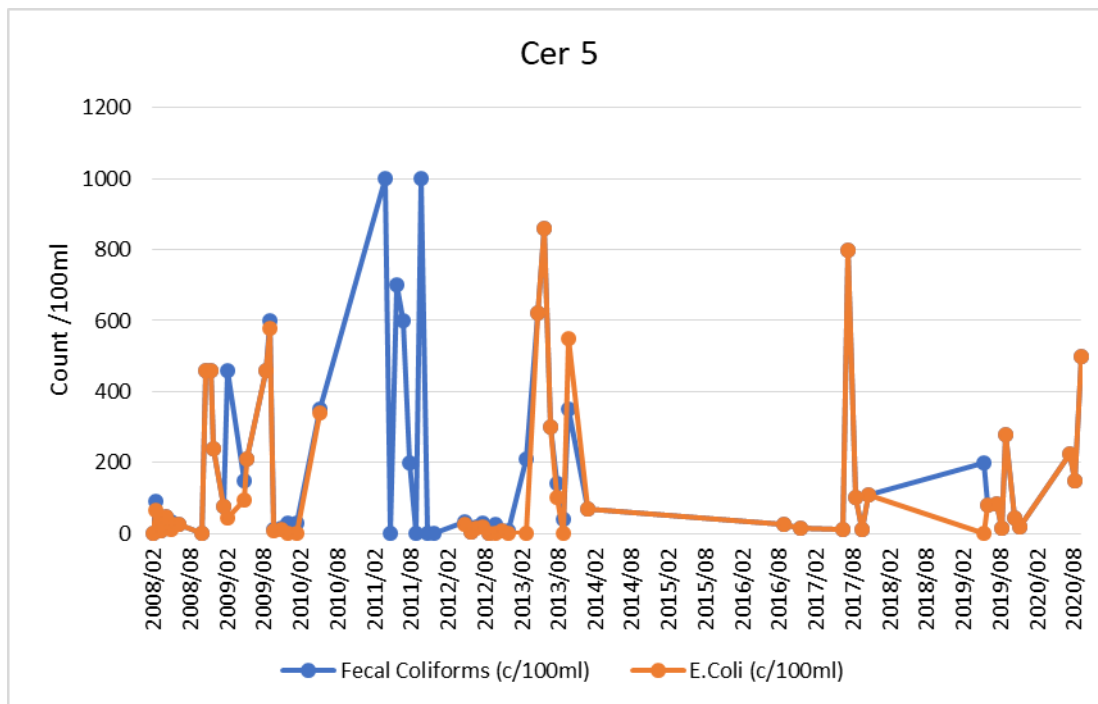
Continue

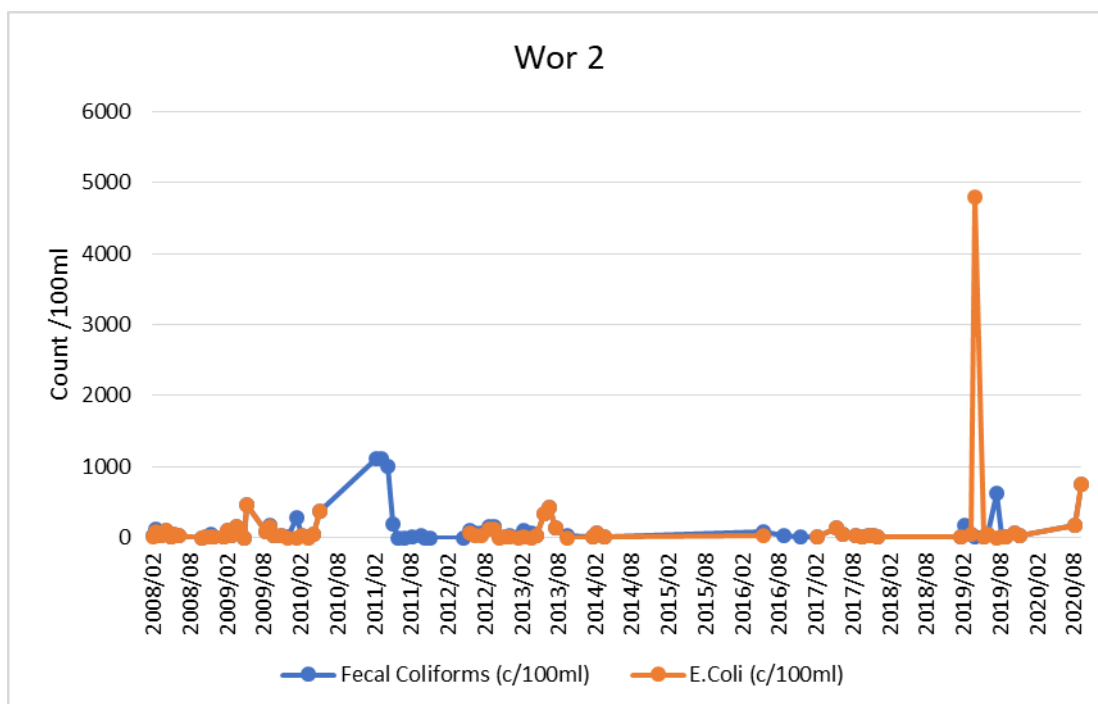
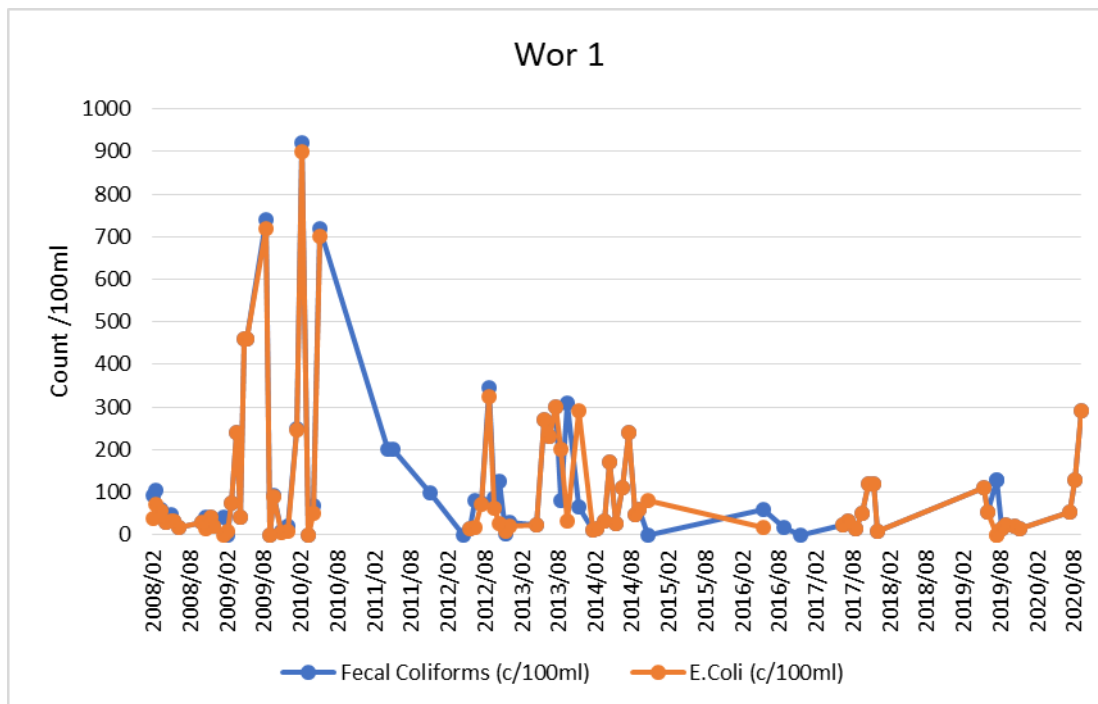
		Wor1				Wor2				Wor3			
		Mean	Median	Min	Max	Mean	Median	Min	Max	Mean	Median	Min	Max
Fecal Coliforms (c/100ml)	2008	47,91	43,00	18,00	106,00	39,40	29,00	0,00	127,00	116,55	23,00	0,00	1100,00
E.Coli (c/100ml)		35,82	34,00	15,00	72,00	32,70	19,50	0,00	100,00	30,09	6,00	0,00	210,00
Fecal Coliforms (c/100ml)	2009	381,83	166,00	9,00	1300,00	187,67	83,50	9,00	1100,00	1130,92	66,00	0,00	11000,00
E.Coli (c/100ml)		276,17	82,50	0,00	1200,00	183,67	82,00	0,00	1100,00	564,92	39,00	0,00	4600,00
Fecal Coliforms (c/100ml)	2010	391,80	248,00	1,00	920,00	150,80	55,00	15,00	380,00	17,80	12,00	5,00	50,00
E.Coli (c/100ml)		379,60	247,00	1,00	900,00	89,20	23,00	0,00	370,00	12,40	9,00	5,00	30,00
Fecal Coliforms (c/100ml)	2011	166,67	200,00	100,00	200,00	347,60	18,00	0,00	1120,00	188,29	18,00	0,00	1000,00
Fecal Coliforms (c/100ml)	2012	84,89	76,00	0,00	345,00	63,56	58,00	0,00	162,00	44,75	33,00	0,00	102,00
E.Coli (c/100ml)		68,50	23,00	8,00	326,00	48,00	26,50	0,00	125,00	37,29	39,00	1,00	73,00
Fecal Coliforms (c/100ml)	2013	182,57	230,00	23,00	310,00	138,75	79,50	6,00	420,00	40,00	40,00	40,00	40,00
E.Coli (c/100ml)		192,14	230,00	23,00	300,00	115,13	12,00	0,00	420,00	13,00	13,00	13,00	13,00
Fecal Coliforms (c/100ml)	2014	71,60	41,00	0,00	240,00	26,67	10,00	10,00	60,00				
E.Coli (c/100ml)		79,60	54,00	13,00	240,00	26,67	10,00	10,00	60,00				
Fecal Coliforms (c/100ml)	2016	26,33	18,00	1,00	60,00	41,00	34,00	4,00	85,00	49,83	4,50	0,00	200,00
E.Coli (c/100ml)		18,00	18,00	18,00	18,00	34,00	34,00	34,00	34,00	47,50	47,50	5,00	90,00
Fecal Coliforms (c/100ml)	2017	53,00	34,00	8,00	120,00	34,63	20,50	5,00	140,00	64,80	17,00	2,00	270,00
E.Coli (c/100ml)		53,00	34,00	8,00	120,00	34,63	20,50	5,00	140,00	64,80	17,00	2,00	270,00
Fecal Coliforms (c/100ml)	2019	62,50	39,50	15,00	130,00	102,80	30,00	6,00	630,00	43,80	25,50	11,00	100,00
E.Coli (c/100ml)		30,00	18,00	0,00	110,00	556,78	15,00	0,00	4800,00	141,30	28,00	11,00	1000,00
Fecal Coliforms (c/100ml)	2020	158,33	130,00	55,00	290,00	465,00	465,00	170,00	760,00	786,67	390,00	330,00	1640,00
E.Coli (c/100ml)		158,33	130,00	55,00	290,00	465,00	465,00	170,00	760,00	786,67	390,00	330,00	1640,00

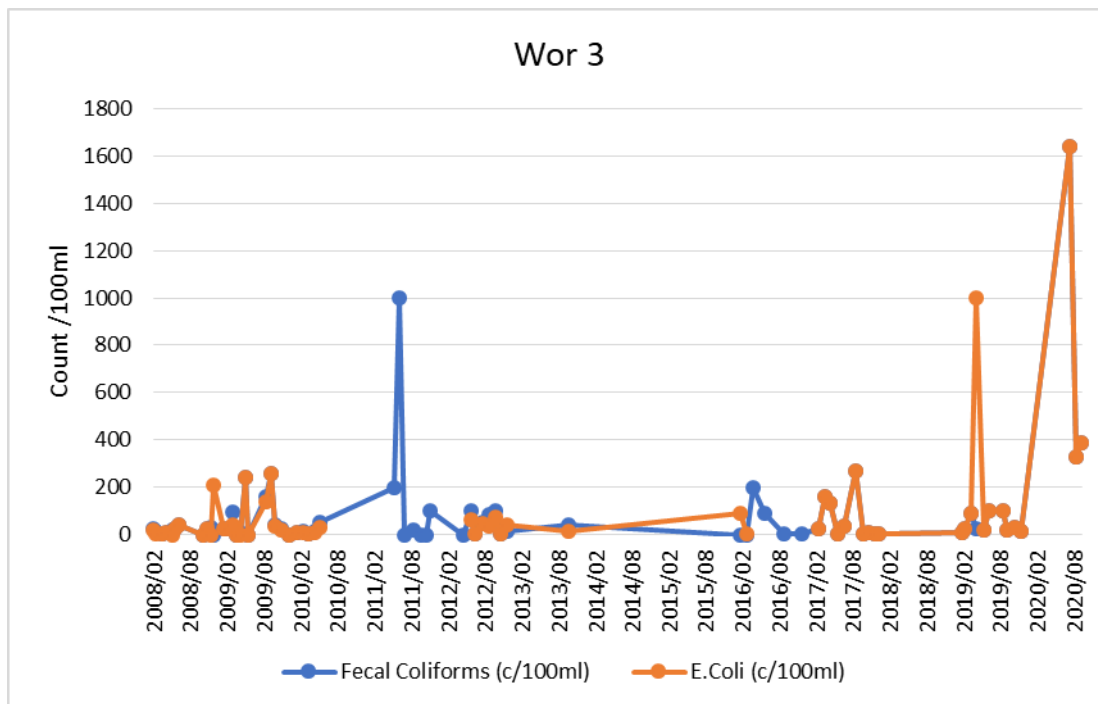
ANNEXURE J: TIME SERIES PLOTS FOR MICROBIOLOGICAL WATER QUALITY











Chemical and microbiological compliance of municipal WWTW in the study area

WWTW	Microbiological		Chemical		Green Drop	
	2010 *	2018 **	2010 *	2018 **	2008/2009 **	2014 *** CRR/CRR max % deviation
	(%)	(%)	(%)	(%)		
Ceres	7	100	59	100	74	36
Wolseley	100	100	83	75	60	35
Rawsonville	33	98	54	96	26	77
Worcester	64	96	68	95	50	52
Robertson	67	36	79	68	49	64
Ashton	81	91	72	79	49	82
Montagu	95	60	65	39	49	88

* CWDm, 2010; ** Cullis *et al.*, 2018; *** DWS, 2014

ANNEXURE K: WATER QUALITY INDEX (WQI) RESULTS

Upper Breede River section

Site	H1H003Q01				
Period	1970-1979	1980-1989	1990-1999	2000-2009	2010-2018
EC	26,57	23,03	31,55	29,31	41,52
TDS	141,64	120,58	178,07	170,35	279,07
pH	6,51	6,45	7,45	7,48	7,88
Na	26,00	22,31	31,85	30,19	54,48
Mg	7,24	6,16	8,56	5,81	6,76
Ca	9,64	8,10	11,55	11,42	15,96
K	1,25	1,50	2,40	4,04	7,29
Cl	46,78	41,98	56,39	41,60	55,23
NO ₃ +NO ₂	0,25	0,34	0,50	0,66	1,56
HCO ₃	29,17	21,51	41,95	54,72	104,98
WQI	26,66	27,77	26,65	26,74	45,59
Average WQI					30,68

Site	H1H015Q01				
Period	1970-1979	1980-1989	1990-1999	2000-2009	2010-2018
EC	12,49	13,66	13,43	9,81	12,74
TDS	66,27	67,20	71,83	51,44	66,64
pH	6,32	5,82	7,14	7,09	6,80
Na	12,56	13,23	12,00	7,83	11,48
Mg	3,14	3,36	3,59	2,54	3,32
Ca	4,29	3,95	4,74	3,92	4,38
K	1,03	1,22	1,46	1,10	1,33
Cl	23,13	26,26	21,58	15,41	21,51
NO ₃ +NO ₂	0,10	0,37	0,55	0,49	0,49
HCO ₃	14,31	10,45	16,28	11,08	13,81
WQI	28,90	48,17	9,25	5,91	11,24
Average WQI					20,69

Middle Breede River section

Site	H2H010Q01				
Period	1970-1979	1980-1989	1990-1999	2000-2009	2010-2018
EC	410,70	324,28	255,09	238,77	214,36
TDS	2602,00	2105,02	1683,32	1502,24	1431,07
pH	7,70	8,02	8,27	8,22	8,50
Na	585,00	451,31	359,46	323,82	299,97
Mg	129,00	109,69	82,29	70,33	68,83
Ca	126,90	99,17	77,40	68,26	68,99
K	9,73	9,80	9,05	7,97	9,00
Cl	842,40	644,30	507,34	442,31	417,70
NO ₃ +NO ₂	1,01	0,91	1,25	0,76	0,77
HCO ₃	234,29	236,00	277,44	294,10	312,36
WQI	158,11	143,40	129,97	120,26	124,89
Average WQI					135,33

Site	H3H011Q01				
	1970-1979	1980-1989	1990-1999	2000-2009	2010-2018
EC	310,42	288,68	330,69	324,24	270,77
TDS	1899,33	1747,86	2069,50	1919,11	1640,64
pH	7,82	7,91	8,28	8,19	8,28
Na	466,02	424,27	508,36	469,42	411,80
Mg	90,53	80,67	90,43	84,01	73,36
Ca	69,32	64,26	72,32	69,60	60,28
K	4,97	6,96	9,43	8,44	9,79
Cl	766,62	700,81	837,57	769,48	641,12
NO ₃ +NO ₂	0,13	0,45	0,64	1,03	0,90
HCO ₃	301,81	263,26	321,50	302,02	255,56
WQI	127,99	123,67	150,34	143,12	131,25
Average WQI					135,27

Site	H4H017Q01				
Period	1970-1979	1980-1989	1990-1999	2000-2009	2010-2018
EC	87,00	27,54	27,39	27,20	26,40
TDS	47,00	142,87	146,83	137,12	136,17
pH	5,60	6,42	7,43	7,41	7,47
Na	10,50	31,26	30,57	28,89	29,54
Mg	2,00	6,89	6,90	6,21	5,44
Ca	1,70	6,94	7,28	7,22	6,89
K	0,81	1,49	1,78	1,59	2,13
Cl	15,40	53,12	51,68	50,08	51,16
NO ₃ +NO ₂	0,11	0,28	0,34	0,37	0,27
HCO ₃	10,25	20,52	26,38	22,41	16,56
WQI	69,19	29,99	24,44	23,10	24,99
Average WQI					34,34

Site	H4H020Q01				
Period	1970-1979	1980-1989	1990-1999	2000-2009	2010-2018
EC	253,70	322,46	367,66	444,93	455,73
TDS	1537,00	2027,93	2358,42	2746,80	2853,23
pH	7,31	8,00	8,23	8,18	8,28
Na	323,90	446,22	521,55	627,27	658,76
Mg	76,40	103,22	119,10	134,01	156,44
Ca	83,20	96,10	109,50	125,28	118,83
K	9,84	13,11	15,30	17,06	15,27
Cl	560,40	732,42	920,58	1087,53	1178,65
NO ₃ +NO ₂	0,77	0,47	0,52	0,30	0,13
HCO ₃	213,49	264,10	310,04	328,39	194,97
WQI	92,91	141,47	165,59	185,96	197,12
Average WQI					156,61

Site	H5H004Q01				
Period	1970-1979	1980-1989	1990-1999	2000-2009	2010-2018
EC	59,94	76,24	94,64	116,11	97,82
TDS	335,52	426,37	555,47	654,38	563,92
pH	6,91	7,04	7,87	7,88	8,02
Na	77,07	101,76	132,08	158,40	132,45
Mg	14,66	19,60	24,62	28,81	23,06
Ca	14,80	16,92	20,74	24,43	21,08
K	2,48	2,80	3,43	3,69	4,03
Cl	119,17	164,35	216,32	259,44	232,62
NO ₃ +NO ₂	0,17	0,27	0,35	0,43	0,19
HCO ₃	67,50	67,35	92,26	103,58	103,58
WQI	21,36	24,17	61,19	67,79	67,23
Average WQI					48,35

Site	H5H005Q01				
Period	1970-1979	1980-1989	1990-1999	2000-2009	2010-2018
EC	65,21	84,13	100,73	112,18	91,07
TDS	378,75	484,60	597,08	632,58	544,68
pH	6,90	7,14	7,98	7,94	7,80
Na	89,79	117,31	141,75	151,50	121,87
Mg	15,91	21,03	25,86	27,45	22,23
Ca	13,95	17,67	21,30	23,39	20,57
K	2,88	3,27	3,86	3,80	3,62
Cl	133,92	180,66	220,10	240,47	218,56
NO ₃ +NO ₂	0,13	0,27	0,28	0,29	0,10
HCO ₃	77,76	87,32	113,28	113,83	100,00
WQI	22,89	30,36	66,78	68,65	57,10
Average WQI					49,15

Lower Breede River section

Site	H7H006Q01				
Period	1970-1979	1980-1989	1990-1999	2000-2009	2010-2018
EC	62,97	54,32	69,96	82,91	60,34
TDS	352,24	299,61	406,10	469,37	338,82
pH	7,01	6,72	7,73	7,71	7,80
Na	86,70	74,61	98,95	115,02	81,85
Mg	14,45	12,88	16,93	19,57	14,64
Ca	12,65	9,99	13,34	16,18	12,32
K	2,14	2,27	2,81	3,08	2,94
Cl	134,49	116,87	157,52	187,69	133,25
NO ₃ +NO ₂	0,09	0,16	0,25	0,29	0,19
HCO ₃	65,52	49,61	71,19	78,11	60,00
WQI	18,89	26,65	48,23	50,88	47,57
Average WQI					38,44

Riviersonderend section

Site	H6H009Q01				
Period	1970-1979	1980-1989	1990-1999	2000-2009	2010-2018
EC	33,55	24,51	35,37	43,62	43,66
TDS	169,99	125,32	187,73	229,05	239,21
pH	6,49	5,92	7,22	7,35	7,22
Na	45,15	33,88	49,60	61,34	65,28
Mg	6,17	4,95	7,10	8,40	8,92
Ca	5,39	3,15	4,65	5,74	4,95
K	1,28	1,15	1,54	1,78	2,37
Cl	76,55	58,81	84,34	103,22	116,71
NO ₃ +NO ₂	0,15	0,14	0,20	0,22	0,17
HCO ₃	24,98	13,69	23,04	26,59	7,62
WQI	27,89	47,11	17,92	25,21	20,92
Average WQI					27,81

ANNEXURE L: WATER QUALITY CLASSIFICATION RESULTS

Based on classes presented in Table 3-3 with colour coding as follows:

Ideal	Acceptable	Tolerable	Unacceptable

Section	Site	Period	EC	pH	NO ₃ +NO ₂	PO ₄
			mS/m		mg/l	mg/l
UPPER BREEDE SECTION	H1H003Q01	1970-1979	26,57	6,5	0,25	0,02
		1980-1989	23,03	6,5	0,34	0,02
		1990-1999	31,55	7,5	0,50	0,07
		2000-2009	29,31	7,5	0,66	0,17
		2010-2018	41,52	7,9	1,56	0,48
	H1H015Q01	1970-1979	12,49	6,3	0,10	0,02
		1980-1989	13,66	5,8	0,37	0,01
		1990-1999	13,43	7,1	0,55	0,02
		2000-2009	9,81	7,1	0,49	0,03
		2010-2018	12,74	6,8	0,49	0,02
MIDDLE BREEDE SECTION	H2H010Q01	1970-1979	410,70	7,70	1,01	0,01
		1980-1989	324,28	8,0	0,91	0,03
		1990-1999	255,09	8,3	1,25	0,05
		2000-2009	238,77	8,2	0,76	0,07
		2010-2018	214,36	8,5	0,77	0,09
	H3H011Q01	1970-1979	310,42	7,8	0,13	0,01
		1980-1989	288,68	7,9	0,45	0,04
		1990-1999	330,69	8,3	0,64	0,09
		2000-2009	324,24	8,2	1,03	0,66
		2010-2018	270,77	8,3	0,90	0,28
	H4H017Q01	1970-1979	87,00	5,60	0,11	0,01
		1980-1989	27,54	6,4	0,28	0,01
		1990-1999	27,39	7,4	0,34	0,02
		2000-2009	27,20	7,4	0,37	0,05
		2010-2018	26,40	7,5	0,27	0,03
	H4H020Q01	1970-1979	253,70	7,31	0,77	0,01
		1980-1989	322,46	8,0	0,47	0,04
		1990-1999	367,66	8,2	0,52	0,05
		2000-2009	444,93	8,2	0,30	0,08
		2010-2018	455,73	8,3	0,13	0,08

Section	Site	Period	EC	pH	NO ₃ +NO ₂	PO ₄
			mS/m		mg/l	mg/l
	H5H004Q01	1970-1979	59,94	6,9	0,17	0,01
		1980-1989	76,24	7,0	0,27	0,01
		1990-1999	94,64	7,9	0,35	0,03
		2000-2009	116,11	7,9	0,43	0,06
		2010-2018	97,82	8,0	0,19	0,05
	H5H005Q01	1970-1979	65,21	6,9	0,13	0,01
		1980-1989	84,13	7,1	0,27	0,02
		1990-1999	100,73	8,0	0,28	0,02
		2000-2009	112,18	7,9	0,29	0,04
		2010-2018	91,07	7,8	0,10	0,01
LOWER BREED SECTION	H7H006Q01	1970-1979	62,97	7,0	0,09	0,01
		1980-1989	54,32	6,7	0,16	0,01
		1990-1999	69,96	7,7	0,25	0,02
		2000-2009	82,91	7,7	0,29	0,03
		2010-2018	60,34	7,8	0,19	0,01
RIVIERSONDER END SECTION	H6H009Q01	1970-1979	33,55	6,5	0,15	0,02
		1980-1989	24,51	5,9	0,14	0,04
		1990-1999	35,37	7,2	0,20	0,02
		2000-2009	43,62	7,4	0,22	0,03
		2010-2018	43,66	7,2	0,17	0,01