EVALUATION OF THE RISKS ASSOCIATED WITH THE USE OF ROOFTOP RAINWATER HARVESTING AND GROUNDWATER FOR DOMESTIC USE AND LIVESTOCK WATERING

(VOLUME 2)
Chemical Quality of Groundwater
For Potable Use and Livestock Watering

Report to the
WATER RESEARCH COMMISSION
and
DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES

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EXECUTIVE SUMMARY

Background

Water quality constituents (WQC) may be inorganic and organic chemicals, which occur either as natural features of all water sources, or as a result of non-natural features related to anthropogenic activities. This report deals with the potential risk to consumers associated with the ingestion of inorganic WQC that may either be of natural or non-natural origins. In the event of naturally occurring inorganic chemicals, the ranges and concentrations vary according to the nature of the geological and rainfall circumstances. The sources of non-natural WQC are associated with anthropogenic activities including agriculture and mining, manufacturing industries and the settling of people in towns and cities.

The potential health risk to domestic consumers and livestock is determined by a complex interaction of parameters that include the concentrations of WQC, the ingestion rates via the water intake (WI) rates and the biological susceptibility of domestic consumers and livestock to a particular inorganic chemical WQC. Risks increase by increasing concentrations and/or WI rates, according to the fate of ingested WQC in the body and consumers' biological characteristics.

This research assesses the quality of water as a potential health risk in terms of inorganic WQC in rooftop harvested rainwater (RRWH), groundwater (GW), river water (RW) and municipal water (MW) sources to people and livestock due to an intake of WQC exceeding water quality guideline (WQG) values. The research is intended to propose changes to the WQG values on GW for domestic use and livestock watering. It is anticipated that the proposed study will generate new knowledge that will inform society of the potential risks associated with the use of these waters resources. In addition, the outcomes of such a study will promote the safe use and appropriate applications of these water resources. The knowledge will enable the relevant national, provincial and local government departments to develop effective intervention strategies and establish appropriate guidelines and regulations.

Aims and objectives

The overall aim of the project was to evaluate potential health risks associated with the use of rooftop harvested rainwater for domestic use and groundwater for domestic use and livestock watering.

The research addressed the following specific objectives:

1. A review of literature on health, risks associated with rooftop harvested rainwater for domestic use and for homestead gardens.
2. An optimising of microbiological techniques to monitor rooftop harvested rainwater and groundwater.

3. The characterising of planktonic and biofilm-forming microorganisms that develop in harvested and surface water stored in 750L low density polyethylene water storage tanks.
4. Determining the risk imposed on crops by planktonic forms of microbes and biofilms in storing and shedding of pathogens.
5. Determining fitness-for-use of rooftop harvested rainwater for homestead gardens.
6. Determining fitness-for-use of rooftop harvested rainwater for livestock production systems and domestic use.
7. A proposed revision of the South African Water Quality Guidelines for Livestock Watering.
8. A proposed refinement and upgrade of available water quality guidelines on groundwater for domestic use and livestock watering.
9. Proposed guidelines and recommendations for the use of rooftop harvested rainwater in tanks.

Research findings

Volume 1 contains objectives 1-4 and objective 5 was not addressed because people in water scarce areas do not use homestead food gardens. This report deals with objectives 6-9 and the extent to which the overall objective of the project was met.

Monitoring of inorganic chemical water quality constituents in water

The problem statement was to compare WQC in GW, RRWH, RW and MW. Samples were collected in the designated districts of Jericho district, Northern Province; Ga-Molepane district (GM), Limpopo Province; and Port St Johns (PSJ) district, Eastern Cape Province. The collecting tanks for RRHW were a range of vessels that included plastic and metal drums or tanks and Ferro-concrete tanks. The samples from these were taken as being rooftop harvested rainwater since it was not possible to distinguish between rainwater straight off the roof and that collected in the tanks in order to test for a tank-effect on the WQC.

The samples were prepared, stored and then analysed by mass spectrometry for a semi-quantitative analysis providing the inorganic micro-water quality constituents and a standard analysis providing the macro-water quality constituents. The results showed distinct differences in the profiles of WQC between GW, RRWH, RW and MW samples drawn from various localities. Constituents of concern (COC) and potentially hazardous chemical constituents (PHCC) may occur in each of the sources. GW is likely to have the highest range of WQC and WQC that may be COC or PHCC. RRWH is likely to differ in the profile of WQC by locality, which is ascribed to wind-blown elements collecting on roofs; for example arsenic (As) that did not appear in the local GW was measured in RRWH. RRWH was characterised by high levels of zinc (Zn) that is ascribed to the zinc-galvanised sheet-iron used for roofing material. Zn in RRWH could be a source to supplement dietary Zn in humans. Seasonal changes measured were marginal, but the lack of consistent and repetitive data severely limited the interpretation of the analytical results. Bromine (Br), a halogen-class element, shown by controlled research to become a potential endocrine disruptor, was measured in GW and RRWH at a locality close to the coast (PSJ). GW contained levels of Br exceeding the SAWQG no observed adverse effect level (NOAEL) value of 0.01 mg/L. International WQG, however, do not consider Br a potential risk factor in drinking water.

Proposed revision to the Water Quality Guidelines for livestock production systems and guidelines on ground water quality

The report considers the recommendations of the current South African Water Quality Guidelines: Volume 5 Agricultural Use: Livestock Watering (1996) against selected international published WQG on WQC and their applicability to groundwater.

The moral philosophy and purpose of WQG is captured in our metaphorical language that is contained in the ancient reference text of the Bible. Each of the WQG reference documents cited set out the moral philosophy and application of guidelines. Guidelines on water quality are primarily aimed at assisting users in determining the fitness-for-use (FFU) of water. Since the circumstances in which water is used differ, WQG values cannot be stand-alone values, but must be interpreted and applied in terms of local conditions and the type and physiology of the livestock. The World Health Organisation (WHO) recommends this approach.

Comparisons are made between the watering and published recommendation. In many cases, there is little consensus between the South African recommended values for NOAEL and recommendations of other countries or international organisations such as the WHO. The reason is the different environments, types of livestock and circumstances in which research was done. It is further evident that since the South African Water Quality Guidelines for Livestock Watering and the equivalent for human consumption were published in 1996, research has shown that elements not included in those documents such as Br pose a risk as endocrine disrupting chemicals. Surveys have shown that a large part of the livestock and rural human population may be exposed to Br occurring naturally in groundwater.

The current South African Water Quality Guidelines for Livestock introduced variability and the probable sensitivity to WQC by classes and physiological ages of livestock. The South African Water Quality Guidelines for Human Consumption and the cited WQG of other countries and organisation differentiate between categories of people by age with reference body mass for each age group. The attempt to categorise people by these parameters does not take into account the wide variation in body size and environmental conditions of people. Likewise, the flaw is repeated with livestock. It is proposed in the document that a more consistent biological reference value be used in determining the likely susceptibility of people of different ages, body mass and activity. Metabolic body mass (MBM = body mass $kg^{0.76}$) is introduced as the reference criterion. This principle can be applied equally successfully to livestock.

Assessments of health risks due to WQC must form the basis of applying the WQG values in context. The document presents procedural steps in making such assessments. In this respect, WQC need not always be viewed as either being of no potential threat to health (NOAEL) or COC or PHCC. The vulnerability of livestock or humans to WQC as COC or PHCC is a factor of WI and turnover, metabolic body mass, demands of the environment and general body condition. However, the inorganic WQC are a source of dietary mineral supplementation, for example Zn.

Conclusions and recommendations

- It is concluded that due to differences in the profiles of WQC from RRWH, GW and RW and the occurrence of inorganic WQC that are COC or PHCC, water from these sources should be monitored to assess their human and livestock health-related risk.

- The recommendations emanating from the report are text-based WQG systems using Target Water Quality Range (TWQR) values as handy quick reference systems, but have limited value. A WQG system should differentiate between types of livestock and people according to their vulnerability and that MBM be applied as the biological reference criterion. WQC previously excluded from the South African Water Quality Guidelines (SAWQG), must be included in a new text-based publication. The limitation of such a system must be recognised and a software-based interactive, health risk assessment system be developed.

- Update and published the 1996 SAWQG.

- Develop algorithms to determine critical parameters for risk assessment.

- Establish a National Water Quality Reference Centre.

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ACRONYMNS

µ	Mean value
ADWG	Australian Drinking Water Guidelines
AUS	Australia
BM	Body mass (kg)
CAN	Canada
CIRRA	Constituent Ingestion Rate Risk Assessment
COC	Constituents of concern
DRWH	Domestic rainwater harvesting
FAO	Food and Agricultural Organisation, United Nations
FFU	Fitness-for-use water
GM	Ga-Molepane district, Limpopo Province
GW	Groundwater
J	Jericho district, Northern Province
MAL	Maximum allowable level
MBM	Metabolic body mass
mg/L	Milligrams per litre
MOE	Ministry of the Environment, British Columbia, Canada
MRA	Microbial risk assessment
MW	Municipal water
NZ	New Zealand
PHCC	WQC levels that exceeded designated WQG levels
PSJ	Port St Johns, Eastern Cape Province
QMRA	Quantitative microbial risk assessment
RRWH	Rooftop harvested rainwater
RW	Riverwater
SA	Standard analyses
SAWQG	South Africa Water Quality Guideline
SQA	Semi-quantitative analyses
SSF	Site-specific factors
TDS	Total dissolved solids
TRAM	Tiered risk assessment and management
TWQR	Target water quality range is the range of WQC in which adverse effects are not likely to occur and that WQC within the range may be tolerated in either short-term or long-term exposure.
WHO	World Health Organisation
WQ	Water quality
WQC	The inorganic elements in water that constitute the chemical and physical characteristics of water, hence quality
WQG	Water quality guidelines
WRC	Water Research Commission
WSQG	Working Sediment Quality Guidelines, British Columbia, Canada
WWQG	Working Water Quality Guidelines, British Columbia, Canada

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CHAPTER ONE

GENERAL INTRODUCTION

Norman Casey[1], Lise Korsten[2] and Lizyben Chidamba[2]

1.1 Introduction to water sources, usage and quality

The socio-geographical feature of South Africa is characterised by high density populations that are concentrated in a few large urban areas, an extensive rural population in regions that are traditionally homeland regions of various African ethnic entities, and an extensive commercial farming industry. Rainfall patterns over the region are seasonal with the South Western Cape experiencing a mediterranean winter rainfall and the eastern and north-eastern regions a summer rainfall. The southern coastal region has year-round rainfall. In addition the spatial distribution of the summer rainfall decreases from east to west and the temporal distributions are highly variable. As a result, South Africa has few perennial rivers with only one major river flowing from the eastern highlands westwards to the Atlantic Ocean, the Vaal-Gariep river system. Rivers flowing from the eastern highlands eastwards to the Indian Ocean that are perennial include the Pongola, Tugela, Umgeni, Umkomaas, Kei, Buffalo, Fish and Sundays rivers. Dams on these rivers supply water for the urban areas and irrigation for agriculture. The distribution of surface water and the possibility to harvest rainwater for domestic purposes and livestock across the country is limited by these factors. Rural communities and livestock farming enterprises become dependent on harvesting rainwater, drawing groundwater and when circumstances permit drawing water from river sources. The high demand for water for domestic, agricultural and industrial needs, coupled to the nature of rainfall and the availability of water in a limited number of river basins cause South Africa to be a water scarce country (Everson *et al*., 2011; Kahinda *et al.*, 2009; Kahinda *et al.*, 2010; Oberholster and Ashton, 2008; Ochse, 2007; Viljoen *et al.*, 2012; Oberholster and Ashton, 2008; Roux *et al.,* 2010; Stockholm Environment Institute, 2009; van Vuuren, 2008).

The predominantly hard rock geology limits groundwater availability, which is frequently over-exploited in areas where groundwater is available, leaving surface water as the most significant resource (van der Merwe-, 2009). However, mining, industrial and agricultural activities and informal settlements next to riverbanks have contaminated surface water. Hence the need to evaluate other alternative sources of clean freshwater (Roux, Oelofse and De Lange 2010). Given the current patterns of water use and discharge, anticipated future population growth rates and expected socio-economic development trends, it is most likely that the available water resources will not be sufficient for future needs (Dalvie *et al.*, 2003; van der Merwe-Botha 2009; Oberholster and Ashton 2008; Roux *et al.*, 2010; Sibusiso and Mndaweni, 2008). It has been forecasted that freshwater resources in South Africa will be depleted and unable to meet the needs of industry and the people by the year 2030 (Postel, 2000; Turton, 2003).

The South African government has made significant advances in providing clean domestic water though many poor and vulnerable inhabitants either have access to insufficient water or the available water is not of suitable quality for drinking or personal hygiene (Statistics South Africa, 2010). The problems of inadequate supplies and insufficient treatment encourage searching for decentralised alternative approaches to access clean domestic and agricultural water, keeping in mind the technical and financial limitations of the poor living in under-developed areas (Alcock and Verste, 1987; Bulcock and Schulze, 2011; Kahinda *et al.*, 2010; Kahinda *et al.*, 2007; Kahinda and Taigbenu, 2011).

Domestic rainwater harvesting (DRWH) describes the small-scale collection, storage, and use of rainwater runoff for production purposes. Rooftop rainwater harvesting (RRWH) is one of the broad categories of DRWH where water is collected from roofs, and stored in underground tanks (UGT) or above-ground tanks and used for domestic purposes, including small scale production activities such as garden watering (Kahinda *et al.*, 2010; Kahinda *et al.*, 2007). RRWH is one of the most appropriate alternative sources of potable and non-potable water supplies at household or community level as the world faces decreasing water sources and increasing energy crisis (Amin and Han, 2009). Prior to promoting RRWH, it is essential to determine potential chemical and microbiological risks that can be associated with such water collection systems (Figure 1.1).

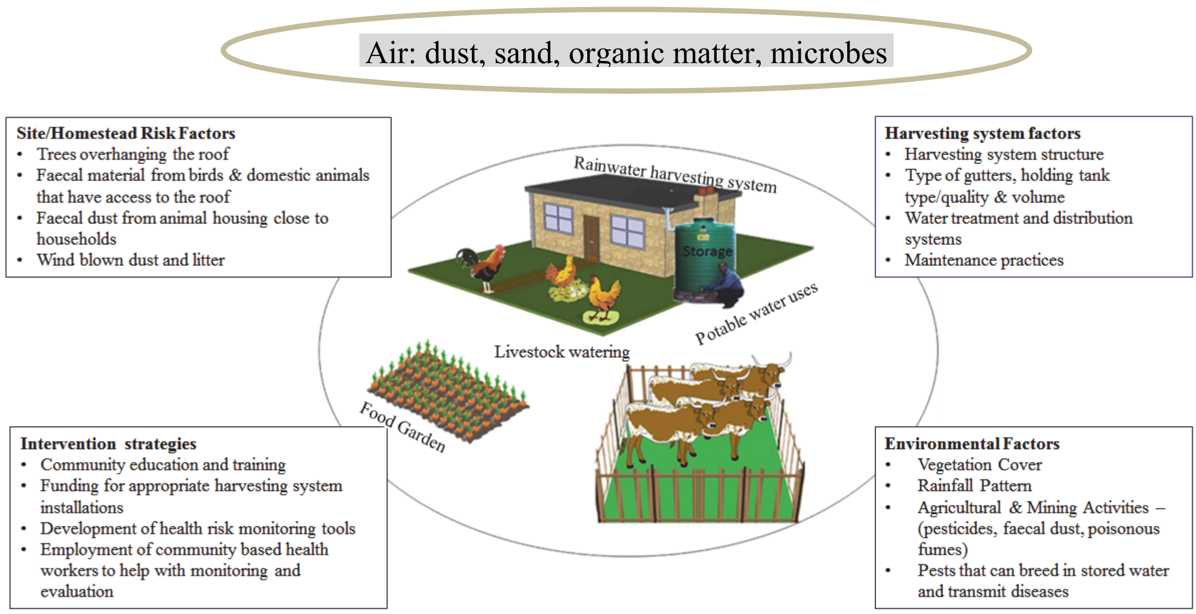

Figure 1.1 The illustration shows a typical setup among rural household communities with a rainwater harvesting system and factors critical in the safe use of harvested rainwater (see Volume 1).

South Africa's estimated GW reserve is 10 million cubic kilometres, which is >90% of the available freshwater resource. The quality of GW varies significantly from one area to another due to geological features and anthropogenic activities. The quality of GW in terms of inorganic WQC for domestic use and livestock watering has been investigated for more than 25 years through projects funded mainly by the Water Research Commission (WRC). Comparisons, however, have not been made between potable GW and RRWH, an important resource in rural areas. By quantifying the WQC of both resources and the potential associated health risk, WQG can be refined and intervention strategies devised in the public interest and to support water quality managed.

The risks posed by inorganic chemical WQC to livestock have been studied in various scenarios in South Africa since 1990 with the focus having been on GW (Casey *et al.*, 1996a,b; Coetzee *et al.*, 1997; Casey *et al.*, 1998a,b,c; Casey, and Meyer, 2001; Casey *et al.*, 2001; Casey and Meyer, 2006). The results showed the potential for a high risks to livestock and rural communities. However, the risks due to naturally occurring WQC in GW are not generic, but are associated with the type of livestock, the livestock production system, location, physiological condition of the livestock and the inorganic constituent being ingested.

An assessment of the risks led to publishing the South African Water Quality Guidelines (First Edition), Volume 4, Agricultural Use: Section 4.4, Water Quality Guidelines for Livestock Watering, 1993 (Casey and Meyer, 1993) followed by a revision in 1996 (Casey *et al.*, 1996a; Meyer *et al.*, 1997) and an easy, handy reference document (Casey and Meyer, 1996b). Further research went into the development of a software system as a useful tool to assess risk by coupling the biological attributes of livestock, the physical attributes of the environment and the ingestion rate of the WQC that gave a constituent ingestion rate risk assessment (CIRRA). The process has recently been described (Meyer and Casey, 2012). Since the publication of the South African Water Quality Guidelines for Livestock Watering, 1996, and the development of the software system reported in 2001, research has progressed to the extent that the Water Quality Guidelines for Livestock Watering need to be updated and republished. This exercise should eventually lead to a revision of the CIRRA software programme.

The risks posed by WQC to humans in rural areas who are dependent on GW were reported by Casey and Meyer (2001) and Casey and Meyer (2006). Since people in the rural areas and their livestock in most cases use the same GW sources, livestock are an acceptable gauge for assessing the risks to people.

1.2 Motivation for the focus of this project

The basic human right of having access to potable water is often seriously compromised by ineffective water management systems and lack of adequate control of industrial and other environmental pollutants (Farahbakhsh *et al.*, 2009; Yadav *et al.*, 2007). It is incumbent on governments to provide safe quality water (van der Merwe-Botha, 2009; Gemmell and Schmidt, 2010; Viljoen *et al.*, 2012). Poor management of water quality increases the risks posed by chemicals and microbes to consumers that may have long-term negative effects on the population, food security and sustainability (van der Merwe-Botha, 2009). The quantification of risks in context to the vulnerability of domestic consumers and livestock enables refining WQG and devising intervention strategies.

Plant, animal and human health and well-being are important pillars in society and require effective regulation and enforcement. Although there are regular public notices of contamination taking place in South African rivers, GW monitoring in rural areas is lacking. In these areas, water collection systems are also more commonly used for domestic consumption and livestock watering. Yet, little is known about the quality and safety of this valuable water resource. Water collection from roof tops also provides an alternative resource for domestic use and has increasingly been used in food gardens. Similarly little is known about the quality and safety of water collected from roof tops and stored for extended periods of time.

This research assesses the quality of RRHW compared with GW, RW and MW sources in terms of inorganic WQC and whether risk to people and livestock might occur due to an intake of WQC exceeding guideline values. The research is intended also to propose changes to the guidelines on GW for domestic use and livestock watering. It is anticipated that the proposed study will generate new knowledge that will inform society of the potential risks associated with the use of these waters resources. In addition, the outcomes of such a study will promote the safe use and appropriate applications of these water resources. Furthermore, this knowledge will enable the relevant government department to develop effective intervention strategies and establish appropriate guidelines and regulations.

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CHAPTER TWO

INORGANIC CHEMICAL QUALITY OF WATER

Norman Casey[1]

2.1 Introduction

Inorganic chemicals in water, referred to as WQC, have variable potential effects on livestock and people ingesting these, whether through drinking water or water used for domestic purposes such as cooking or preparing beverages. Various factors determine the risks posed by WQC that will be elucidated further.

Inorganic WQC occur naturally in water due to a range of conditions that could release molecules or dissociated molecules as anions and cations into the water. The primary conditions that determine this include the geology of the surface over which the water flows, whether it is surface or subterranean water and where surface elements are scoured off and enter the water. Through geothermal activity, the effects of heat and pressure change the chemical characteristics of the geological matter, resulting in the release of elements into the water. Sediments carried by rivers and wind action can add to the inorganic content and change the relative proportions. Evaporation and dry periods concentrate the WQC increasing the possibility of high concentrations of potentially hazardous WQC being ingested. Concentrations of salts concomitantly raise the total dissolved solids (TDS) value, which has been shown to have alleviating effects on the potentially hazardous effect of ingested WQC. This is noted in the literature.

The variability of contributing factors to inorganic WQC in water results in a high variability of any constituent elements. Rivers have a distinctly different profile of WQC in a season of high flow rate compared with a season of low flow rate. In some areas, river flows drop below the river bed to a slow, percolated subterranean flow. Anthropogenic-induced presence of inorganic WQC or changes in the concentrations are due to exposing water sources directly to elements present in dumping waste, runoff from waste dumps, roads, concentrated livestock production systems and disturbances of the surface and geology through agricultural and mining activities. Indirect influences on WQC may be caused by diverting and interrupting the flow of water courses and pumping water from aquifers, which can cause a movement of water containing higher concentrations of WQC from deeper regions or the flow of water from interconnected aquifers.

Changing relative concentrations of WQC are affected by the flow rates. Fast flowing water will have a different relative concentration of WQC to slow or static water, the conjugation of molecules, the relative density of the molecules, pH where acidity or alkalinity affects the dissociation of conjugated molecules and electrical conductivity. Speciation of elements may occur under the influence of temperature, pH and ranges of the light spectrum i.e. infrared or ultraviolet light.

The dynamics of WQC differ between ground and surface water. GW is less exposed to the factors including agriculture and mining than surface water. However, a high range of WQC occurs between GW sources to the extent that boreholes closely located can differ. The inorganic WQC concentrations of rainwater should also vary in association with the noted conditions.

2.2 Aim, hypothesis and problem statement

Aim The aim of investigating the occurrence of inorganic WQC in roof and ground harvested rainwater, GW and RW is to estimate whether risk (due to WQC) to livestock and people might occur from these sources singularly or in combination, and to collate this information into the WQG for livestock and rural communities.

Hypothesis The project attempts to test the H_0 hypothesis that harvested rainwater, groundwater and riverwater should not differ significantly in a given area.

Problem statement: Natural water supply for livestock and rural communities in South Africa

The southern African region has agro-ecological features that make it suitable for production of livestock in extensive systems. The natural rangeland (veld) is the sustaining nutrition source for livestock. It ranges from subtropical bush to vast stretches of grassland to harsh semi-desert and desert features (Tainton *et al.,* 1993). The region's rainfall extends from the east along the Indian Ocean (with an annual average rainfall of around 800 mm per annum) to the dry desert of the western regions along the Atlantic Ocean, where the annual rainfall becomes <10 mm. The central regions have between 300 and 400 mm per annum 90% of the time (De Jager, 1993). Precarious rainfall and the lack of natural perennial rivers and streams cause livestock farmers, rural farming communities and small towns to be reliant on GW sources.

The Water Research Commission of South Africa (WRC) initiated the development of WQG for livestock watering from GW sources in 1989. Farmers were eligible for a conditional government subsidy on GW sources in designated water scarce regions, on condition that the water had to be fit-for-use for livestock watering. The dilemma was, firstly, the differing published WQG and secondly, the WQG for livestock in use in South Africa was a restrictive, single-value system, constructed around single-value reference criteria for maximum tolerable limits (MTL) or recommended maximum exposure concentrations (for example 0.03 mg/L of water). WQC levels and the identification of PHCC had not been considered scientifically and advice given and conclusions drawn were assumptions rather than facts (Casey *et al.,* 1996b). The existing WQG were neither site-specific nor were the types of animals, their physiological status, and the environment and production systems taken into account, or supported by scientific evidence, which rendered the single-value system inappropriate in assessing fitness for use. The lack of certainty in the outcome following the exposure of livestock to WQC provided a motivation for a more accurate guideline format. A description of the development of the guidelines is important in order to grasp the need to scrutinise and update the existing WQG.

2.3 Strategy towards developing water quality guidelines

The strategy followed in developing WQG for livestock focussed on producing an adaptable set of guidelines based on the principles of livestock production, i.e. that animal production is a function of the animal and the production environment. The animal factors should include: species, breed, genetics, physiology and production status; and the environment factors should include nutrition, humidity, temperature and altitude. The aims of such guidelines are to assess and minimise the risks posed to livestock by the ingestion of PHCC, defined as WQC levels that exceeded designated WQG levels, and to consumers of livestock products (Meyer *et al.,* 1997). In the current project this theory is applied to people, though the restriction is that no quantitative research can be done using human subjects. The results previously formulated for livestock as the reference species are extrapolated to human consumers in the rural and village settings where equivalent references do not appear in WQG dealing with domestic usage or drinking water for human consumption.

The WHO (2011) Guidelines for Drinking Water note that not all of the chemicals with WQG values will be present in all water sources or at levels of COC/PHCC. It notes further that chemicals without WQG values or that are not addressed in the WQG may be of legitimate local concern. The interpretation of these statements is that guideline values are not intended to provide a one-value-fits-all approach. Health risk management strategies must consider the chemicals (WQC) most likely to occur in water sources and that are to cause a debilitating condition due to acute exposure (for example methaemoglobinaemia or diarrhoea) or to chronic exposure (for example endocrine disruption).

Differences in the approach to developing WQG for livestock and human consumers are the nature of keeping livestock and the probable exposure and mitigating circumstances compared with the domestic habits of people. Livestock are more likely to be kept in one place and the exposure to COC/ PHCC becomes chronic. However, by mitigating the effects with treatments either of the livestock or the water, such as by altering the TDS levels, this becomes manageable. The gregarious nature of people and the freedom to move about and make dietary choices can reduce exposure to WQC COC/PHCC. There are rural communities in South Africa, however, who are chronically exposed to water sources that have high levels of WQC in the categories of COC/PHCC. Under these circumstances, the interpretation of "chronic exposure" differs markedly between livestock and people. The lifespan of livestock in the different production phases ranging from young growing animals to mature breeders is a fraction of that of humans. Growing and developing people could be exposed to WQC as COC/PHCC in their most vulnerable life-period for as long as 20 years. Apart from an acute effect of nitrate (NO_3) causing methaemoglobinaemia or sulphate (SO_4) causing diarrhoea, other WQC may affect the endocrine system and metabolism leading to stunted growth, impaired cognitive development and compromised immunity.

Developing health risk management strategies regarding WQC for human consumption, must account for the effects of physical activities (manual labour) and physical characteristics of the environment (temperature-humidity indices).

Two separate systematic approaches may be applied to determine health risks to livestock that may be associated with WQC. The one approach is by analysing water for the WQC, noting the concentrations that appear to be COC/PHCC in terms of WQG and to apply the procedural steps to estimate the risks due to the WQC. The second approach is to observe subclinical or clinical indicators of possible pathology that might be linked to WQC. This is followed by a systematic assessment of possible contributing factors.

Table 2.1 Systematic procedures in determining health risk to livestock due to water quality constituents (WQC)

Water analysis	**Observations**
Measure concentrations of WQC (mg/L, g/L)	Observe subclinical or clinical indicators of possible pathology
Procedural steps	Procedural steps
Review each of the WQC in the analysis - Concentration (mg/L, µg/L) - The potential physiological effect of the WQC - Possible alleviatory factors such as TDS, competitive WQC Note the source of the sample Note the water user group (sheep – lactating, broiler chickens – one week old, horses – endurance) Note the site-specific factors (SSF) that can influence water intake - Dry rations - High physiological demand for a high water intake as with young animals, lactation, high physical activity - High altitude Note the expected or given exposure time Repeat the sample and analysis for wet and dry seasons	Do a clinical examination of the single animal or user group and establish the incidence within the group or region Consider known causes of both a subclinical and clinical observation Eliminate known factors Do an analysis of the water Review each of the WQC in the analysis - Concentration (mg/L) - The potential physiological effect of the WQC - Possible alleviatory factors such as TDS, competitive WQC Note the source of the sample Note the water user group (sheep – lactating, broiler chickens – one week old, horses – endurance) Note the site-specific factors (SSF) that can influence water intake - Dry rations - High physiological demand for a high water intake as with young animals, lactation, high physical activity - High altitude Note the expected or given exposure time Repeat the sample and analysis for wet and dry seasons

2.4 Physiological risks associated with WQC

Due to the nature of livestock production in southern Africa, the WQG were developed principally around GW, since the WQC in GW have the highest potential risk to livestock and rural communities. The principles apply equally to rainwater.

The extent of risk due to WQC in GW and the risks posed by PHCC were determined in a number of ways, beginning with a review of existing data of WQC in GW and supplemented by systematic sampling of boreholes, reservoirs and at the point of use, over seasons.

Geo-hydrological data from the Department of Water Affairs and Forestry for the periods 1987 to 1994 were used to form the basis of the analysis. The data had been analysed for TDS, Na, Mg, Ca, F, Cl, NO_3, SO_4, PO_4, TAL (total alkalinity), Si, K, and pH (Meyer, 1992; Casey *et al.,* 1996b; Meyer *et al.,* 1997). The PHCC were expressed as a percentage of the total number of recorded PHCC in a designated area. Of the WQC in the data reviewed F, TDS, Cl and SO4 were considered important variables in terms of existing WQG. The characteristics of the data did not allow for statistical analyses to establish correlations and trends between constituents. High risk areas were identified in the northern and northwest regions followed by surveys that are more extensive.

The incidence of PHCC in the water showed F 38%, TDS 19.1%, and Cl 24.8% with Na, SO_4, Mg, NO_3 and Ca at < 10% (Casey, *et al.,* 1996b). Of the samples that constitute the data, 37.2% of the boreholes were unfit for livestock watering and others had WQC close to the level for PHCC. Further surveys included trace minerals and were over a wider set of regions, including the Western Cape, the Great Karoo, the Little Karoo and the Kalahari region, and a more recent survey over a wider range across South Africa.

The values, published by Coetzee *et al.* (2000), Casey *et al.* (2001) and Casey and Meyer (2006), show a high range of WQC throughout South Africa and that these can differ markedly between regions. It emerged that the mean values for As, F, Hg, NO_3, Se, Sr, U, V and TDS are COC throughout South Africa, but not necessarily in the Western Cape.

Static reference values for selected WQC shown in Table 2.2 illustrate the range of values, published as WQG, which complicates the interpretation and application of acceptable single reference values.

2.5 Physiological advantages associated with water quality constituents in dietary mineral supplementation

People and livestock require a combination of essential micro-minerals (trace elements) and macro-minerals for numerous biochemical functions in the body. It is generally assumed these are acquired through food. Analyses of diets show that the micro and macro-mineral content are often unbalanced and do not provide the animals or people with the necessary intake of these minerals. The value of supplementation is well documented and animals may supplement their mineral requirements through geophagia especially by consuming concentrated minerals in salts such as those occurring in pans, dams, river banks and around windmills (where there is an overflow, the water evaporates and WQC form crystalline deposits). WQC are a potential source of supplementary micro and macro-minerals.

Casey and van Ryssen (2013) described the extent to which micro-minerals occur abundantly in the environment and are contained in various herbages for livestock. The uptake of the micro-minerals into plant material is a function of the presence of the micro-mineral in the soil and the characteristics of the soil. An example is Se. This element is present in soil throughout South Africa. However, plants containing Se generally grow on alkaline soils with low rainfall, while plants in the high rainfall, acid soils have a low bioavailability of Se. In the one scenario high levels of Se in the water coupled to a high WI due to the demands of the dry environment is a potential cause of Se toxicity. In the second scenario, water-borne Se can supplement the dietary intake substantially. This point is elucidated in the discussion of the results of the WQC of the respective sources sampled.

Table 2.2 Range of maximum acceptable levels (MAL) (mg/L) of water quality constituents (WQC) published as static water quality guideline (WQG) reference values for poultry watering

WQC	WQG range of MAL (mg/L)	References *
Aluminium	0.25-5	4; 6; 10.
Antimony	0.006	10.
Arsenic	0.05-1	1; 4; 5; 6; 8; 10.
Barium	1-2	8; 10.
Beryllium	0.004	10.
Bicarbonate (CO_3^{2-})	98-500	5.
Boron	5	6.
Cadmium	0.005-50	4; 6; 10.
Calcium	200-600	1; 4; 5; 8.
Chloride	200-1500	1;2; 4; 5; 7; 8; 9; 10.
Chromium	0.05-5	4; 8; 10.
Cobalt	1	4; 6.
Copper	20.06-2.5	1; 4; 2; 3; 4; 5; 6; 7; 8; 9; 10.
Cyanide (CN^-)	0.2	10
Fluoride	0.06-4	1; 4; 5; 6; 8; 10.
Iron	0.3-6	2; 4; 5; 7; 8; 9.
Lead	0.015-0.5	1; 2; 4; 5; 6; 7; 8; 9.
Magnesium	50-350	1; 2; 4; 5; 7; 8; 9.
Magnesium sulphate	200-400	4.
Manganese	0.05-4.6	1; 4; 5; 8.
Mercury	10-0.002l-10	4; 6; 8; 10.
Molybdenum	10	4.
Nickel	0.001-1	6; 10.
Nitrates	10-200	2; 3; 4; 5; 6; 7; 9; 10.
Nitrites	1-4	2; 6; 7; 9; 10.
Phosphate($^-PO_4$)	0.7-5	1; 4.
Salinity	3000	6.
Selenium	0.01-0.05	4; 6; 8; 10.
Silver	0.05	8.
Sodium sulphate (Na_2SO_4)	1200	4.
Sodium	50-200	2; 5.
Sodium chloride (NaCl)	1500	4.
Sulphate	60-400	2; 5; 6; 7; 8; 9.
Thallium	0.002	10.
Vanadium	0.1	6.
Zinc	1.5-25	1; 2; 5; 6; 7; 8; 9.
TDS	3000	4.

[*] The numbered references are listed alphabetically in the References: [1]Carter, 1985; [2] Ernst, 1989; [3] Good, 1985; [4] Kempster, *et al.,* 1981; [5] Keshavarz, 1987; [6] Mancl *et al.,* 1991; [7] Schwartz, 1994; [8] Vohra, 1980; [9] Waggoner *et al.,* 1994; [10] Zimmerman, 1995.

2.6 Assessments of the interactions between water quality constituents and livestock

WI is the most important determinant of potential adverse effects of WQC due to the direct relationship between WI and ingestion rates of WQC. WI is determined by chronological age where young animals accumulate water in tissues, especially muscle fibres undergoing hypertrophic development, the physiological state such as with lactation, the peripheral demands of the environment as in a dry climate or extremes in the temperature-humidity index, and the moisture content of rations.

Palatability is a factor of the WQC that might influence WI. Consequently, the palatability of water can be manipulated by changing the relative content of WQC and the level of TDS (Meyer, 1992; Casey *et al.,* 1996a and b; Meyer *et al.,* 1997). The effects on palatability of NaCl, $NaSO_4$, CaCl, and $MgSO_4$ were determined in beef steers, dairy cows and S.A. Mutton Merino wethers. The animals adapted to incremental increases in TDS concentrations. The types and concentrations of salts and the ratios between salts ($P > 0.05$) influenced the WI of cattle and sheep. Palatability curves were developed that could be used to predict WI response to zones of preference and non-preference. This allowed an intervention to be made to improve the palatability of water, with one or more of the WQC > the recommended WQG levels. An example is that water with a SO_4 concentration > 1000 mg/L is less palatable and could depress WI and have a roll-on effect on productivity. The palatability rating is moved into a zone of preference by changing the ratio of SO_4: TDS. The results demonstrated the potential role of TDS as an alleviator for unpalatable water and possibly as an alleviator of the potential toxicity of a WQC that could be in the category of a PHCC.

WQC have the potential for adverse physiological effects and become toxic under particular circumstances, including:

- Long-term, consistent intake of a WQC (chronic exposure) at levels below being classified a PHCC if it (1) has a propensity to accumulate in the body, (2) has a relatively slow clearance rate, (3) disrupts metabolic pathways, or (4) competes with other elements and in that way disrupts metabolic pathways.
- Short-term intake at levels exceeding the WQG values, i.e. a PHCC, if it has the propensity to interfere with the physiology, or may compete with or displace other elements and disrupt metabolism.
- Intake by animals in hypersensitive physiological stages especially during stages requiring high volumes of WI, such as early growth, lactation, a period of adverse temperature-humidity indices, or when fed a dry ration regime.
- Biologically inactive WQC may undergo speciation and become biologically active under conditions of storage in open, exposed reservoirs and when ingested. Various factors can initiate chemical speciation, including oxygen, solar radiation, pH, temperature, ionic strength and time.
- Clearance rate is a pharmacokinetic parameter that describes the dynamics of a substance from ingestion and absorption to a NOAEL in the body. Chronic exposure of low concentrations of WQC coupled to a low clearance rate can increase the residual concentration in the body and raise the risk level. In terms of WQC, acute

exposure of high concentrations WQC would at most have acute physiological reactions such as SO_4 salts (e.g. $MgSO_4$) causing diarrhoea.

Bioavailable WQC refers to WQC being taken up into the body from the digestive tract, but bioavailable does not necessarily imply that the WQC is bioactive The bioavailability of WQC and the effects of these on the physiology of an animal depend on interactive factors that include concentration, ingestion rate, length of exposure and the type of livestock. Speciation may also happen in the digestive tract that would make the WQC more or less bioavailable. A WQC may become bioactive if it enters the metabolic processes of the body through which it may disrupt a metabolic pathway, displace an element or become bonded within or deposited in a tissue. Ingested WQC that pass through the milk are bioavailable, but may not be bioactive. The competitiveness of elements to enter a metabolic process offers an opportunity to exploit this fact, and by careful reconstitution of WQC, both the bioavailability and the bioactivity can be influenced. A challenging aspect to the inter-relationships between elements relates to the potential element speciation. This is well documented for elements such as Cr (hexavalent) and As (trivalent versus pentavalent) that the oxidation state determines risk and therefore fitness-for-use. In the case of Se, these different oxidation states may result in an exposure concentration varying from having antioxidant to pro-oxidant effects.

As TDS can be used to manipulate the palatability of water, likewise TDS may be an effective means of influencing the bioavailability and bioactivity of WQC. TDS effectively alleviated the accumulation of As, Pb and Br in tissues of broiler chickens (Mamabolo *et al.,* 2009). Increasing the TDS of the water and subsequently causing a pressure diuresis, which increased renal clearance rates, achieved the reduction of clinical fluorosis in cattle, both in terms of dental enamel hypoplasia and skeletal exocytosis. Lowered whole blood Se values were also observed using this method (Casey and Meyer, 2006). Another outcome of interactions is that some exposure concentrations do not result in primary toxicity, but rather result in induced deficiencies of other elements that may complicate differential diagnoses. A simple example of this application may be found in dietary supplementation of iodine (I) as a mitigation measure for exposure to goitrogenic substances where Br and F may increase the requirement for I. This principle was demonstrated (Du Toit and Casey, 2010; Du Toit and Casey, 2011) where the interaction between Br and I had no significant effect on WI ($P = 0.0928$) or feed intake ($P = 0.9593$). However, although Br administered at 1 and 3 mg Br/L or at ingestion rates of 1.59 and 4.44 mg Br/day affected production and physiological parameters, I had an effective ameliorating effect on Br.

The variability in exposure concentration and intake might alter ingestion of a WQC, and thereby induce variability in observed effects and concentrations. However, interactions with electrolytes that alter fluid balances can also change the outcome of exposure. An example of this relates to volume-loaded hypertension with neural endocrine homeostatic mechanisms able to alter the renal clearance rates. This may explain the reason for a tolerance of higher concentrations in some cases, but may also allow mitigating measures to be implemented based on manipulating water quality.

The formula for assessing the risk of toxicity due to WQC is multifactorial. The risk becomes dependent on the animal, site-specific conditions, the ingested form and ingestion rate, the bioavailability and bioactivity, and the clearance rate of the WQC.

2.7 Water quality guideline values

WQG developed by accounting for these factors and advanced the generic single-value static system (South African Water Quality Guidelines, 1996) to a classification system. The guidelines give a description of the WQC, the occurrence in the aquatic environment, the interdependence with other WQC and properties. It further includes current methods of measuring WQC, likely interpretations of the listed WQC, site-specific factors (SSF) and a target guideline range where applicable (sheep, pigs, beef and dairy cattle, chickens and a generic all species). An example of the more comprehensive WQG for WQC using F and Se as they appear in the South African Water Quality Guidelines (1996) (SAWQG) is given in Box 2.1. This set of guidelines was by no means sufficiently accurate, but it was an improvement on preceding static systems.

Box 2.1 Example of water quality guideline (WQG) for a water quality constituent (WQC) in SA Water Quality Guidelines (1996) pertaining to fluoride (F) and selenium (Se)

Fluoride (F)
Incidence: High
Description:
Excessive F results in tooth damage in growing animals and bone lesions resulting in crippling of older animals, especially in cattle (Canadian Guidelines, 1987). F is a cumulative poison and signs of fluorosis may only be observed in the second and third year of exposure to high levels. Toxic effects include anorexia, hyperostosis, pitting and erosion of teeth, loss of appetite, decreased feed intake and performance. Breeding sheep should tolerate a diet with < 60 mg F on a dry matter basis.

Occurrence in the aquatic environment:
F, a relatively common element, comprises approximately 0.3 g/kg of the Earth crust. It exists as F in a number of minerals, including fluorspar, cryolite and fluorapatite. Fluorides are also present in numerous industrial products (phosphate fertilisers, bricks, tiles, and ceramics) and in a wide range of pharmaceutical products. Traces of F occur in many waters and higher concentrations are often associated with groundwater. In areas rich in fluoride-containing minerals, groundwater may contain levels in excess of 20 mg/F. F concentrations in most surface waters are > 1 mg/L. F may enter rivers as a by industrial discharge or the use of rock phosphate fertilisers. Levels of around 50 mg/F and higher have been recorded. F concentrations in surface and groundwater are high in some areas in South Africa, such as the Karoo. Occurrence of fluorspar deposits is of relevance, particularly those occurring in the north-western Cape and parts of the Transvaal (previous province in pre-1994 Republic of South Africa and is the extensive region north of the Vaal River).

Interdependence with other constituents and properties:
F is thought to be one of the main ions responsible for solubilising Be, Sc, Nb, Ta and Sn in natural waters. Occurrence of Ca together with F limits fluoride toxicity. Fluorosis is less severe when drinking water is hard, rather than soft, and the presence of Ca and Cl reduces the toxicity of F to fish. Aquatic plants and animals accumulate F (Canadian Guidelines, 1987). Aluminium-fluoride complexes are likely to occur in water with pH levels of below neutral.

Guideline range:
Non-ruminant target guideline range: 0-2 mg/L
Ruminant target guideline range: 0-6 mg/L
Potential effects in non- ruminants: At > 2 mg/L, long-term exposure could result in fluorosis developing.
Potential effects in ruminants: At > 6 mg/L, assess site-specific factors that may influence F toxicity before allowing long-term watering.

Selenium (Se)
Incidence: Low
Description:
Chronic selenium poisoning causes "alkali disease", of which the symptoms include a loss of hair (principally the mane and tail), lameness and decreased feed intake. Death may occur from starvation. Acute selenium poisoning causes "blind

staggers", with symptoms such as impaired vision, decreased feed intake, weakened front legs and paralysed tongue and throat. Death may occur from respiratory failure. Young animals are more susceptible to selenium poisoning.
Maximum and toxic levels of selenium (Se) for livestock (NRC, 1980)

Livestock	Maximum total recommended by US FDA (mg/head/day)	Toxic level in feed (mg/kg)	Toxic level (mg/head/day)
Beef'	1	10-30	100-300
Dairy	2	3-5	30-60
Sheep	0.23	3-20	7-50
Swine	-	5-10	8-16
Chicken	-	2	-
All species	2 mg/kg	-	-

The lethal dose of Se salts for cattle is taken to be 4.4 mg/kg body mass. An estimated threshold level of 5 mg/kg feed of dietary Se is required to induce Se poisoning. Plants can concentrate Se from irrigation and soils. Se protects against Hg toxicity, and may be an anti-carcinogen. High SO_4 intakes can increase Se requirement.

Occurrence in the aquatic environment:
Surface and subterranean waters usually contain less than 0.05 mg/L. Se occurs in the stable anion form of selenite in aerated water at pH 6.6.

Guideline range:
The target guideline range for selenium in livestock drinking water is 0.05 mg/L

Due to the shortcomings of the 1993 SAWQG and the need for a user-friendly document, Casey and Meyer (1996b) published a set of WQG as Interim Water Quality Guidelines for Livestock Watering.

These WQG gave the user more applicable information on risk, taking samples and interpreting the results on a site-specific basis and according to the type of livestock. It contained a listing of the incidence of WQC considered high, medium and low risk according to the occurrence of the WQC in the aquatic environment. It more specifically introduced the concept of a TWQR. Adverse effects are not likely to occur in the given range and either short-term or long-term exposure to WQC within the range may be tolerated. The consequences would depend on the important SSF of synergistic and antagonistic interactions between constituents in the feed and the water, the type of livestock production system and the actual ingestion of water that determines the ingestion rate of the WQC. Two formats of the WQG are set out in Boxes 2.2 and 2.3 (Casey and Meyer, 1996b).

Box 2.2 Examples using arsenic (As), boron (B) and cadmium (Cd) of generic target water quality ranges (TWQR, mg/L) applicable to all livestock based on formats of the water quality guidelines (WQG).

Arsenic (As)	Medium incidence
TWQR mg/L	Effects – all livestock
0-1.0	No adverse effects.
1.0-1.5	Adverse acute effects, e.g. anaemia, incoordination, haemorrhagic diarrhoea and dehydration may occur in sensitive species (pigs and poultry), although short-term exposure is usually tolerated. Acute effects are unlikely in larger animals (cattle, sheep, goats and horses), but may occur if arsenic feed concentrations are elevated and could be tolerated in long-term exposure according to SSF.
> 1.5	Adverse acute effects may occur, particularly in more sensitive species (pigs and poultry), although short-term exposure could be tolerated according to SSF.
Boron (B)	Low incidence
TWQR mg/L	Effects – all livestock
0-5	No adverse effects.
5-50	Adverse chronic effects (decrease in feed intake and weight loss) may occur, but are unlikely if feed concentrations are normal, and exposure is short-term. Ruminants may be more tolerant than monogastrics. Could be tolerated in the long-term according to SSF.

> 50	Adverse chronic effects may occur (see above), although short-term exposure may be tolerated according to SSF.
Cadmium (Cd)	
TWQR mg/L	Effects – all livestock
0-0.01	No adverse effects.
0.01-0.02	Adverse chronic effects such as anaemia, testicular degeneration, reduced feed intake and milk production and reduced growth may occur, but are unlikely if exposure is short-term, dietary protein, calcium and phosphorus intake is adequate, and feed concentration of cadmium is normal. Adverse acute effects such as abortions, stillbirths, hepatotoxicity and nephrotoxicity may occur, but suckling and pregnant livestock are principally at risk. Could be tolerated in the long-term depending on Ca: P ratio present and SSF.
> 0.02	Adverse chronic and acute effects (as above) may occur, although short-term exposure could be tolerated depending on feed concentrations of Cd, adequate intake of dietary protein, Ca and P, and according to SSF.

Casey and Meyer (1996b)

Box 2.3 Examples using chloride (Cl), copper (Cu) and fluoride (F) of target water quality range (TWQR, mg/L) differentiated by type of livestock and physiology based on formats of the water quality guidelines (WQG).

Chloride	High incidence					
TWQR mg/L	Effects					
	Sheep	Cattle	Dairy cattle, pregnant and lactating cattle	Ruminants	Monogastrics	Poultry
0-1500	○○○	○○○	○○○	○○○	○○○	○○○
1500-2000	○○○	○○○	○○○	○○○	○○●	○○●
2000-3000	○○○	○○○	○○○	○○○	○●●	●●●
3000-4000	○○●	○○●	○○●	●●●	●●●	●●●
4000-5000	○●●	○●●	●●●	●●●	●●●	●●●
5000-6000	○●●	●●●	●●●	●●●	●●●	●●●
> 6000	●●●	●●●	●●●	●●●	●●●	●●●

Key for Cl

○○○ TWQR. No adverse effects.

○○● Adverse chronic effects such as decreased feed and water intake and a decline in productivity may occur, but are unlikely. Adverse effects that do occur will most likely be temporary and normal production should continue once stock are adapted (see TDS).

○●● Adverse chronic effects such as decreased feed and water Intake, weight loss and a decline in productivity may occur, but will most likely be temporary and normal production should continue once stock are adapted (see TDS).

●●● Adverse chronic (as above) and acute effects such as osmotic disturbances, hypertension, dehydration, renal damage and salt poisoning may occur. May be tolerated for shorter exposure time▼ depending on site-specific factors and adaptation. Stock may subsist under certain conditions, but production will in all likelihood declines (see TDS).

Copper	Medium incidence		
TWQR mg/L	Effects		
	Horses, pigs and poultry	Cattle	Sheep and pre-weaned calves
0-0.5	○○○	○○○	○○○
0.5-1	○○○	○○○	○○●
1-2	○○○	○●●	●●●
2-5	○○○	●●●	●●●
5-10	○●●	●●●	●●●
> 10	●●●	●●●	●●●

Key for Cu

○○○ TWQR No adverse effects.

○○● Adverse chronic effects such as diarrhoea and liver damage may occur, but may be tolerated if there is adequate Mo and S intake, feed concentrations are normal, and exposure is short-term. Could be tolerated in the long-term according to SSF.

○●● Adverse chronic effects (as above) may occur, but are unlikely if there is adequate Mo and S intake, — feed concentrations are normal and exposure is short-term. Could be tolerated in the long-term according to SSF.

●●● Adverse chronic (as above) and acute effects such as liver damage haemolytic jaundice may occur, although short- term exposure could be tolerated according to SSF.

Fluoride	High incidence		
TWQR mg/L	Effects		
	Horses, pigs and poultry	Cattle	Sheep and pre-weaned calves
0-2	○○○	○○○	○○○
2-4	○○○	○○○	○○●
4-6	○○○	○●●	○●●
6-12	○○●	●●●	○●●
> 12	○●●	●●●	○●●

Key for F

○○○ TWQR. No adverse effects.

○○● Adverse chronic effects associated with dental fluorosis in young livestock and skeletal fluorosis In mature livestock such as mottling of teeth and enamel hypoplasia, a decrease in feed and water Intake and a decline in productivity may occur, with continuous long-term exposure, but are unlikely if feed concentrations are normal, and exposure is short-term. Could be tolerated in the long-term according to SSF.

○●● Adverse chronic (as above) and acute effects such as crippling, lameness and weight loss may occur, although short- term exposure could be tolerated according to SSF.

Casey and Meyer (1996b)
These systems are applicable with limitations. The limitations are the additional information derived since these were published in 1996, and the user needs to physically assess the risk based on the WQG values of the TWQR values and the SSF. In order to overcome the second limitation, a computer software system was developed that multi-sourced the interactive biological and environmental parameters and presented an estimate of risk (CIRRA) under a specific set of circumstances. The modelling concepts were designed and described by Meyer (1998) and Casey *et al.,* (1998a, b, c). As noted, the risk associated with a WQC is a multifactorial functional. The programme has become outmoded.

2.8 Methodology: Water quality constituents: sampling and analysis of roof and ground harvested rainwater, groundwater and riverwater
The methodology for taking water samples for analysis of WQC and the methodology for semi-quantitative analysis (SQA) and standard analysis (SA) were conducted as described by Casey *et al.* (1996b) and Meyer *et al.* (2012). The Agricultural Research Council, Institute for Soils, Climate and Water (ARC, ISCW), Pretoria, performed the analyses.

Four sampling sites were selected to represent areas with predominantly summer seasonal rainfall and a long dry winter period (Jericho district, Northern West Province and Ga-Molepane, Limpopo Province) and modest distribution of rain year-round (Port St Johns district, Eastern Cape Province). Table 2.4 shows the names of the sampling sites and sampling schedules.

Water samples taken were RRWH collected via a gutter and piping into water containers; RW either flowing or from a shallow well dug in the riverbed during the dry season; GW from boreholes; and MW where this was available. A sampler introduced ad hoc a category of ground harvested rainwater (GHRnW) that was taken as RRWH.

The SQA and SA analyses included the respective WQC shown in Table 2.3.

Table 2.3 Water quality constituents (WQC) measured by the semi-quantitative analysis and the standards analysis procedures

Semi-quantitative analysis (SQA)	**Standard analysis (SA)**
As	Ca
B	Cl
Ba	F
Be	HCO_3^-
Bi	Na
Br	NO_2^-
Cd	NO_3^-
Co	$S0_4^{2-}$
Cr	
Cs	TDS
Cu	
Hg	
I	
La	

Semi-quantitative analysis (SQA)	Standard analysis (SA)
Li	
Mn	
Mo	
Ni	
Pb	
Pt	
Rb	
Sb	
Se	
Sn	
Sr	
Te	
Ti	
Tl	
U	
V	
W	
Zn	

Table 2.4 Water sampling sites, schedules and water sources

District	Year	Month	Season	Water source				
				RRWH	GHRnW	RW	GW	MW
Jericho, NW (Seasonal rainfall)	2013	Dec.	Early summer (Early rain)	X		X	X	X
	2014	Jan.	Mid-summer			X	X	
	2014	Mar	Early autumn (Accumulated summer rain)	X				
	2014	July	Mid-winter (Dry period)			X	X	
	2014	Dec.	Early summer (Early rain)			X	X	
Ga-Molepane, LP (Seasonal rainfall)	2013	Dec.	Early summer (Early rain)	X				
Port St Johns, EC (Year-round moderate rainfall)	2013	Dec.	Early summer	X	X		X	
	2014	Mar.	Early autumn		X			
	2014	Dec.	Early summer	X		X	X	

2.9 Results and comments: Analyses for water quality constituents in rainwater, groundwater, riverwater and municipal water

The results are from SQA and SA of water from the respective sources. SQA was done on all the samples, but SA was not done in all cases. The results, therefore, in the Jericho district are of both SQA and SA, while those of the other districts do not include SA analysis data. The SQA gives a full range of microelements as WQC, while the SA gives the results for macroelements, NO_3/NO_2 and TDS. This deficiency in the dataset was due to circumstances beyond the control of the research team. A further deficiency in the data is the lack of replicates in the respective districts and over time.

2.10 Interpretation of the results

The results are presented as commentary notes on each WQC analysed by SQA and SA methodologies followed by the relevant tables. The WQC values are compared with the current South African Water Quality Guidelines Volume 1 for Domestic Use (SAWQG Dom, 1996) and the South African Water Quality Guidelines Volume 5 for Agriculture: Livestock Watering (SAWQG Livestock, 1996). In addition, international references are drawn from the Australia (AUS) and New Zealand (NZ) (ANZECC, 1992, NHMRC, NRMMC, 2011), Canada (CAN) (Olkowski, 2009) and the World Health Organisation Guidelines for Drinking Water (WHO, 2011). The discussion includes references to US Environmental Protection Agency (EPA) and the US Agency for Toxic Substances and Disease Registry (ATSDR).

Certain elements, while they may or may not be present in international WQG, do not have guideline values for South African water sources. This fact presents a potential problem in that the SAWQG tend to be stricter than those of other countries; elements that may be within acceptable limits for other countries may be COC or even PHCC in South Africa.

GPS co-ordinates are given where these were recorded.

The following are comments on values of WQC in mg/L, unless noted as µg/L, in GW, RRWH, RW and MW of samples taken from the sources noted on each of the tables. Previously noted, a category of ground harvested rainwater was taken as RRWH. The SAWQG for Domestic Use are interpreted and applied as for human consumption.

The results are direct comparisons of values. No statistical analyses were done on the results owing to the lack of replicates, which limited the estimation of the degree of significant difference between samples.

Arsenic (As)

The SAWGQ NOAEL value for human consumption is 0.1 mg/L, which is higher than that of AUS/NZ (0.01 mg/L) as well as that for livestock in CAN (0.025 mg/L).

RRWH at Jericho (J): As in two samples of RW (0.183 and 0.218 mg/L) was PHCC for human consumption (Table 2.10).

In terms of these results, As is a low incidence WQC.

Barium (Ba)

The SAWQG does not list Ba. Ba at 0-0.46 mg/L (across all measurements) is within recommended AUS/NZ guidelines for human consumption (0.0-2.0 mg/L) with the values obtained from GW being higher than those of RW, which are higher than those of MW.

In terms of these results, Ba is a low incidence WQC.

Bromine (Br)

The SAWQG NOAEL value is 0.01 mg/L, but Br does not appear in the AUS/NZ and CAN WQG. Concentrations exceeding the SAWQG value of 0.01 mg/L were measured in RRWH, GW and MW. GW had the highest value of 0.842 mg/L at Jericho (Table 2.8, 01/2014) and a repeat measure in 12/2014 recorded 1.51 mg/L (Table 2.12). At PSJ, concentrations > 0.01 mg/L were recorded in GW 1.38 mg/L (12/2013) (Table 2.16) and GHRnW as high as 0.915 mg/L (Table 2.16).

In terms of these results, Br occurs at different concentrations in GW in the J and PSJ districts that may exceed the SAWQG value of 0.01 mg /L by 150 times.

Cadmium (Cd)

The SAWQG NOAEL value for Cd is 0.01 mg/L in all livestock. Recorded values exceeding this were in GW (0.0809 mg/L) at PSJ (12/13) (Table 2.16); in RRWH at PSJ up to 0.2567 mg/L Table 2.18), at GM up to 0.1738 mg/L (Table 2.14), in RW at GM 0.1438 mg/L (Table 2.14).

Values > 0.08 mg/L are PHCC for livestock in CAN, and values > 0.01 mg/L are PHCC for livestock in AUS/NZ.

Cd occurred in GW, RW and RRWH. The highest occurrence was in RRWH at values placing Cd as a PHCC.

Calcium (Ca)

The SA and AUS/NZ WQG level for NOAEL for livestock is 1000 mg/L and none of the samples exceeded this value.

Chlorine (Cl)

SAWQG NOAEL for Cl for livestock ranges from 1500 mg/L for monogastric animals and poultry to 3000 mg/L for ruminants, and for humans the TWQR value is 100 mg/L. In the J district (Tables 8 and 13) GW recorded a wide range with the upper end, 257.9-341.24 mg/L, surpassed the standard for humans by magnitudes 2.5 to 3.4 times. GW values at PSJ were 107 mg/L (Table 2.23). These high values place Cl in the PHCC category.

The SAWQG for humans is more stringent than those of AUS/NZ. No WQG for livestock are available from AUS/NZ or CAN.

Chromium (Cr)

The SAWQG NOAEL value for Cr is 1 mg/L in all livestock. None of the sampled sources exceeded 1 mg/L.

In terms of these results, Cr is a low incidence WQC and the levels pose no expected concern.

Copper (Cu)

The SAWQG advises on potential Cu toxicity for livestock according to a range shown in Table 2.5.

Table 2.5 Effects of copper on the health of livestock

Cu range (mg/L)	**Effects**		
	Horses, pigs and poultry	**Cattle**	**Sheep and pre-weaned calves**
0-0.5	NOAEL	NOAEL	NOAEL
0.5-1	NOAEL	NOAEL	*
1-2	NOAEL	*	**
2-5	NOAEL	**	**
5-10	*	**	**
> 10	**	**	**

**May cause mild adverse effects.*

**Acute probability of adverse effects.

In terms of the TWQR values in Table 2.5, none of the sampled sources have values in the category of 5-10 mg/L that may cause mild effects. The AUS/NZ WQG value for Cu as a maximum impurity level in drinking water is 2 mg/L.

Fluoride (F)

SAWQG NOAEL for F for livestock is 2 mg/L and the AUS/NZ WQG 1.5 mg/L. For human consumption, the standard is 1.5 mg/L with mottling of teeth at occurring between > 1.5 to 4 mg/L; severe tooth decay and skeletal effects begin to occur incrementally at > 4 mg/L. The same begins to occur at higher levels in livestock and chronic exposure can result in severe skeletal effects and laminitis in cattle.

In the samples analysed, F occurred only in GW at Jericho at a maximum of 1.155 mg/L (Table 2.7), which was marginally higher than 1 mg/L, the NOAEL level for humans and none greater than 2 mg/L the NOAEL for livestock.

None of the F concentrations are a risk to humans or livestock.

Magnesium (Mg)

The SAWQG NOAEL value for Mg for humans is 30 mg/L for human consumption and 500 mg/L for livestock. RW and GW in the Jericho district recorded 25.66 mg/L (Table 2.12), which may approach a borderline COC for vulnerable humans with gastric disorders.

Manganese (Mn)

The SA and the AUS/NZ WQG NOAEL values for Mn for human consumption is 0.05 mg/L, while the WHO (2011) recommends 0.4 mg/L. It is noted that values > 0.01 may have effects on taste. The SAWQG NOAEL for livestock is 10 mg/L.

The concentrations exceeding the SAWQG values were recorded only in GW at PSJ, namely 0.062 mg/L (Table 2.19), GHRnW 0.2949 mg/L (Table 2.17) and 0.5796 mg/L (Table 2.16), which constitute the category PHCC for human consumption.

Mn occurs primarily in GW in terms of these results and was measured only in the PSJ district.

Mercury (Hg)

The SAWQG NOAEL value for Hg for all livestock is 1 mg/L. Adverse chronic effects may occur at levels > 1 mg/L, with incremental probability of toxicity and related physiological effects ≥ 6 mg/L. The AUS/NZ WQG notes 0.001 mg/L as the maximum impurity level and the CAN WQG lists 0.003 mg/L as the Target Water Quality value for livestock. A discrepancy of magnitude appears between the SAWQG for livestock and for domestic use, and the AUS/NZ and CAN WQG. The SAWQG values are in mg/L given at the wrong concentration, and the AUS and CAN, in µg/L, while the WHO gives the values in µg/L. Standardising to mg/L, the recommended value is 0.001 mg/L. This error in the SAWQG must be corrected.

Concentrations > 0.001 mg/L were recorded in GW and RW with no potentially hazardous levels in RRWH. At Jericho, GW had up to 0.9445 mg/L (Table 2.7) and at PSJ 0.1239 mg/L and 0.6592 mg/L (Table16) and in RW at GM 0.9374 mg/L (Table 2.14). RRWH at GM recorded 0.1838 mg/L (Table 2.14) and GHRnW at PSJ 0.3296 mg/L (Table 2.17) making the element a PHCC to humans at these sources.

Nickel (Ni)

The SAWQG NOAEL for Ni for livestock is 1 mg/L, but may vary according to livestock type. Concentration from 2 to 5 mg/L may have mild effects in pigs, but no effect in other livestock. Concentration ≥ 6 mg/L may begin to cause adverse effects. The AUS/NZ WQG sets 0.02 mg/L for health in humans. The WHO (2011) lists the NOAEL at 0.07 mg/L, while the CAN WQG does not list Ni.

Nitrate/Nitrite (NO_3 / NO_2)

The SAWQG NOAEL value for NO_3 for livestock is 100 mg/L and the AUS/NZ level is 50 mg/L. The SA NOAEL for humans is 6 mg/L with incrementally increasing probability of methaemoglobinaemia occurring in infants. The WHO (2011) guideline value is much higher at 50 mg/L.

GW is the most likely source to contain high levels of NO_3/NO_2. GW samples from Jericho district had levels as high as 35.815 mg/L (Table 2.11), which while not a risk to livestock is a high risk to human infants, being a PHCC. None of the other samples had NO_3/NO_2 levels in the category of COC.

Sodium (Na)

The SAWQG NOAEL value for Na for human consumption is 100 mg/L, the AUS/NZ value is180 mg/L and the CAN value 200 mg/L. The NOAEL value for livestock is 2000 mg/L. GW samples from the Jericho district had high-end values of 114.49 mg/L (Table 2.8) and 123.74 mg/L (Table 2.13), these being COC for human consumption in terms of the SAWQG, but do not pose a risk in terms of the AUS/NZ NOAEL values.

Strontium (Sr)

Strontium does not appear in the WQG, but is a recognised radionuclide associated with industrial activity and the waste of gold mining. Since no values are given, it may be worth recording that Sr occurred in RW of the Jericho district in a range of 0.14-0.949 mg/L (Tables 2.12 and 2.8), which exceeded the level of 0.074 mg/L in MW of the Jericho district (Table 2.7).

The deduction is that Sr occurring in the GW, RW and MW of the Jericho district might be associated with mining activity that would have trace amounts of heavy metals (Pb, Au and U) and isotopes.

Lead (Pb)

None of the values measured in these samples exceeded the guideline levels of 0.01 mg/L.

Table 2.6 Target water quality range (TWQR) of lead (Pb) for livestock noted in the SAWQG

TWQR: Pb range (mg/L)	**Effects**	
	Pigs	All other livestock
0-0.1	NOAEL	NOAEL
0.1-0.2	NOAEL	NOAEL
0.2-0.5	NOAEL	*
0.5-1	NOAEL	*

Zinc (Zn)

The NOAEL for Zn for livestock is 20 mg/L in SA and AUS/NZ WQG, while the Canadian level is 2.5 times higher at 50 mg/L. The SA and WHO (2011) WQG set 3 mg/L as the NOAEL for human consumption in which chronic toxicity may occur at concentrations > 10 mg/L.

In terms of the values recorded in the samples, Zn exceeded 3 mg/L at the following sampling points: RRWH at Jericho ranged from 0.0805 to 4.531 mg/L (Table 2.10), and RRWH at PSJ ranged from 14.85 to 19.65 mg/L (Table 2.22) and GM had a maximum 9.6050 mg/L (Table 2.14).

The high Zn values are associated with RRWH in terms of these results, which may be attributed to Zn-containing roofing material.

Total Dissolved Solids (TDS)

The SAWQG NOAEL value for TDS for livestock is a range according to the type of livestock. The lowest value is ≥ 2000 mg/L for dairy cows, pigs and poultry. In terms of risk to humans, SAWQG NOAEL value is 450 mg/L, while the AUS/NZ level is 600 mg/L.

GW in the Jericho district recorded values 820 mg/L (Table 2.8) and 889 mg/L (Table 2.13) at the same boreholes, placing these water sources in the category of PHCC against the NOAEL value of the SA and AUS/NZ WQG.

Table 2.7 Jericho, December 2013: Water quality constituents (WQC) (mg/L) in groundwater (GW), riverwater (RW) and municipal water (MW)

	Water source			
	GW1	**GW2**	**RW**	**MW**
GPS	S 25° 19.492 E 27° 49.767	S 25° 19.553 E 27° 49.894	S 25° 19.710 E 27° 49.650	House tap
WQC				
As	0.0012	0.0013	0.0015	0.0008
B	0.0053	0.0043	0.0043	0.0018
Ba	0.0590	0.0790	0.1335	0.0113
Be	0.0025	0.0035	0	0
Bi	0	0	0	0
Br (µg/L)	126	329.95	42.475	55
Br (mg/L)	0.1260	0.3300	0.0428	0.0550
Ca	96.405	116.48	32.2	34.455
Cd	0.00004	0.00003	0.0054	0.0005
Cl	77.825	107.57	23.63	25.825
Co	0.0017	0.0003	0.0001	0.0002
Cr	0.0064	0.0037	0.0032	0.0016
Cs	0.00003	0.00003	0.0002	0.00006
Cu	0.0023	0.0001	0.0038	0.0037
F	1.155	1.31	0.58	0.34
HCO_3^-	289.445	346.175	146.705	174.155
Hg (µg)	0.9445	0.4205	0.2195	0.1460
I	0.0370	0.0191	0.0017	0.0098
La	0.00007	0.00005	0.0163	0.000004
Li	0.0037	0.0063	0.0007	0.0017
Mn	0.0209	0.00001	0.0045	0.0456
Mo	0.0015	0.0003	0.0016	0.0008
Na	70.29	89.645	31.64	26.61
Ni	0.0046	0.0028	0.00003	0.0010
NO_2	1.775	0	0	0.52
NO_3	7.695	26.945	9.59	0.86
Pb	0.0006	0.0004	0.0077	0.0042
Pt	0.00003	0.00002	0.0006	0.00002
Rb	0.0020	0.0029	0.0012	0.0048
SO_4	43.56	25.225	21.205	23.305
Sb	0.0002	0.0003	0	0.0001
Se	0.0023	0.0037	0.0875	0.0016
Sn	0	0	0	0
Sr	0.3073	0.4286	0.0604	0.0741
Te	0.000002	0	0.00003	0

	Water source			
	GW1	**GW2**	**RW**	**MW**
GPS	S 25° 19.492 E 27° 49.767	S 25° 19.553 E 27° 49.894	S 25° 19.710 E 27° 49.650	House tap
WQC				
Ti	0.0040	0.0049	0.0003	0.00006
Tl	0.00001	0.000008	0.0073	0.000004
U	0.0032	0.0060	0.00002	0.0001
V	0.0121	0.0127	0.0075	0.0009
W	0.00004	0	0.0015	0
Zn	0.0061	0.0719	0.0043	1.426
TDS	463.28	565.915	208.65	220.425

Table 2.8 Jericho, January 2014: Water quality constituents (WQC) (mg/L) in groundwater (GW) and riverwater (RW)

	Water source					
	***RW**	**GW 1**	**GW 2**	**GW 3**	**RW**	****RW**
GPS	S 25° 20.029 E 27° 48.163	S 25° 19.492 E 27° 49.767	S 25° 19.553 E 27° 49.894	S 25° 19.269 E 27° 49.806	S 25° 19.710 E 27° 49.650	S 25° 19.453 E 27° 49.744
WQC						
As	0.0025	0.0021	0.0027	0.0039	0.0032	0.0026
B	0	0	0.0076	0.0106	0.0138	0
Ba	0.0372	0.0615	0.0749	0.1350	0.0163	0.0215
Be	0.0002	0.000007	0	0	0.000004	0
Bi	0	0	0	0	0	0
Br	0.002	0.134	0.363	0.842	0.090	0.081
Ca	22.27	95.81	118.86	156.26	41.78	42.43
Cd	0.0450	0.0530	0.0430	0.0120	0.001	0
Cl	3.46	78.058	131.27	257.90	46.38	47.43
Co	0.0006	0.0020	0.0003	0.0009	0.0006	0.0007
Cr	0.0071	0.0061	0.0039	0.0047	0.0040	0.0042
Cs	0.0002	0.0001	0.0001	0.00001	0.00004	0.00008
Cu	0.0033	0.0062	0.0015	0.2864	0.0027	0.0025
F	0.27	0.72	1.16	0.66	0.36	0.45
HCO_3	76.86	312.93	353.19	419.68	168.36	163.48
Hg	0	0.0015	0.0011	0.0005	0.0014	0
I	0.0089	0.0374	0.0185	0.0203	0.0064	0.0064
La	0.0044	0.0001	0.00008	0.00008	0.0012	0.0014
Li	0.0024	0.0037	0.0064	0.0084	0.0021	0.0022
Mn	0.0286	0.0473	0.0020	0.0037	0.0201	0.0197
Mo	0.0004	0.0015	0.0002	0.00008	0.0010	0.0010
Na	9.94	70.54	88.60	114.49	59.69	59.80
Ni	0.0095	0.0072	0.0040	0.0094	0.0037	0.0040
NO_2	0.19	18.19	3.44	4.22	0.62	1.13
NO_3	10.38	6.92	24.60	17.01	9.13	9.47
Pb	0.0003	0	0.00006	0.0005	0.00008	0.0001
Pt	0.00001	0.00005	0.00003	0.00005	0.00003	0.00002
Rb	0.0084	0.0025	0.0034	0.0058	0.0090	0.0089
SO_4	6.56	43.34	23.44	20.32	38.09	38.26
Sb	0.0003	0.0001	0.0002	0.0002	0.0004	0.0004
Se	0.0006	0.0003	0.0040	0.0081	0.0017	0.0012
Sn	0	0	0	0	0	0
Sr	0.949	0.3109	0.4497	0.6912	0.1329	0.1322

Te	0	0	0	0	0	0
Ti	0.1146	0.0043	0.0051	0.0069	0.0171	0.0219
Tl	0.00004	0.00003	0.00002	0.00001	0.00002	0.00001
U	0.0002	0.0031	0.0056	0.0085	0.0005	0.0005
V	5.972	12.19	12.97	16.86	8.319	8.651
W	0	0	0	0	0	0
Zn	0.0053	0.0034	0.0753	0.0477	0.0022	0.0028
TDS	104.57	492.54	593.41	820.16	306.82	307.26

*RW from well in riverbed.

**RW from an irrigation pipe pumped from the river.

Table 2.9 Jericho, January 2014: Water quality constituents (WQC) (mg/L) in rooftop harvested rainwater (RRWH)

Jericho 01/2014 RRWH										
	J4.1	**J4. 2**	**J4. 3**	**J4.4**	**J4.5**	**J4.6**	**J4.7**	**J4.8**	**J4.9**	**J4. 10**
Analysis: SQA										
As	0.0007	0.0003	0.0007	0.0001	0.0004	0.0003	0	0.0002	0.0004	0.0002
B	0	0	0	0	0	0	0	0	0	0
Ba	0	0	0	0	0	0	0	0	0	0
Be	0	0	0	0	0	0	0	0	0	0
Bi	0	0	0	0	0	0	0	0	0	0
Br	0	0	0	0	0	0	0	0	0	0
Cd	0	0.0001	0.0002	0.0001	0.0001	0	0	0	0	0.0001
Co	0.0005	0.0001	0	0	0	0.0001	0	0	0	0
Cr	0	0	0	0	0	0	0	0	0	0
Cs	0	0	0	0	0	0	0	0	0	0
Cu	0.0047	0	0.0216	0.0013	0.0031	0	0.0047	0.001	0.0128	0.0031
Hg	0	0	0	0	0	0	0	0	0	0
I	0	0.0274	0.0037	0	0	0.0016	0	0	0	0
La	0	0	0	0	0	0	0	0	0	0
Li	0	0	0	0	0	0.0014	0	0	0	0
Mn	0.0221	0	0	0	0	0	0	0	0	0
Mo	0	0	0	0	0	0.0003	0	0	0	0
Ni	0	0	0	0	0	0	0	0	0	0
Pb	0.0002	0	0.0001	0	0	0	0	0	0	0
Pt	0	0	0	0	0	0	0	0	0	0
Rb	0.0004	0	0	0.0001	0.0003	0.0019	0	0	0	0
Sb	0	0	0.0002	0	0	0.0003	0	0.0003	0	0.0003
Se	0.002	0.002	0.0027	0.002	0.0017	0.0014	0.0013	0.0017	0.002	0.0013
Sn	0	0	0	0	0	0	0	0	0	0
Sr	0.0031	0.0016	0.0013	0.0035	0.0038	0.0315	0.0007	0.0015	0.0009	0.0013
Te	0	0	0	0	0	0	0	0	0	0
Ti	0	0	0	0	0	0	0	0	0	0
TI	0	0	0	0	0	0	0	0	0	0
U	0	0	0	0	0	0	0	0	0	0
V	0	0	0	0	0	0.0009	0	0	0	0
W	0	0	0.0003	0	0	0	0	0	0	0
Zn	1.797	1.68	1.126	2.131	2.899	1.437	2.338	2.357	2.232	2.312
Analysis: SA	Not analysed									

Note: more than 3 decimal places before a significant number were rounded to zero.

Table 2.10 Jericho, March 2014: Water quality constituents (WQC) (mg/L) in rooftop harvested rainwater (RRWH)

Jericho: RRWH										
	J1	**J 2**	**J 3**	**J4**	**J5**	**J6**	**J7**	**J8**	**J9**	**J 10**
Analysis: SQA										
As	0.0004	0	0	0	0.183	0	0	0	0	0.218
B	0	0	0	0	0	0	0	0	0	0
Ba	0	0	0	0	0.0281	0	0.0003	0	0	0.0349
Be	0	0	0	0	0	0	0	0	0	0
Bi	0	0	0	0	0	0	0	0	0	0
Br	0.0094	0.0046	0	0	0.0773	0	0	0	0	0.1107
Cd	0	0	0.0002	0	0	0	0.0002	0	0	0
Co	0	0	0.0002	0	0.0001	0.0001	0	0	0	0.0002
Cr	0.0015	0.0003	0.0003	0	0.0001	0	0	0	0	0.0017
Cs	0	0	0	0	0	0	0	0	0	0
Cu	0.015	0.0128	0.2455	0.0014	0.0016	0.012	0.0002	0	0.0005	0.0004
Hg	0.0003	0.0002	0	0	0	0	0	0	0	0
I	0.0009	0.0015	0.0008	0	0.0024	0	0.0031	0.0292	0.0015	0.006
La	0	0	0.0002	0	0	0	0	0	0	0
Li	0.0002	0.0002	0	0	0.0013	0	0.0001	0.00049	0	0.0015
Mn	0	0	0.0228	0	0	0	0	0	0	0
Mo	0	0	0	0	0	0	0	0	0	0
Ni	0	0	0	0	0	0	0	0	0	0
Pb	0.0003	0	0.0311	0	0.0006	0	0	0	0	0
Pt	0	0	0	0	0	0	0	0	0	0
Rb	0	0.0004	0.0004	0	0.0008	0	0	0.0008	0	0.0009
Sb	0.0001	0	0.0002	0.0004	0.0001	0.0008	0	0	0	0.001
Se	0.0005	0	0	0.0002	0.001	0	0.0003	0	0	0.001
Sn	0	0	0	0	0	0	0	0	0	0
Sr	0.0024	0.0118	0.0044	0.0023	0.0899	0.0033	0.0017	0.0013	0.006	0.1093
Te	0	0	0	0	0	0	0	0	0	0
Ti	0	0	0.0003	0	0.0007	0	0	0	0	0.0008
TI	0	0	0	0	0	0	0	0	0	0
U	0	0	0	0	0.0005	0	0	0	0	0.0013
V	0.0004	0.0006	0.0005	0.0002	0.0023	0	0	0	0	0.0037
W	0	0	0	0	0	0	0	0	0	0
Zn	0.5373	0.0805	4.531	2.703	0.9501	2.891	2.819	2.091	1.856	0.451
Analysis: SA	Not analysed									

Note: more than 3 decimal places before a significant number was rounded to zero

Table 2.11 Jericho, July 2014: Water quality constituents (WQC) (mg/L) in groundwater (GW), and riverwater (RW)

	GW1	GW2	GW3	RW
As	0.0012	0.0012	0.0023	0.0009
B	0.0082	0.0056	0.0072	0.0066
Ba	0.2554	0.2193	0.4645	0.0571
Be	0	0	0	0
Bi	0.0014	0.0014	0.0015	0.0014
Br	0.4886	0.4063	1.19	0.1501
Ca	102.155	84.18	129.305	38.735
Cd	0	0.0002	0	0
Cl	92.71	64.865	161.04	38.395
Co	0.0009	0.0003	0.0003	0.0004
Cr	0.011	0.0069	0.0077	0.0061
Cs	0	0	0	0
Cu	0.0008	0.0131	0.0062	0.0024
F	0.6	0.955	0.71	0.455
HCO_3	0	0	0	0
Hg	0	0	0	0
I	0.0229	0.0152	0.0219	0.0039
La	0	0	0	0.0002
Li	0.0046	0.0071	0.0091	0.0028
Mn	0.0142	0.0005	0.0006	0.0075
Mo	0.0012	0.0004	0	0.0009
Na	82.125	64.36	91.825	54.445
Ni	0.0034	0.0028	0.0035	0.0042
NO_2	0	0	0	0
NO_3	35.815	26.085	19.835	27.53
Pb	0	0	0	0
Pt	0	0	0	0
Rb	0.0029	0.0027	0.0056	0.0079
Sb	0	0	0.0001	0.0005
Se	0.0046	0.0033	0.0089	0.0012
Sn	0.0017	0.0017	0.0019	0.0018
SO_4	40.505	22.815	22.45	51.65
Sr	0.4233	0.43	0.0219	0.1626
Tc	0	0	0	0
Ti	0.0044	0.005	0.0067	0.0095
TI	0	0	0	0.0055
U	0.0045	0.0046	0.0085	0.0007
V	0.0112	0.0112	0.0151	0.0052
W	0	0	0	0.0012
Zn	0.0131	0.3176	0.0403	0
TDS	536.85	434.365	655.05	322.01

Note: more than 3 decimal places before a significant number was rounded to zero

Table 2.12 Jericho, December 2014: Water quality constituents (WQC) (mg/L) in groundwater (GW) and riverwater (RW)

WQC	RW	GW1	GW2
As	0.001	0	0
B	0.04	0.03	0.04
Ba	0.043	0.19	0.385
Be	0	0	0
Bi	0	0	0
Br	0.146	0.558	1.517
Ca	38.08	90.13	138.53
Cd	0	0	0
Cl	72.86	146.5	341.24
Co	0	0	0
CO_3	0	0	0
Cr	0.001	0	0
Cs	0	0	0
Cu	0.001	0.003	0.001
F	0.76	1.12	0.69
HCO_3	209.23	328.18	413.58
Hg	0	0	0.001
K	11.53	5.15	9.35
La	0	0	0
Li	0.003	0.007	0.008
Mg	14.95	15.48	25.66
Mn	0	0	0
Mo	0.001	0	0
NO_3	0.71	0.36	0
Na	74.18	87.41	123.74
Ni	0	0	0
NO_3	1.01	18.68	18.27
Pb	0.001	0.001	0.001
PO_4	8.62	0	0
Pt	0	0	0
Rb	0.006	0.001	0.003
Sb	0	0	0
Se	0	0.003	0.004
Sn	0	0	0
SO_4	48.62	24.04	25.06
Sr	0.14	0.412	0.641
TDS	375.39	552.91	889.21
Te	0	0	0
Ti	0.003	0.003	0.003
Tl	0	0	0
U	0	0.002	0.004
V	0.007	0.009	0.011
W	0	0	0
Zn	0.025	0.148	0.015

Table 2.13. Jericho, December 2014: Water quality constituents (WQC) (mg/L) in groundwater (GW) and riverwater (RW)

WQC	RW	GW	GW
B	0.04	0.03	0.04
Ca	38.08	90.13	138.53
Cl	72.86	146.5	341.24
CO_3	0	0	0
F	0.76	1.12	0.69
HCO_3	209.23	328.18	413.58
K	11.53	5.15	9.35
Mg	14.95	15.48	25.66
NO_3	0.71	0.36	0
Na	74.18	87.41	123.74
NO_3	1.01	18.68	18.27
PO_4	8.62	0	0
SO_4	48.62	24.04	25.06
TDS	375.39	552.91	889.21

Table 2.14 Ga-Molepane, December, 2013: Water quality constituents (WQC) (mg/L) in rooftop harvested rainwater (RRWH) collected in Ferro-concrete tanks (F tanks) and plastic tanks (P tanks) and riverwater (RW)

WQC mg/L	RRWH			F tanks			P tanks			RW
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	
As	0.0005	0.0000	0.0001	0.0003	0.0000	0.0001	0.0005	0.0000	0.0002	0.0008
B	0.0835	0.0082	0.0448	0.0772	0.0170	0.0390	0.0835	0.0082	0.0506	-
Ba	0.0376	0.0000	0.0117	0.0285	0.0000	0.0138	0.0376	0.0000	0.0096	0.0097
Be	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	-
Bi	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-
Br	0.0645	0.0038	0.0159	0.0546	0.0041	0.0184	0.0645	0.0038	0.0135	0.0321
Cd	0.1738	0.0020	0.0632	0.1139	0.0170	0.0484	0.1738	0.0020	0.0779	0.1438
Co	0.0010	0.0000	0.0002	0.0010	0.0000	0.0002	0.0004	0.0000	0.0001	0.0005
Cr	0.0222	0.0005	0.0025	0.0222	0.0006	0.0036	0.0030	0.0005	0.0014	0.0049
Cs	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	-
Cu	0.0505	0.0001	0.0116	0.0505	0.0001	0.0141	0.0221	0.0007	0.0091	0.0047
Hg	0.1838	0.0000	0.0102	0.0000	0.0000	0.0000	0.1838	0.0000	0.0204	0.9374
I	0.0013	0.0000	0.0005	0.0009	0.0000	0.0004	0.0013	0.0000	0.0006	0.0045
La	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
Li	0.0111	0.0003	0.0042	0.0103	0.0003	0.0050	0.0111	0.0005	0.0035	0.0007
Mn	0.0226	0.0001	0.0054	0.0099	0.0005	0.0039	0.0226	0.0001	0.0069	0.0027
Mo	0.0004	0.0000	0.0001	0.0004	0.0000	0.0001	0.0003	0.0000	0.0001	0.0002
Ni	0.0195	0.0000	0.0018	0.0195	0.0000	0.0024	0.0067	0.0000	0.0012	0.0256
Pb	0.0041	0.0000	0.0010	0.0041	0.0000	0.0012	0.0041	0.0001	0.0009	0.0003
Pt	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	-
Rb	0.0023	0.0002	0.0009	0.0023	0.0003	0.0010	0.0012	0.0002	0.0007	0.0017
Sb	0.0003	0.0000	0.0001	0.0002	0.0000	0.0001	0.0003	0.0000	0.0001	0.0003
Se	0.0010	0.0000	0.0002	0.0009	0.0000	0.0002	0.0010	0.0000	0.0002	0.0009
Sn	0.0008	0.0000	0.0001	0.0008	0.0000	0.0001	0.0007	0.0000	0.0001	-
Sr	0.0539	0.0019	0.0156	0.0462	0.0019	0.0167	0.0539	0.0019	0.0145	0.0991
Ti	0.0029	0.0000	0.0011	0.0021	0.0000	0.0008	0.0029	0.0002	0.0014	0.0055
Tl	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-
U	0.0003	0.0000	0.0001	0.0003	0.0000	0.0001	0.0003	0.0000	0.0000	0.0004
V	0.0048	0.0001	0.0016	0.0048	0.0002	0.0023	0.0023	0.0001	0.0008	0.0233

WQC mg/L	RRWH			F tanks			P tanks			RW
W	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0005
Zn	9.6050	0.6462	2.7138	3.8706	0.6462	1.8133	9.6050	0.8920	3.6143	0.0001

Table 2.15 Ga-Molepane, December 2013: Water quality constituents (WQC) (mg/L) in rooftop harvested rainwater (RRWH)

WQC mg/L	RRWH		
	Min	Max	Mean
As	-	0.0002	0.0001
B	0.0099	0.0716	0.0308
Ba	-	0.0264	0.0062
Be	-	0.0001	0.0000
Bi	-	0.0019	0.0002
Br	0.0029	0.0075	0.0046
Cd	-	0.4695	0.0599
Co	0.0000	0.0010	0.0002
Cr	0.0002	0.0064	0.0043
Cs	-	0.0001	0.0000
Cu	-	0.0005	0.0002
Hg	-	-	-
I	0.0002	0.0006	0.0003
La	-	0.0008	0.0001
Li	0.0004	0.0043	0.0029
Mn	0.0001	0.0468	0.0053
Mo	-	0.0003	0.0001
Ni	-	0.1051	0.0122
Pb	0.0001	0.0078	0.0011
Pt	-	0.0000	0.0000
Rb	0.0001	0.0028	0.0017
Sb	0.0001	0.0002	0.0001
Se	-	0.0002	0.0000
Sn	-	0.0008	0.0001
Sr	0.0033	0.0204	0.0147
Ti	-	0.0031	0.0011
Tl	-	-	-
U	-	0.0001	0.0000
V	0.0002	0.0068	0.0045
W	-	0.0001	0.0000
Zn	-	0.0698	0.0160

Table 2.16 Port St Johns, December 2013: Water quality constituents (WQC) in ground harvested rainwater (GHRnW), rooftop harvested rainwater (RRWH) and groundwater (GW)

WQC mg/L	GHRnW			RRWH			GW
	Min	Max	Mean	Min	Max	Mean	
As	0.0082	0.0160	0.0109	-	0.0003	0.0001	0.0034
B	0.0011	0.0284	0.0144	0.0115	0.0649	0.0421	0.0033
Ba	-	0.0170	0.0079	-	0.0176	0.0025	0.1241
Be	0.0001	0.0002	0.0001	-	0.0001	0.0000	-
Bi	-	-	-	-	-	-	-
Br	0.0082	0.9148	0.4286	0.0071	0.0142	0.0104	1.3804
Cd	-	0.0220	0.0055	0.0020	0.1888	0.0573	0.0809
Co	0.0003	0.0035	0.0013	-	0.0011	0.0002	0.0004
Cr	0.0013	0.0060	0.0039	0.0002	0.0011	0.0005	0.0101
Cs	0.0000	0.0006	0.0003	0.0000	0.0002	0.0000	0.0002
Cu	0.0027	0.0048	0.0042	0.0000	0.0175	0.0033	0.0132
Hg	-	0.6592	0.1648	-	0.0030	0.0003	0.1239
I	0.0004	0.0150	0.0048	-	0.0018	0.0005	0.0166
La	0.0008	0.0016	0.0014	-	0.0010	0.0001	0.0000
Li	0.0014	0.0020	0.0017	0.0003	0.0009	0.0005	0.0067
Mn	0.0088	0.5796	0.1523	0.0009	0.0046	0.0020	-
Mo	0.0002	0.0026	0.0011	-	0.0001	0.0000	0.0007
Ni	-	0.0023	0.0016	-	0.0686	0.0097	0.0030
Pb	0.0005	0.0013	0.0008	0.0001	0.0064	0.0015	0.0000
Pt	-	0.0000	0.0000	-	0.0002	0.0000	-
Rb	0.0018	0.0092	0.0064	-	0.0008	0.0003	0.0028
Sb	0.0000	0.0001	0.0001	0.0000	0.0010	0.0003	0.0000
Se	0.0001	0.0067	0.0030	-	0.0009	0.0002	0.0122
Sn	-	-	-	-	0.0017	0.0003	-
Sr	0.0172	0.0961	0.0486	0.0011	0.0050	0.0024	0.4165
Ti	0.0050	0.0654	0.0383	-	0.0021	0.0008	0.0046
Tl	0.0000	0.0001	0.0000	-	0.0000	0.0000	0.0000
U	0.0001	0.0003	0.0002	-	0.0000	0.0000	0.0054
V	0.0012	0.0048	0.0037	0.0001	0.0005	0.0002	0.0108
W	-	-	-	-	0.0005	0.0001	-
Zn	0.0692	0.1313	0.1007	0.4493	4.0454	2.4614	0.0706

Table 2.17 Port St Johns, March 2014: Water quality constituents (WQC) (mg/L) in ground harvested rainwater (GHRnW) analysed by semi-quantitative analysis (SQA).

WQC mg/L	**GHRnW**		
	Min	Max	Mean
As	0.0004	0.0097	0.0063
B	-	0.0147	0.0083
Ba	0.0035	0.0087	0.0068
Be	0.0001	0.0001	0.0001
Bi	-	-	-
Br	0.1933	0.4843	0.3780
Cd	0.0081	0.0130	0.0107
Co	0.0005	0.0020	0.0012
Cr	0.0016	0.0036	0.0029
Cs	0.0001	0.0003	0.0003
Cu	0.0015	0.0047	0.0033
Hg	-	0.3296	0.1648
I	0.0018	0.0087	0.0051
La	0.0005	0.0016	0.0011
Li	0.0016	0.0020	0.0018
Mn	0.0138	0.2949	0.1539
Mo	-	0.0017	0.0009
Ni	0.0016	0.0021	0.0018
Pb	0.0002	0.0011	0.0007
Pt	0.0000	0.0000	0.0000
Rb	0.0028	0.0073	0.0053
Sb	0.0001	0.0002	0.0001
Se	0.0006	0.0034	0.0024
Sn	-	-	-
Sr	0.0069	0.0680	0.0390
Ti	0.0161	0.0415	0.0319
Tl	0.0000	0.0001	0.0000
U	0.0002	0.0002	0.0002
V	0.0017	0.0044	0.0031
W	-	-	-
Zn	0.0043	0.1019	0.0644

Table 2.18 Port St Johns, March 2014: Water quality constituents (WQC) (mg/L) in rooftop harvested rainwater (RRWH)

WQC mg/L	RRWH 1			RRWH 2		
	Min	Max	Min	Min	Max	Min
As	-	0.0016	0.0005	-	0.0010	0.0004
B	-	0.0097	0.0024	-	0.0770	0.0186
Ba	-	0.0126	0.0013	-	0.0433	0.0106
Be	-	0.0000	0.0000	-	0.0004	0.0001
Bi	-	-	-	-	-	-
Br	0.1787	0.6256	0.3178	0.0147	0.3939	0.1676
Cd	-	0.2567	0.0652	-	0.0120	0.0019
Co	0.0000	0.0008	0.0001	0.0000	0.0012	0.0004
Cr	-	0.0009	0.0003	0.0001	0.0074	0.0027
Cs	-	0.0001	0.0000	-	0.0004	0.0001
Cu	0.0001	0.0477	0.0053	-	0.0059	0.0016
Hg	-	-	-	-	0.1568	0.0157
I	-	0.0005	0.0000	-	0.0091	0.0018
La	-	0.0006	0.0000	-	0.0102	0.0020
Li	0.0000	0.0002	0.0001	0.0009	0.0045	0.0018
Mn	-	0.0432	0.0046	-	0.0497	0.0115
Mo	-	0.0003	0.0000	-	0.0006	0.0001
Ni	-	0.0063	0.0010	-	0.0048	0.0013
Pb	-	0.0179	0.0017	-	0.0028	0.0007
Pt	-	0.0000	0.0000	-	0.0000	0.0000
Rb	-	0.0007	0.0002	0.0005	0.0070	0.0023
Sb	0.0000	0.0009	0.0002	-	0.0008	0.0001
Se	-	0.0040	0.0018	-	0.0015	0.0007
Sn	-	-	-	-	-	-
Sr	0.0008	0.0049	0.0028	0.0068	0.1543	0.0618
Ti	-	0.0009	0.0001	0.0019	0.2462	0.0321
Tl	-	0.0000	0.0000	-	0.0001	0.0000
U	-	0.0000	0.0000	-	0.0011	0.0003
V	0.0001	0.0011	0.0004	0.0004	0.0082	0.0034
W	-	-	-	-	0.0000	0.0000
Zn	1.0967	3.8896	2.2723	0.0000	0.0270	0.0098

Table 2.19 Port St Johns, December 2014: Water quality constituents (WQC) (mg/L) in groundwater (GW)

WQC	EC3-GW1	EC3-GW2	EC3-GW3	EC3-GW4	EC3-GW5	EC3-GW6
As	0.002	0.002	0.001	0.002	0	0
Ba	0.017	0.005	0.021	0.019	0.012	0.012
Be	0	0	0	0	0	0
Bi	0	0	0	0	0	0
Br	0.235	0.243	0.371	0.341	0.064	0.055
Cd	0	0	0	0	0	0
Co	0.001	0.001	0	0	0	0
Cr	0.001	0.001	0.003	0.002	0	0
Cs	0	0	0	0	0	0
Cu	0.004	0.003	0.003	0.003	0	0.001
Hg	0.001	0.001	0.001	0	0.001	0
La	0	0	0.001	0	0	0
Li	0.001	0	0.004	0.004	0.002	0.002
Mn	0.062	0.009	0.006	0.006	0.004	0.001
Mo	0.002	0.001	0.001	0.001	0.004	0
Ni	0	0	0	0	0	0
Pb	0.001	0.002	0.003	0.002	0.001	0.001
Pt	0	0	0	0	0	0
Rb	0.002	0.002	0.002	0.002	0.001	0.001
Sb	0	0	0	0	0	0
Se	0.001	0.002	0.002	0.001	0	0
Sn	0	0	0	0	0	0
Sr	0.028	0.027	0.031	0.029	0.003	0.003
Te	0	0	0	0	0	0
Ti	0.011	0.009	0.058	0.056	0.006	0.005
Tl	0	0	0	0	0	0
U	0	0	0	0	0	0
V	0.002	0.001	0.004	0.005	0	0
W	0	0	0	0	0	0
Zn	0.044	0.022	0.026	0.017	0.015	0.02

Table 2.20 Port St Johns, December 2014: Water quality constituents (WQC) (mg/L) in rooftop harvested rainwater (RRWH)

WQC	EC3-RRWH 2	EC3-RRWH 4	EC3-RRWH 4	EC3-RRWH 6	EC3-RRWH 7	EC3-RRWH 8	EC3-RRWH 9	EC3-RRWH 10	EC3-RRWH 11	EC3-RRWH 14
As	0	0	0	0	0	0	0	0	0	0
Ba	0.002	0.001	0.001	0.002	0	0.001	0.002	0.002	0.001	0.001
Be	0	0	0	0	0	0	0	0	0	0
Bi	0	0	0	0	0	0	0	0	0	0
Br	0.02	0.016	0.016	0.012	0.016	0.013	0.018	0.02	0.015	0.014
Cd	0	0	0	0	0	0	0	0	0	0
Co	0	0	0	0	0	0	0	0	0	0
Cr	0	0	0	0	0	0	0	0	0	0
Cs	0	0	0	0	0	0	0	0	0	0
Cu	0.005	0	0	0.002	0.001	0.001	0.001	0.001	0.001	0.001
Hg	0	0	0	0	0	0	0	0	0	0
La	0	0	0	0	0	0	0	0	0	0
Li	0	0	0	0	0	0	0	0	0	0
Mn	0	0.003	0.003	0.004	0.003	0	0.003	0.003	0	0.005
Mo	0	0	0	0	0	0	0	0	0	0
Ni	0	0	0	0	0	0	0	0	0	0
Pb	0.002	0.001	0.001	0.004	0.001	0.001	0.001	0.001	0.001	0.001
Pt	0	0	0	0	0	0	0	0	0	0
Rb	0	0	0	0	0	0	0	0	0	0
Sb	0	0	0	0	0	0	0	0	0	0
Se	0	0	0.002	0.001	0	0	0	0	0	0.001
Sn	0	0	0	0	0	0	0	0	0	0.001
Sr	0.002	0.001	0.002	0.001	0.002	0.004	0.004	0.004	0.004	0.001
Te	0	0	0	0	0	0	0	0	0	0
Ti	0	0	0	0	0	0	0.001	0.001	0	0
Tl	0	0	0	0	0	0	0	0	0	0
U	0	0	0	0	0	0	0	0	0	0
V	0	0	0	0	0	0	0	0	0	0
W	0	0	0	0	0	0	0	0	0	0
Zn	4.252	4.29	4.616	5.916	4.864	0.719	3.364	3.188	0.705	5.376

Table 2.21 Port St Johns, December 2014: Water quality constituents (WQC) (mg/L) in riverwater (RW)

WQC	EC3-RW1	EC3-RW2	EC3-RW3	EC3-RW8	EC3-RW9	EC3-RW10
As	0.001	0.002	0	0	0	0
Ba	0.149	0.163	0.003	0.003	0.001	0.001
Be	0.001	0.001	0	0	0	0
Bi	0	0	0	0	0	0
Br	0.0293	0.032	0.03	0.03	0.01	0.01
Cd	0	0	0	0	0	0
Co	0.002	0.001	0	0	0	0
Cr	0.014	0.016	0	0	0	0
Cs	0	0.001	0	0	0	0
Cu	0.028	0.031	0	0	0	0
Hg	0.001	0.001	0	0	0	0
La	0.005	0.005	0	0	0	0
Li	0.011	0.012	0.001	0.001	0	0
Mn	0.039	0.045	0	0	0.002	0.002
Mo	0.002	0.001	0	0	0	0
Ni	0	0	0	0	0	0
Pb	0.01	0.011	0.001	0.001	0.001	0.001
Pt	0	0	0	0	0	0
Rb	0.016	0.018	0	0	0	0
Sb	0	0	0	0	0	0
Se	0.001	0.002	0.001	0	0	0
Sn	0.002	0.001	0	0	0	0
Sr	0.025	0.026	0.007	0.007	0.001	0.001
Te	0	0	0	0	0	0
Ti	0.643	0.761	0.002	0.001	0	0.004
Tl	0	0	0	0	0	0
U	0	0	0	0	0	0
V	0.027	0.032	0.001	0.001	0	0
W	0.001	0.001	0	0	0	0
Zn	4.922	5.387	0.016	0.01	4.913	5.339

Table 2.22 Port St Johns, December 2014: Water quality constituents (WQC) (mg/L) in roof-harvested rainwater (RRWH)

WQC	EC3-RRWH 18	EC3-RRWH 19	EC3-RRWH 20	EC3-RRWH 21	EC3-RRWH 22	EC3-RRWH 23	EC3-RRWH 24	EC3-RRWH 25	EC3-RRWH 26	EC3-RRWH 27
As	0.001	0	0	0	0	0	0	0	0.001	0
Ba	0.049	0.005	0.011	0.003	0.007	0.002	0	0.013	0.013	0.011
Be	0.001	0	0	0	0	0	0	0	0	0
Bi	0	0	0	0	0	0	0	0	0	0
Br	0.09	0.025	0.019	0.011	0.013	0.006	0.008	0.01	0.01	0.008
Cd	0	0	0	0	0.001	0	0	0.001	0.001	0
Co	0	0	0	0	0	0	0	0	0	0
Cr	0.008	0	0.001	0	0	0	0	0	0	0
Cs	0	0	0	0	0	0	0	0	0	0
Cu	0.006	0	0.002	0.003	0	0	0.004	0	0	0
Hg	0.001	0	0	0	0	0	0	0	0	0
La	0.004	0	0	0	0	0	0	0	0	0
Li	0.005	0	0	0	0	0	0	0	0	0
Mn	0.01	0.014	0.054	0.009	0.026	0.011	0.009	0.007	0.007	0.006
Mo	0	0	0	0	0	0	0	0	0	0
Ni	0	0	0	0	0	0	0	0	0	0

WQC	EC3-RRWH 18	EC3-RRWH 19	EC3-RRWH 20	EC3-RRWH 21	EC3-RRWH 22	EC3-RRWH 23	EC3-RRWH 24	EC3-RRWH 25	EC3-RRWH 26	EC3-RRWH 27
Pb	0.007	0.002	0.001	0.018	0.001	0.001	0.001	0.001	0.001	0.001
Pt	0	0	0	0	0	0	0	0	0	0
Rb	0.005	0	0.001	0	0	0	0	0	0	0
Sb	0	0	0	0	0	0	0.001	0.001	0.001	0.001
Se	0.001	0	0	0.001	0	0.001	0	0	0	0.001
Sn	0	0	0	0	0	0	0	0	0	0
Sr	0.014	0.003	0.006	0.002	0.005	0.002	0.001	0.01	0.01	0.008
Te	0	0	0	0	0	0	0	0	0	0
Ti	0.184	0	0.006	0	0	0	0	0.003	0	0
Tl	0	0	0	0	0	0	0	0	0	0
U	0	0	0	0	0	0	0	0	0	0
V	0.007	0.001	0.001	0.001	0	0.001	0.001	0	0	0
W	0	0	0	0	0	0	0	0	0	0
Zn	4.456	17.696	17.151	15.228	19.648	8.552	8.879	16.795	16.952	14.846

Table 2.23 Port St Johns, December 2014: Water quality constituents (WQC) (mg/L) in groundwater (GW)

WQC	EC3-GW1	EC3-GW2	EC3-GW3	EC3-GW4	EC3-GW5	EC3-GW6
B	0.07	0.06	0.05	0.05	0.03	0.02
Ca	11.68	11.8	8.87	8.86	4.36	4.34
Cl	60.81	62.06	106.5	107.03	17.7	17.81
CO_3	0	0	0	0	0	0
F	0.26	0.38	0.42	0.62	0.08	0.07
HCO_3	54.29	55.51	73.2	69.54	11.59	11.59
K	15.88	15.88	1.67	1.8	0.68	0.47
Mg	6.4	6.61	8.75	8.82	2.25	1.99
NO_2	0.28	0.25	0	0	0.16	0.09
NO_3	0.2	0.21	0.23	0.4	1.18	1.21
Na	27.24	27.09	69.66	69.88	10.47	9.78
PO_4	0	0	0.28	0	0	0
SO_4	5.06	4.96	6.41	6.13	4.01	3.74
TDS	154.86	156.25	239.4	238.23	46.21	45.21

Table 2.24 Port St Johns, December 2014: Water quality constituents (WQC) (mg/L) in rooftop harvested rainwater (RRWH)

WQC	EC3-RRWH	EC3-RRWH	EC3-RRWH	EC3-RRWH	EC3-RRWH	EC3-RRWH	EC3-RRWH	EC3-RRWH	EC3-RRWH	EC3-RRWH
B	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02
Ca	4.4	4.7	4.73	4.72	4.68	7.46	6.61	6.93	7.86	4.74
Cl	5.11	5.24	5.17	3.4	5.04	3.96	6.22	6.37	4.13	4.51
CO_3	0	0	0	0	0	0	0	0	0	0
F	0.06	0.11	0.19	0.13	0.12	0.08	0.1	0.1	0.12	0.1
HCO_3	10.98	13.42	13.42	13.42	12.2	17.69	15.86	16.47	18.3	14.64
K	0.51	0.46	0.35	0.51	0.44	0.36	0.75	0.82	0.41	0.57
Mg	1.49	1.41	1.42	1.36	1.49	1.76	1.78	1.76	1.85	1.45
NO_3	0.05	0.1	0.05	0.08	0.06	0.05	0.14	0.11	0.1	0.05
NO_4	1.71	1.66	1.09	2.13	2.1	2.38	2.41	2.59	2.59	1.56
Na	2.64	2.71	2.78	1.93	2.78	2.34	3.37	3.37	2.42	2.4
PO_4	0	0	0.52	0	0	0	0	0	0	0
SO_4	1.7	2.24	1.62	2.43	1.74	2.2	1.95	2.08	2.33	2.42
TDS	22.51	25.29	24.29	23.29	23.9	29.16	31.07	31.77	30.85	24.68

Table 2.25 Port St Johns, December 2014: WQC (mg/L) of riverwater (RW) samples analysed by semi-quantitative (SQA) and standards analysis (SA)

WQC	EC3-RW	EC3-RW	EC3-RW	EC3-RW	EC3-RW	EC3-RW
B	0.02	0.02	0.02	0.02	0.04	0.04
Ca	8.06	8.01	4.54	4.7	11.54	11.47
Cl	12.4	12.13	3.33	3.33	9.17	9.18
CO_3	0	0	0	0	43.92	0
F	0.08	0.1	0.2	0.15	0.16	0.16
HCO_3	34.16	34.77	14.64	14.64	60.15	42.7
K	0.36	0.16	0.44	0.48	7.08	7.88
Mg	4.93	5.04	1.48	1.39	5.49	5.64
NO_2	0.06	0.13	0.05	0.07	0.16	0.09
NO_3	0.05	0.12	1.1	1.02	3.74	3.18
Na	8.64	8.81	1.97	2.28	5.43	5.38
PO_4	0	0	0	0.44	0	0
SO_4	2.41	2.33	1.42	1.46	0	3.06
TDS	53.92	53.62	21.68	21.68	67.04	67.65

Table 2.26 Port St Johns, December 2014: WQC (mg/L) of rooftop harvested rainwater (RRWH) samples analysed by semi-quantitative (SQA) and standards analysis (SA)

WQC	EC3-RRWH 18	EC3-RRWH W 19	EC3-RRWH W 20	EC3-RRWH W 21	EC3-RRWH W 22	EC3-RRWH W 23	EC3-RRWH W 24	EC3-RRWH W 25	EC3-RRWH W 26	EC3-RRWH W 27
B	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02
Ca	10.09	5.76	6.75	5.3	6.24	4.82	4.49	7.93	8.03	7.87
Cl	11.08	0.88	1.16	0.73	1.53	1.15	4.72	1.85	1.83	1.85
CO_3	0	0	0	0	0	0	0	0	0	0
F	0.31	0.32	0.29	0.32	0.22	0.25	0.12	0.36	0.24	0.25
HCO_3	21.35	12.81	10.37	9.76	15.86	9.15	6.1	20.13	20.74	21.35
K	2.01	0.55	0.89	0.73	0.74	0.47	0.27	0.81	0.69	0.62
Mg	2.59	1.27	1.55	1.17	1.27	1.15	1.19	1.34	1.34	1.34
NO_2	0.07	0.18	0.08	0.15	0.25	0.21	0.12	0.15	0.13	0.13
NO_3	3.71	4.29	9.04	4	5.75	2.71	4.13	4.59	4.48	4.49
Na	10.37	0.61	0.85	0.56	0.72	0.59	3.4	1.54	1.52	1.5
PO_4	0	0	0	0	0	0.09	1.86	0.81	0.05	0
SO_4	12.28	10.81	12.25	10.01	11.89	5.44	4.94	12.81	12.86	13.14
TDS	62.33	30.6	37.82	27.12	36.07	21.43	27.95	41.94	40.63	41.33

2.11 Seasonal comparisons between water sources

Comparative values between water sources are shown in Tables 2.27 and 2.28. Seasonal changes in WQC (mg/L) (Table 2.28) occurred in the three sources GW, RW and RRWH. The symbol "+" signifies an increase and "–" a decrease. The greatest increases from summer to winter in GW were Br (+) and Zn (+), and decreases were Cd (-), Cu (-), Mn (-), Sr (-). RW remained quite stable with minor shifts in Se (-), Sr (-) and Ti (-). RRWH shifts from summer to winter were Hg (-), Mn (-), Sr (+) and Zn (-). GW showed major changes in Br, Cu, Hg, Sr and Zn. None of the changes in the WQC posed an increased risk.

Table 2.27 Seasonal comparison the summer rainfall (2013) and dry winter (2014) periods of mean values (μ) of WQC (mg/L) from respective water sources (groundwater, GW; riverwater, RW; rainwater, RRWH, with municipal water (MW) (Control1) and deionised water (Control 2) in the Jericho district

	GW				RW				RRWH				Cont1	Cont2
	J-Summer		J-Winter		J-Summer		J-Winter		J-Summer		J-Winter			
	μ	Range	μ	Range	μ	Range	μ	Range	μ	Range	μ	Range		
WQC														
As	0.0022	0.0012-.0039	0.0016	0.0012-0.0023	0.0025	0.0015-0.0032	0.0009	0 - 0.0009	0.0001	0-0.0007	0.0003	0-0.0011	0.0008	0
B	0.0056	0-0.0106	0.007	0.0056-0.0082	0.0045	0-0.0138	0.0066	0-0.0066	0.0205	0-0.0516	0	0	0.0018	0.002
Ba	0.0189	0.059-0.135	0.3131	0.2193 0.4645	0.0521	0.0163-0.1335	0.0571	0-0.0571	0.009	0-0.035	0.0045	0-0.0679	0.0113	0.0054
Be	0.0012	0-0.0035	0	0	0.0001	0-0.0002	0	0	0	0-0.0001	0	0	0	0
Bi	0.0000	0	0.0014	0.0014 - 0.0015	0	0	0.0014	0-0.0014	0	0	0	0	0	0
Br	0.3590	0.126-0.842	0.695	0.4063-1.19	0.054	0.002-0.09	0.1501	0-0.1501	0.0076	0.003-0.0244	0.0154	0-0.2833	0.055	0.0748
Cd	0.0216	0-0.053	0.0001	0-0.0002	0.0129	0-0.045	0	0	0.1029	0.039-0.1998	0.1036	0.0198-0.3047	0.0005	0
Co	0.0010	0.0003-0.002	0.0005	0.0003-0.0009	0.0005	0.0001-0.0007	0.0004	0-0.0004	0.0003	0.0001-0.001	0.0001	0-0.0005	0.0002	0.0002
Cr	0.0050	0.0037-0.0064	0.0085	0.0069-0.011	0.0046	0.0032-0.0071	0.0061	0-0.0061	0.0004	0-0.0008	0.0002	0-0.0017	0.0016	0.0001
Cs	0.0001	0-0.0001	0	0	0.0001	0-0.0002	0	0	0.0001	0-0.0003	0	0	0.00006	0
Cu	0.0593	0.0001-0.2864	0.0067	0.0008-0.0131	0.0031	0.0025-0.0038	0.0024	0-0.0024	0.0104	0-0.0314	0.0137	0-0.2452	0.0037	0.1079
Hg (μg/L)	0.2736	0.0005-0.9445	0	0	0.0552	0-0.2195	0	0	0.2964	0-1.0078	0.0147	0-0.3166	0.146	0.4165
I	0.0265	0.0185-0.0374	0.02	0.0152-0.0229	0.0059	0.0017-0.0089	0.0039	0-0.0039	0.0007	0.0002-0.0011	0.0039	0-0.0292	0.0098	0.004
La	0.0001	0-0.0001	0	0	0.0058	0.0012-0.0163	0.0002	0-0.0002	0.0001	0-0.0013	0	0-0.0002	4E-06	0
Li	0.0057	0.0037-0.0084	0.0069	0.0046-0.0091	0.0019	0.0007-0.0024	0.0028	0-0.0028	0.0003	0.0002-0.0006	0.0003	0-0.0031	0.0017	0.0009
Mn	0.0148	0-0.0473	0.0051	0.0005-0.0142	0.0182	0.0045-0.0286	0.0075	0-0.0075	0.0243	0.0046-0.061	0.0022	0-0.0265	0.0456	0.0124
Mo	0.0007	0.0001-0.0015	0.0005	0-0.0012	0.001	0.0004-0.0016	0.0009	0-0.0009	0.0001	0-0.0002	0	0-0.0003	0.0008	0.0005
Ni	0.0056	0.0028-0.0094	0.0032	0.0028-0.0035	0.0043	0-0.0095	0.0042	0-0.0042	0.0052	0-0.0294	0	0	0.001	0.0223
Pb	0.0003	0-0.0006	0	0	0.002	0.0001-0.0077	0	0	0.0011	0.0002-0.0052	0.0011	0-0.031	0.0042	0.0014
Pt	0.0000	0-0.0001	0	0	0.0002	0-0.0006	0	0	0	0-0.0001	0	0	0.00002	0
Rb	0.0033	0.002-0.0058	0.0037	0.0027-0.0056	0.0069	0.0012-0.009	0.0079	0-0.0079	0.0008	0.0002-0.0023	0.0003	0-0.0021	0.0048	0.0021
Sb	0.0002	0.0001-0.0003	0	0-0.0001	0.0003	0-0.0004	0.0005	0-0.0005	0.0002	0-0.0004	0.0002	0-0.0014	0.0001	0.0002
Se	0.0037	0.0003-0.0081	0.0056	0.0033-0.0089	0.0228	0.0006-0.0875	0.0012	0-0.0012	0.0002	0-0.0005	0.0014	0-0.0039	0.0016	0.0006
Sn	0.0000	0	0.0018	0.0017-0.0019	0	0	0.0018	0-0.0018	0.0003	0-0.0017	0	0	0	0.0001
Sr	0.4375	0.3073-0.6912	0.2917	0.0219-0.43	0.3186	0.0604-0.949	0.1626	0-0.1626	0.0089	0-0.0191	0.0204	0.0007-0.2137	0.0741	0.0366
Te	0.0000	0	0	0	0	0	0	0	0	0	0	0	0	0
Ti	0.0050	0.004-0.0069	0.0054	0.0044-0.0067	0.0385	0.0003-0.1146	0.0095	0-0.0095	0.0007	0-0.0017	0.0001	0-0.0019	0.00006	0
Tl	0.0000	0	0	0	0.0018	0-0.0073	0.0055	0-0.0055	0	0-0.0001	0	0	4E-06	0
U	0.0053	0.0031-0.0085	0.0059	0.0045-0.0085	0.0003	0-0.0005	0.0007	0-0.0007	0	0-0.0001	0.0002	0-0.0031	0.0001	0.0001
V	0.0134	0.0121-0.0169	0.0125	0.0112-0.0151	0.0076	0.0059-0.0087	0.0052	0-0.0052	0.0007	0.0001-0.0011	0.0006	0-0.0081	0.0009	0.0002
W	0.0000	0	0	0	0.0004	0-0.0015	0.0012	0-0.0012	0.0003	0-0.0008	0	0-0.0003	0	0.0004
Zn	0.0409	0.0034-0.0753	0.1237	0.0131-0.3176	0.0037	0.0022-0.0053	0	0	3.5781	1.8279-4.9064	2.1136	0.0804-5.0113	1.426	0.3043

Table 2.28 Seasonal changes from summer rainfall (2013) to dry winter (2014) periods of mean values (μ) of WQC (mg/L) from respective water sources (groundwater, GW; riverwater, RW; rooftop harvested rainwater, RRWH) in the Jericho district where "-" indicates a decrease and "+", an increase

	GW			RW			RRWH		
	Summer	**Winter**		**Summer**	**Winter**		**Summer**	**Winter**	
	μ	**μ**	**Δ**	**μ**	**μ**	**Δ**	**μ**	**μ**	**Δ**
WQC									
As	0.0022	0.0016	-	0.0025	0.0009	-	0.0001	0.0003	+
B	0.0056	0.007	-	0.0045	0.0066	+	0.0205	0	-
Ba	0.0189	0.3131	+	0.0521	0.0571	+	0.009	0.0045	-
Be	0.0012	0	-	0.0001	0	0	0	0	0
Bi	0.0000	0.0014	+	0	0.0014	+	0	0	0
Br	0.3590	0.695	+	0.054	0.1501	+	0.0076	0.0154	+
Cd	0.0216	0.0001	-	0.0129	0	-	0.1029	0.1036	0
Co	0.0010	0.0005	-	0.0005	0.0004	0	0.0003	0.0001	0
Cr	0.0050	0.0085	+	0.0046	0.0061	+	0.0004	0.0002	0
Cs	0.0001	0	-	0.0001	0	0	0.0001	0	0
Cu	0.0593	0.0067	-	0.0031	0.0024	-	0.0104	0.0137	+
Hg (μg/L)	0.2736	0	-	0.0552	0	-	0.2964	0.0147	-
I	0.0265	0.02	-	0.0059	0.0039	-	0.0007	0.0039	+
La	0.0001	0	-	0.0058	0.0002	-	0.0001	0	0
Li	0.0057	0.0069	+	0.0019	0.0028	+	0.0003	0.0003	0
Mn	0.0148	0.0051	-	0.0182	0.0075	-	0.0243	0.0022	-
Mo	0.0007	0.0005	-	0.001	0.0009	-	0.0001	0	0
Ni	0.0056	0.0032	-	0.0043	0.0042	0	0.0052	0	-
Pb	0.0003	0	-	0.002	0	-	0.0011	0.0011	0
Pt	0.0000	0	-	0.0002	0	0	0	0	0
Rb	0.0033	0.0037	+	0.0069	0.0079	+	0.0008	0.0003	0
Sb	0.0002	0	-	0.0003	0.0005	0	0.0002	0.0002	0
Se	0.0037	0.0056	+	0.0228	0.0012	-	0.0002	0.0014	+
Sn	0.0000	0.0018	+	0	0.0018	+	0.0003	0	0
Sr	0.4375	0.2917	-	0.3186	0.1626	-	0.0089	0.0204	+
Te	0.0000	0	0	0	0	0	0	0	0
Ti	0.0050	0.0054	+	0.0385	0.0095	-	0.0007	0.0001	-
Tl	0.0000	0	0	0.0018	0.0055	+	0	0	0
U	0.0053	0.0059	+	0.0003	0.0007	+	0	0.0002	0
V	0.0134	0.0125	-	0.0076	0.0052	-	0.0007	0.0006	0
W	0.0000	0	0	0.0004	0.0012	+	0.0003	0	0
Zn	0.0409	0.1237	+	0.0037	0	-	3.5781	2.1136	-

2.12 Discussion of analytical results

The results have been presented in terms of highlighting the anomalies of WQC that are potentially hazardous. The criteria used are the current South African Water Quality Guidelines Volume 1 for Domestic Use (SAWQG Dom, 1996) and the South African Water Quality Guidelines Volume 5 for Agriculture: Livestock Watering (SAWQG Livestock, 1996). International references come from WQG documents AUS and NZ (ANZECC, 1992, NHMRC, NRMMC, 2011), CAN (Olkowski, 2009) and the World Health Organisation Guidelines for Drinking Water (WHO, 2011). A clear difference exists between the WQG set out in the reference documents. In some instances the SAWQG are stricter and in other instances more lenient than the comparative references. This anomaly poses a questionable situation. In many instances, the source of the WQG cannot be found to corroborate the guideline value. Casey and van Ryssen (2013) noted the publication of Suttle (2010) and the guidelines on nutrient requirements of various livestock published by the NRC (2005) are the classical references on minerals in livestock nutrition. The reference cited in these two publications show the large range of recommendations. Analysis of the cited references reveals that the anomalies arose because of a lack of standardisation in methodologies used when testing dietary micro-minerals in animals. The variations are due to: not conducting research on livestock of the same type (but in different production phases such as dry cows or lactating cows), in different environments and on different dietary regimes. The forms in which the minerals are presented also differ, thereby affecting the bioavailability of the element and their respective turnover rates. Further causes of the differing WQG values are that mineral intake rates are not quantified, either according to the MBM of animals or rates of ingestion. Developing WQG that can fit the spectrum of livestock, their production status and the range of environments remains a complex challenge (Meyer and Casey, 2012). Risk assessment of WQC is determined as WI, clearance rates and physiological impact according to the physiological status of an animal or person (Meyer and Casey, 2012).

The results presented in Tables 2.7 to 2.26 show distinct differences between sources. In Tables 2.7 to 2.13, water from the Jericho region showed GW to contain a wider range of WQC than RRWH.

The following discussion considers WQC that may be COC or PHCC or that appear in the analyses, but are not in the WQG.

Arsenic

The element As exceeded the WQG value in two samples by 200% (0.183 and 0.218 mg/L vs WQG 0.01 mg/L) (Table 2.10). None of the other RRWH samples contained As values > 0.1 mg/L. This suggests a source of As in the Jericho area that contaminates RRWH.

Bromine

The element Br occurs in disturbingly high concentrations in GW at all sampling sites and in RRWH at Jericho and Port St Johns (with the exception of RRWH from Jericho sampled in December 2013). The high levels in RRWH from Port St Johns could be attributed to the influence of the sea, since seawater has a reference concentration of 65 mg/L. The high concentrations in GW in this research corroborate the values reported by Casey and Meyer in a number of cited publications. Br levels increased in GW by 36% from summer to winter.

The intake of Br per person-group is illustrated in Table 2.29, based on the WQG value and the daily intake in litres. The result is intake of 1.2 mg/day. This is not considered potentially toxic in a WHO (2011) publication on Br in drinking water. The statement is made that the acceptable daily intake (ADI) of Br for a 60 kg person may be 24 mg/day, but also states “the dietary bromide contribution for a 10 kg child would probably be less than that for an adult.” This statement is not clear as to the potential risk to young children.

Table 2.29 Estimated intakes of bromine (Br) through water for categories of humans

Persons	WQG	Br in water mg/L		WI	Br intake mg/day		Comment
	0.01	Max	Mean	(L) per day*	Max	Mean	
Adults and adolescents		0.842	0.525	2.3	1.937	1.2075	Max > WQG; mean > WQG
Children: both sexes 4-12 years		0.842	0.525	0.55	0.463	0.28875	Max > WQG; mean > WQG
Children: both sexes 0-3 years		0.842	0.525	0.4	0.337	0.21	Max > WQG; mean > WQG

The Br ion has a guideline value of 0.01 mg/L in South Africa. It is clearly shown in Tables 2.7, 2.8 and 2.9 that the concentrations are above the WQG value. Even in some samples of RRWH, Br is a COC and in one case, a PHCC. This makes Br a PHCC of particular interest, as it has been shown to demonstrate physiologically disruptive effects in chickens (Du Toit and Casey, 2010, 2011). Since all animals are not homogenous, all agricultural practices are not the same and the climate of South Africa is not uniform, it is unrealistic to assume that one guideline value for a WQC is sufficient for all purposes. Although some effort has been made to provide distinction between at least different species of livestock in terms of the guideline values for WQC, in most cases the effects are simply grouped under 'all livestock,' with no distinction of age or physiological stage of the animal, production system or SSF.

Br is a trace element found naturally occurring in the GW of South Africa. It has no known essential functions in livestock, but has been shown to demonstrate goitrogenic activity (Du Toit and Casey, 2011) as well has having several chemical forms that are carcinogenic. Recommended NOAEL values for safety in livestock vary: 2.3 mg/L is the recommended maximum level of intake by the NRC (2005), with values varying from 0.01 mg/L (standard recommended intake rate) up to even 6 mg/L (representing crisis level intake).

Reports by Casey and Meyer (2001, 2006), Casey *et al.* (1996a, 1996b, 1998a, 1998b, 1998c, 2001), Du Toit and Casey (2010), Mamabolo *et al.* (2009), Meyer and Casey (2004, 2012), Meyer *et al.* (2014) indicated Br has a high point of use prevalence in rural communities and livestock enterprises. It was indicated as a PHCC as it exceeded the guideline value for maximum intake of 0.01 mg/L.

Br salts are absorbed rapidly and completely in the gastrointestinal tract using the chloride ion-transport system and while formal bioavailability studies have not been done, 96% of an oral Br dose is absorbed in humans. Toxicity of Br from drinking water is uncertain; maximum tolerable levels (MTL) of Br have not been accurately estimated for any species except the rat and residue levels of Br in the meat, milk and eggs of animals fed at MTL have not been determined. Estimations of maximum tolerable Br levels in water are non-existent.

Since plasma Br levels increase linearly with those in the feed, there is a potential problem with Br residues in animal products. Cows excrete Br in their milk in a linear relationship to the amount in the diet and accumulate it in their tissues. This same linear relationship for bioaccumulation in body tissues has been demonstrated in rats. This could pose health risks to humans that consume products produced by animals that are receiving high, chronic or acute doses of inorganic Br salts from their feed or water. Bioaccumulation in the tissues of animals consumed, like chicken and beef, can also pose a health-risk to humans.

Calcium

Calcium (Ca) in GW (22.27 to 156.26 mg/L) is well below the WQG for livestock in SA, AUS/NZ and CAN (1000 mg/L), but is a PHCC (SAWQG) for humans in samples > 32 mg/L.

Chlorine

Chlorine (Cl) in GW (3.46 to 257.9 mg/L) shows a wide range, where some water sources exceed the SAWQG value of 100 mg/L for human consumption. The SAWQG for human consumption is more stringent than the WQG of AUS/ NZ. SAWQG for livestock range from 1500 mg/L for monogastric animals and poultry to 3000 mg/L for ruminants. No WQG for livestock are available from AUS/ NZ or CAN. It is noted that the SAWQG for aquaculture is quite high at 600 mg/L. The Cl levels do not pose a potential risk.

Fluoride

Fluoride (F) in GW (0.34 to 1.31 mg/L) that exceeds 1.0 mg/L is PHCC for human consumption in SA and a COC for human consumption in AUS/NZ (1.5 mg/L). F is slightly above the recommended guideline for livestock in CAN (1.0 mg/L). The SAWQG note that F begins to become problematic in sheep and pre-weaned calves at 4 to 6 mg/L. Chronic fluorosis occurs in cattle in extensive ranching systems at values > 6 mg/L. The occurrence of F is associated with GW and RW. The levels measured in these samples do not pose a risk to agricultural livestock.

Magnesium

Magnesium (Mg) in GW (29.15 mg/L) is a borderline COC / PHCC (SAWQG 0 to 30 mg/L) for human consumption. The WQG for livestock (Kempster, 1981) is 200 to 400 mg/L, while the ATSDR states that no ATSDR comparison values exist for Mg, which is regionally detected in soils ranging from non-detect to 10,000 mg/m3.

Manganese

Manganese (Mn) can occur in GW throughout South Africa. The current monitoring showed values between 0 and 0.0473 mg/L, considered against the SAWQG value of 0.05 mg/L, shows a COC verging on becoming a PHCC. Values > 0.02 mg/L are PHCC for irrigation in South Africa. The SAWQG value for livestock is 10 mg/L, well above that of CAN (5 mg/L), which raises a question as to the validity of the SAWQG value. Mn is a naturally occurring element and is necessary in trace amounts for human and animal health. An EPA (2007) publication on Mn toxicity presents guidelines showing incremental estimated safe and adequate daily dietary intake (ESADDI) for people ranging from infants to > 10 years old. There is, however, no current recommended daily allowance (RDA) for Mn, though the US Institute of Medicine (2001) recommends 0.003 mg/day for persons older than 6 months published by the NRC (2001). The EPA (2007) issued a warning that the ESADDI for Mn and the calculated toxicity value for Mn are close in value. This suggested a relatively narrow range of acceptable exposure to Mn, for example, an ESADDI of 1-2 mg, compared to a recommended maximum daily intake of 3.5 mg for an 8-year-old, child weighing 25 kg (ATSDR, 2000).

Mercury

Mercury (Hg) levels exceed the WQG of 0.001 µg/L in South Africa. The range extends from 0 to 0.9445 µg/L. Hg in groundwater in the Western Cape was noted by Casey *et al.* (2001) with levels as high as 4.1819 µg/L (Mean 0.7756, SD 1.0104, n=18 boreholes). These authors reported Hg in GW in the Klein Karoo and Kamanassie mountain region of levels high enough to have caused accumulation of Hg in the organs of ostriches.

Hg has no beneficial physiological effect, but rather a disruptive one, causing reduced egg production and suppressed growth in chickens. There is a problem with the WQG in that the values are the same, but the unit of measurement in the SAWQG and CAN WQG is µg, while the AUS/NZ WQG presents the data in mg. This is a suspected error and should be in µg. Kempster *et al.* (1985) recommended 0.01 µg/L for South Africa. In terms of the SAWQG, Hg is a PHCC in GW, RRWH and in one MW sample. Hg, as a heavy metal, bioaccumulates and can result in chronic Hg toxicity. The level of exposure and intake via drinking water would likely have a marginal effect on livestock that have a short productive life. However, people exposed to consistent intake of inorganic Hg through water, and long living livestock such as horses are likely to develop toxicity symptoms. These are first expressed as dermatitis, neuro-dysfunction, gastrointestinal disorders and disrupted kidney function; these symptoms can become progressively worse. Organic Hg compounds are more readily absorbed, but the Hg measured in GW is inorganic. It is not certain the extent to which speciation of Hg can occur in storage, or be taken up by micro- and other organisms in reservoirs (that are incidentally consumed with the water) and thereby increasing the potential exposure.

The WHO (2011) publication on Hg in drinking water notes that levels of Hg in rainwater are in the range 5 to 100 ng/L (0.005 to 0.1 µg/L), but mean levels as low as 1 ng/L have been reported (IPCS, 1990). Natural occurring levels of Hg in GW and surface water are less than 0.5 µg/L, although local mineral deposits may produce higher levels in GW. A small number of GWr and shallow wells surveyed in the USA were shown to have Hg levels that exceeded the maximum contaminant level of 2 µg/Lset by the US Environmental Protection Agency for drinking water (Ware, 1989). An increase in the Hg concentration up to 5.5 µg/L was reported for wells in Izu Oshima Island (Japan), where volcanic activity is frequent (Magara *et al.,* 1989). The concentration range for Hg in drinking water is the same as in rain, with an average of about 25 ng/L (IPCS, 1990).

The WHO (2011) document states further that in a contaminated lake system in Canada, methyl mercury was found to constitute a varying proportion of total Hg, depending on the lake (IPCS, 1990). There have been no reports of methyl mercury being found in drinking water. GW with high Hg levels should be noted and used with care.

Nitrate

NO_3 in all GW samples (6.92 to 35.815 mg/L) exceeded the SAWQG of 6 mg/L, making NO_3 a PHCC in all GW samples. The SAWQG for human consumption is very much lower than those of AUS/NZ (50 to 100 mg/L). A value of 50 mg/L is specified for infants < 3 months old, while the value of 100 mg/L is specified for adults and children > 3 months. WQG values for livestock in South Africa and Canada are the same, whereas the AUS/NZ WQG is much more stringent in terms of absolute value and differentiation between WQG at species level. According to SAWQG, values > 0.05 mg/L are unsuitable for aquaculture. NO_3 is a precursor to NH4 being formed in the rumen, with nitrite (NO_2) a by-product that forms methaemoglobin restricting the blood oxygen capacity.

Sodium

Sodium (Na) in GW (9.94 to 114.49 mg/L) is generally below the SAWQG for human consumption (100 mg/L) and well below the AUS/NZ WQG (180 mg/L) and CAN (200 mg/L). Only values that exceed 70 mg/L are PHCC for irrigation in South Africa. TDS is shown to be an alleviator of potential toxicity in a number of water-borne elements (Du Toit and Casey, 2010).

Strontium

Strontium (Sr) levels exceeded 0.1 mg/L. This value is taken as a benchmark, since it is not listed and is not presently considered a potential risk in the stable, non-radioactive isotope form (ATSDR). One can note that RW (0.0219 to 0.949) generally exceeded those in MW (0.0741 mg/L) and RRWH (0.0007 to 0.1093 mg/L).

Zinc

Zinc (Zn) is an essential micro-mineral for humans and livestock. The deficiency of dietary Zn in South Africa is more likely a cause for concern than over exposure from natural occurring Zn. Zn toxicity results primarily from zinc metal fumes, i.e. persons working in industrial situations. Toxicity can result in a number of physiological dysfunctions that can include decreased growth, infertility and muscular dystrophy. The ATSDR found no conclusive results on Zn toxicity in animals other than research on the effects of metal fumes using laboratory animals. According to the SAWQG, Zn in RRWH up to 4.531 mg/L, with values greater than WQG of 3 mg/L are PHCC for human consumption, but not for livestock (20 mg/L in SA and AUS/NZ; CAN 50 mg/L). The values obtained in RRWH are generally higher than those obtained from GW (0 to 1.426 mg/L), presumably due to the nature of the roofing material from which the water is harvested. The question is whether the inorganic Zn could rather be considered a dietary supplement. Inorganic Zn has a low bioavailability, though a marginal retention could be a sufficient dietary supplement. Since the bioavailability of inorganic Zn is considerably lower than that of organic compounds, the tendency in animal nutrition is to supplement dietary Zn using organic compounds. Table 2.30 is constructed from RDA values for categories of people, the recorded Zn values in the data and WI per day of people according to categories. This construction shows the potential extent to which water might be a dietary supplementary source of micro-minerals.

Table 2.30 Estimated Zinc (Zn) intake through water as a dietary supplement for humans

Persons	RDA mg/d	Zn in RRWH (mg/L)			WI	Zn / day by WI (mg)			Supplementation consequences**
		Max	Min	Mean	(L) per day*	Max	Min	Mean	
Males: Adults and adolescents	11	9.60	0.646	2.713	2.3	22.09	1.486	6.241	Max > RDA; mean < RDA
Children: both sexes 4-12 yr	6	9.60	0.646	2.713	0.55	5.283	0.355	1.493	Max = RDA; mean < RDA
Children: both sexes 0-3 yr	3	9.60	0.646	2.713	0.40	3.842	0.258	1.086	Max > RDA; mean < RDA
Women: Pregnancy <18 years	12	9.60	0.646	2.713	2.3	22.09	1.486	6.241	Max > RDA; mean < RDA
Women: Pregnancy 19-50 yr	11	9.60	0.646	2.713	2.3	22.09	1.486	6.241	Max > RDA; mean < RDA
Women: Lactating <18 yr	13	9.60	0.646	2.713	2.9	27.85	1.873	7.870	Max > RDA; mean < RDA
Women: Lactating 19-50 yr	12	9.60	0.646	2.713	2.9	27.85	1.873	7.870	Max > RDA; mean < RDA

*Assumed for normal healthy people of moderate lifestyle at 95% of the empirical distribution (EPA, 2004).
**No conclusive evidence on MTL for Zn in humans but is an interpretation in terms of the RDA and WQG values.

The TDS values in GW ranged from 104.57 to 820.16 mg/L. The SAWQG for TDS for human consumption sets a NOAEL limit of 450 mg/L and AUS/NZ WQG has a higher value of 600 mg/L. The values in upper end of the analyses are PHCC for human consumption. These values are within the guideline limits for livestock in SA, AUS/NZ and CAN. The WQG for livestock in SA are much lower and less differentiated than those of AUS/NZ and CAN. TDS is shown to be an alleviator of potential toxicity in a number of water-borne elements (Du Toit and Casey, 2010).

2.13 Conclusion

The conclusions drawn here are that the WQC-profile differs between GW, RRWH, RW and MW samples drawn from various localities. GW had the highest content of elements constituting WQC, while RRWH was characterised by high levels of Zn. It was also clear that contamination of roofs increases the amount of selected WQC depending on the locality for example As that did not appear in the local GW was measured in RRWH. Seasonal changes measured were marginal, but the lack of consistent and repetitive data severely limited the interpretation of the analytical results.

The results have shown that the WQC-profile differs between GW, RRWH, RW and MW samples drawn from various localities. COC and potentially PHCC may occur in each of the sources. GW is likely to have the highest range of WQC and WQC that may be COC or PHCC. RRWH is likely to differ in the profile of WQC by locality, which is ascribed to wind-blown elements collecting on roofs. RRWH was characterised by high levels of Zn that is ascribed to the zinc-galvanised sheet-iron used for roofing material. Zn in RRWH could be a source to supplement dietary Zn in humans. Seasonal changes measured were marginal, but the lack of consistent and repetitive data severely limits the interpretation of the analytical results. Br, a halogen-class element, shown by controlled research to become a potential endocrine disruptor, was measured in GW and RRWH at a locality close to the coast. GW contained levels of Br exceeding the SAWQG NOAEL value of 0.01 mg/L. International WQG, however, do not consider Br a potential risk factor in drinking water. The conclusion drawn is that due to the differences in the profiles of WQC from rooftop harvested rainwater, groundwater and riverwater and the occurrence of inorganic WQC that are COC or PHCC, water from these sources should be monitored to assess their human and livestock health-related risk.

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CHAPTER THREE

PROPOSED CHANGES TO THE GUIDELINE ON GROUNDWATER FOR DOMESTIC USE AND LIVESTOCK WATERING

Norman H Casey[1]

3.1 Introduction

WQG are intended to provide the public with information on the quality of water acceptable for a specific use. The quality parameters are constituents (WQC) and the physical properties of water. The constituents may be inorganic elements and molecules, organic compounds and biological matter. The quality of GW is important in the South African context because the seasonal and erratic nature of rainfall limits the availability of surface water with GW being the alternative for farms, small towns and villages across the country.

Inorganic WQC are the main determinants of GW quality. In terms of health risks, some inorganic WQC can have negative affects on people and livestock under specific conditions, hence the need for WQG that assist in managing the health risks associated with inorganic WQC. In most cases, however, WQG are presented in a generic format, whereas susceptibilities to risk depend on user-specific factors and environmental influences.

The South African Water Quality Guidelines for Domestic Use and for Livestock Watering were published in 1996 (SAWQG Dom; SA WQG LW, 1996). Since 1996, the Food and Agricultural Organisation of the United Nations (FAO), the World Health Organisation (WHO), Canada, European Union, Australia and the Environmental Protection Agency of the USA (EPA) published new versions of WQG documents. The WQG are text-based with notes for application where applicable. In general, differentiating biological references in terms of WQC becoming COC PHCC are chronological and based on body mass. A software-based system that estimates the CIRRA for assessing the risk of WQC to livestock had been developed, but has since become obsolete. In addition, subsequent observations have been made on WQC not included in the guidelines.

This report considers the published WQG values, proposes MBM as a biological reference and notes the advantages of an interactive metric assessment of health risk.

3.2 Moral philosophy and purpose water quality guidelines

Noting the good and the bad, the threats and opportunities of life is fundamental to survival. People have developed moral philosophies throughout history in dealing with these by advancing favourable situations and taking steps to deal with threats. Moral philosophies became rules of conduct written into legislation. In terms of water quality, legislation has set parameters on standards for drinking water and on polluting water to the extent of it being unsafe to drink and harmful to industry, including agriculture.

The value of good water and the need not to spoil the environment is set deep in our cultural literature. Water is not only the essence of biological life on earth, but our metaphorical language captures the value of water for everyday living. If water were not the physical state of a simple composite inorganic molecule of two hydrogen molecules and an oxygen molecule (H_2O), it might conform to the requirements of being classified as a living entity. Water has often been invested with metaphysical power because of its overwhelming necessity and significance in our lives. The essence of water for sustenance is reflected in ancient texts: the Bible has 617 uses of the word water. These include the waters being parted from the land and to "*teem with living creatures*" (Genesis 1:20). Agricultural use is illustrated as in "*a river watering the garden flowed from Eden*" (Genesis 2:10), and the reference to GW and benevolence in: "*then God opened her eyes and she saw a well of water... and filled the skin with water and gave the boy a drink*" (Genesis 21:19).

Moral behaviour is linked to respecting feed and water in "*Is it not enough for you to feed on the good pasture? Must you also trample the rest of your pasture with your feet? Is it not enough for you to drink clear water? Must you also muddy the rest with your feet?*" (Ezekiel 34:18), while quality as in drinkable water is brought to the fore in "*when they came to Marah, they could not drink its water because it was bitter*" (Exodus 15:23) with another seven connotations between "*bitter water*" and hardship or vileness. The metaphor of "*living water*" relates to a way of life and spiritual well-being (John 4:10, 11 and other references).

These foregoing references to water in the biosphere, respecting its value, using water for agriculture and households (and associated industries) and noting its quality and value-categories, all underscore the need for distinct WQG.

The moral philosophy of a set of WQG should be primarily to assist the user category in determining the FFU of water, which would include untreated water direct from the source; water treated to comply with WQG values; untreated water exposed to sunlight, which can cause changes in the nature and concentration of inorganic and organic WQC.

3.3 Published guidelines on water quality

Various government and international agencies have published WQG. Six published WQG documents from prominent countries and entities were selected to compare with South African Water Quality Guidelines for Livestock Watering (1996). The first comparison is the justification as set out in the document as follows:

3.3.1 South African Water Quality Guidelines: Livestock Watering

The South African Water Quality Guidelines for Livestock Watering (1996) is essentially a user needs specification of the quality of water required for different livestock production systems.

The following aspects can be highlighted from this document

- The Department of Water Affairs and Forestry (former) uses the Water Quality Guidelines (1996) as its primary source of information and decision-support to judge the FFU of water and for other water quality management purposes. The information is more detailed (*than the international literature*), and not only provides information on the ideal water quality for water uses, but in addition provides background information to help users of the guidelines make informed judgments about the FFU of water.

- The South African Water Quality Guidelines (1996) were developed as an important information resource, primarily for water quality managers. Nevertheless, educators and other interested and affected members of the public are likely to find them a valuable source of information for many aspects of water quality and its management.

3.3.2 World Health Organisation Guidelines for Drinking Water Quality

The key aspects of the World Health Organisation (WHO) Guidelines for Drinking Water Quality 4th Edition includes the following:

- The moral philosophy of the WHO is contained in the following statement "*The primary purpose of the Guidelines for drinking water quality is the protection of public health. The Guidelines provide the recommendations of the World Health Organisation (WHO) for managing the risk from hazards that may compromise the safety of drinking water. The recommendations should be considered in the context of managing the risk from other sources of exposure to these hazards, such as waste, air, food and consumer products*."
- The WHO (2011) WQG considers that safe drinking water does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages. Persons at greatest risk of water-borne disease are infants and young children, people who are debilitated and the elderly, especially when living under unsanitary conditions. This stated principle of the WHO (2011) WQG is equally applicable to livestock.
- The WHO (2011) WQG is intended to support the development and implementation of strategies for risk management that would ensure the safety of drinking water through the control of hazardous constituents. These strategies may include national or regional standards developed from the scientific basis provided in the WHO (2011) WQG.
- The approach to a NOAEL describes reasonable minimum requirements of safe practice to protect the health of consumers and derive numerical "guideline values" for constituents of water or indicators of water quality.
- The WHO guidelines should be considered in the context of local or national environmental, social, economic, cultural conditions and user in deriving local guideline values.
- The WHO (2011) notes that the WQG should be part of an overall health-protection strategy. This would include sanitation and other strategies such as managing the contamination of foods.
- Since the nature and form of drinking water standards may vary among countries and regions, no single approach is universally applicable. The WHO (2011) does not encourage countries or regions to adopt international standards for drinking water quality purely for the advantage provided by a risk-benefit approach (qualitative or

quantitative) in establishing national standards and regulations.

- The numeric guideline values should not form a standard to which water quality might be degraded.
- The WHO (2011) guidelines advocate implementing the guidelines in terms of a conceptual framework with three key components.
    - Health-based targets based on an evaluation of health risks.
    - Water safety plans (WSP), comprising:
        - An assessment system to determine whether the drinking water supply (from source through treatment to the point of consumption) as a whole can deliver water of a quality that meets the health-based targets;
        - Operational monitoring of the control measures in the drinking water supply that are particularly important in securing drinking water safety;
        - Management plans that (1) document the system assessment, (2) monitor and describe actions to be taken in normal operation and incident conditions, (3) include upgrading and improving systems, documentation and communication.
    - An independent surveillance system, which can verify the above is operating properly.
    - In terms of a guiding principle, the WHO (2011) considers that most chemicals in water become hazardous to humans after prolonged exposure.

3.3.3 Australian Drinking Water Guidelines

The Australian Drinking Water Guidelines (ADWG, 2011, updated 2016) are intended to provide a framework for good management of drinking water supplies that, if implemented, will assure safety at point of use.

The key aspects of the Guidelines include the following:

- The ADWG (2011) have been developed after consideration of the best available scientific evidence, are designed to provide an authoritative reference on what defines safe, good quality water, how it can be achieved and how it can be assured, and are concerned with health safety and with aesthetic quality.
- The ADWG (2011) are not mandatory standards. They provide a basis for determining the quality of water to be supplied to consumers in all parts of Australia. These determinations need to consider the diverse array of regional or local factors, and take into account economic, political and cultural issues, including customer expectations and willingness and ability to pay.
- The Australian community and all agencies intend the ADWG (2011) for use with responsibilities associated with the supply of drinking water, including catchment and water resource managers, drinking water suppliers, water regulators and health authorities.
- ADWG (2011) considers GW of shallow aquifers to be at greater risk of adverse chemical constituents originating from industrial and agricultural activity than deep

aquifers, which in certain areas may be prone to seawater incursion.

- Key characteristics in drinking water supply systems pertaining to GW are among others:
  - o Geology.
  - o Agricultural surface irrigation.
  - o Topography and drainage patterns.
  - o Depth to aquifer.
  - o Flow rates and directions.
- Associated with the moral philosophy are storage and delivery facilities.

3.3.4 Environmental Protection Agency Drinking Water Quality Guidelines

The Environmental Protection Agency Drinking Water Quality Guidelines (EPA, USA) (2009) has a comprehensive moral philosophy on water quality that addresses every user category and potential sources of pollution. The EPA, representing the federal state, issues guidelines on assessing water quality by state or by county. The latest guidelines for drinking water quality posted on 01/04/2015 are the WHO guidelines of 2008.

3.3.5 European Union Drinking Water Regulations

European Union (Drinking Water) Regulations 2014 (EU [DW] R 2014) do not express a moral philosophy other than "*protection of human health*", but are statutory regulations regarding:

- o Duties of suppliers, point of compliance and duties in relation to water on premises;
- o Monitoring, records, protection of human health, remedial action, departures from standards and intervention by supervisory authority;
- o Quality of treatment, equipment and materials, information in case of exempted supplies, quality to be maintained, directions and performance verification;
- o Injunctive relief, powers of authorised persons, charges by supervisory authorities, offences by bodies corporate and prosecutions and penalties.

3.3.6 Canada, British Columbia, Water Quality Guidelines

The Canada, British Columbia, Water Quality Guidelines (2015) cover the following key aspects:

- The moral philosophy of the Canadian, B.C. (CAN, 2015) WQG is to represent safe levels of substances that protect different water uses, including: drinking water, recreation, aquatic life, wildlife and agriculture which, the document notes, is not the approach of many authorities that develop WQG to protect water quality.
- WQG provide policy direction to those making decisions affecting water quality. It notes that although WQG do not have any direct legal standing, CAN (2015) WQG must be considered in any decision affecting water quality made within the Ministry of the Environment (MOE) once the CCME has approved the WQG.
- Water quality is assessed according to the WQG, which may be used as a reference for determining the allowable limits in waste discharge.
- WQG applies to approved criteria; two approaches apply in the event of non-approved

criteria:

- o Working Water Quality Guidelines (WWQG): WWQG provides benchmarks for substances that have not been fully assessed and formally endorsed by the MOE.

Table 3.1 An example of the Working Water Quality Guidelines (WWQG)

Substance	Class	Water use	Long- term WWQG	Units	Notes	Reference
Bromocil	Pesticides	Livestock	1.1	mg/L		CCME (1997)
Cadmium	Metals	Livestock	80	µg/L	Short-term maximum guideline	CCME (1996)

- o Working Sediment Quality Guidelines (WSQG): WSQG derive from observations of sediments on benthic aquatic life in freshwater and marine environments, and are applied as guideline values for these organisms and environments. As in the case of WWQG, the WSQG are benchmarks for substances not assessed and endorsed by the MOE.

Table 3.2 An example of the Working Sediment Quality Guidelines (WSQG)

Substance	Group	Use	*Lower WSQG (µg/g DM)	**Upper SWQG (µg/g DM)	Reference
Cadmium (total)	Metals	Freshwater aquatic life	0.6	3.5	CCME (1997)
Cadmium (total)	Metals	Marine aquatic life	0.7	4.2	CCME (1997)

*Lower WSQG: A concentration that will protect aquatic life from adverse effects of toxic substance in most situations (equivalent to CCME's Threshold Effect Level)
**Upper WSQG: A concentration that if exceeded will likely cause severe effects on aquatic life (equivalent to CCME's Probable Effect Level).

- The CAN (2015) WQG alludes to a risk-based assessment:
  - o Exceeding a WQG does not imply an unacceptable risk. It indicates that a potential for adverse effects may be increased, which may require an additional investigation.
  - o Risk posed by a WQC is considered a long-term occurrence of a potentially adverse WQC measured as 5 samples in 30 days.
  - o The Canadian, B.C. WQG has the approach to periodically update the guideline values (virtually annually) to incorporate new information and represent the best guidance of the MOE on water quality standards, for substances without approved WQG.

3.3.7 Food and Agricultural Organisation Water Quality for Agriculture

The Food and Agricultural Organisation, United Nations: Water Quality for Agriculture (1985) guidelines on water quality for agriculture (FAO, 1985, reprinted 1989, 1994) focuses on the concept that the document is a framework, intended to provide users that may include farmers, project managers, consultants and engineers – a management tool with which they can evaluate and identify potential problems related to water quality.

The following points can be considered from this document:

- It is often mentioned in the document that since the majority of the research pertains to arid and semi-arid regions, primarily in the western United States, care and critical judgement should be exercised when using this guide. It is crucial to consider the local and site-specific factors relevant to the actual field usage of the water, as well as the management capability of the user.
- The main goal is stated as the maximum production per unit of available water.
- With regard to water quality for livestock in particular, the FAO guidelines frequently emphasize that local, site-specific conditions, as well as animal and environmental conditions need to be taken into account when evaluating water as FFU. It also states that while the use of poor quality water may be unavoidable, sound judgement on the part of the user may mitigate or eliminate possible poor production and concomitant economic loss provided the user recognises that the guidelines provide a framework of reference and that the limits or values are not set in stone.
- In terms of salinity, the FAO provides a guideline on a scale range of concentrations and suitability for livestock by type and physiological status.
- Other guidelines for toxic substances have a wide safety margin and are not necessarily based on the limits of the animal, but on the amounts normally found in usable surface and ground water.
- The FAO guidelines for livestock clearly acknowledge the problem inherent in setting values or limits: The complexity of the issue is loosely summed up as "varying conditions of use". These conditions incorporate local, SSF, management ability, environmental conditions, livestock type, age and physiological status, their weight and relative WI as well as the interaction between water constituents, from the source all the way to the animal.
- When it comes to water quality, not all problems are directly related to toxicity; management problems are also briefly discussed, relating to F, NO_3, and iron (Fe) or hydrogen sulphide (H_2S).
- Mention is also made of the potential hazards of plants being irrigated with the same potentially toxic water that the animals drink from – an accumulation of a toxic element in crops (such as Se) may exacerbate toxicity if the animals are fed on those plants.

3.4 Inorganic, organic and biological water quality constituents

The preceding cited documents are focussed on inorganic WQC since these are the most prevalent WQC that could become COC or PHCC. The risk of GW containing organic or potentially hazardous biological material (bacteria and viruses) is considered generally to be minimal. GW of shallow aquifers is likely to be at greater risk of adverse chemical constituents originating from industrial and agricultural activity, than deep aquifers (ADWG, 2004). A growing body of literature, however, has reported on organic compounds and potentially hazardous biological material occurring in GW.

Mader and Merkle (2000) reported on microbial pathogens in GW increasing in the United States. Approximately 5.9 million illnesses were associated over the review period with biologically contaminated GW, and mortalities in the order of 1.4 million occurred. The most common biological contaminant was faecal material. Straus and Griebler (2011) present the following summary of their paper on Pathogenic Microorganisms and Viruses in GW: "*GW represents the quantitative most important freshwater resource on our planet. Generally well protected by overlaying soil and sediment layers, it is a valued source for drinking water. Along with demographic development and global change, the quality of groundwater is increasingly challenged by anthropogenic impacts including the direct and indirect introduction of potentially harmful pathogenic microorganisms and viruses. Does this pose a new risk to human health?*"

McKay (2010) and Morris *et al.* (2003) emphasize the view of increasing contamination of GW by pathogens. The CAN (2012) guidance document for determining GW at risk of containing pathogens (GARP) including GW under direct influence of surface water (GWUDI), Version 1, 2012, (CAN, 2012), addresses the probability of pathogen contamination of GW. The document sets out possible routes of contamination and methods of sampling for water-borne pathogens. The guidelines are based on confidence levels published in the Australian Drinking Water Guidelines (2016). These consider that if results of 150 samples showed no faecal bacteria, there would be a 95% confidence level that 98% of the well water is free of microbial contamination (see reference graphs below). The CAN (2012) WQG proposed "*this level of confidence (95%) to be met in order to support an opinion that the GW source is at low risk of containing pathogens and therefore will not require treatment, under current conditions*".

This is illustrated in the Figures 3.1 and 3.2 below (CAN, 2012):

Figure IS3.5.1 Level of confidence that 98% of water in a supply is free of faecal contamination for different numbers of samples when all samples tested are free of faecal contamination (Source: Ellis 1989, reprinted with permission of the Water Research Centre, Medmenham)

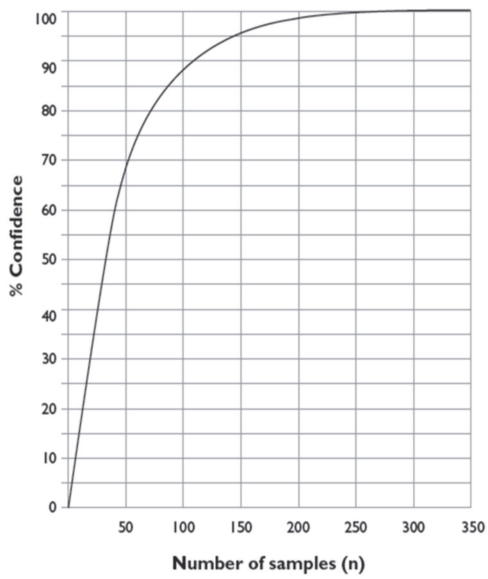

Figure 3.1 Level of confidence that 98% of water in a supply is free of faecal contamination for different numbers of samples tested are free of faecal contamination.

Figure IS3.5.2 Level of confidence that 98% of water in a supply is free of faecal contamination for different numbers of samples when 1, 2, 3 or 4 samples give positive results (Source: Ellis 1989, reprinted with permission of the Water Research Centre, Medmenham)

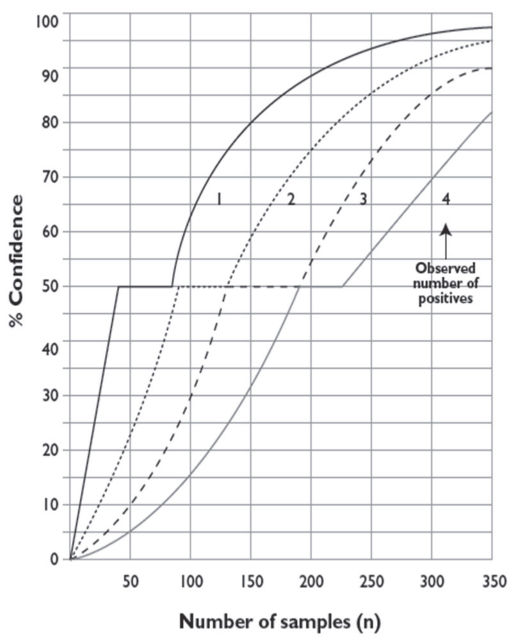

Figure 3.2 Level of confidence that 98% of water in a supply is free of faecal contamination for different numbers of samples when 1, 2, 3, or 4 samples give positive results.

This project did not include the possibility of pathogens in GW, which was an oversight in the initial planning.

3.5 Deductions

The WQG documents referred to above are not the only published guidelines for water quality, though these were chosen because they are viewed to represent a selection of processes and approaches. The documents and the WQG they present are not exhaustive. The principle points made are:

- The need for WQG is elucidated.
- The departure point is user-specific.
- WQG are health risk-based recommendations that consider the vulnerability of end-users.
- The purpose of WQG is to assist with managing health and well-being.
- WQG should be considered in the context of being site-specific as with local or national environmental, social, economic and cultural conditions.
- Risks posed by WQC should be considered in terms of exposure as when a potentially hazardous WQC is consistent over a sampling period (e.g. 5 samples in 30 days) and the rate of intake per period.
- The GW is source-specific (e.g. deep or shallow aquifers, associated geology).
- Deriving WQG values applicable to a range of users cannot be based solely on linear relationships of cause and effect due to the many interacting factors.

3.6 Problem statement on inorganic water quality constituents

The southern African geology is extremely mineral-rich, a result of it being one of the oldest land mass regions on earth since the formation of the ancient mega-continent of Gondwanaland. A large area of the region, such as the extent of the Karoo, was an inland sea that received high rainfall and was drained by large, constant rivers. The climate had supported a magnificent stand of vegetation that, due to cataclysmic geological activity, became covered and buried by volcanic lava flows and mud. The breaking up of the Gondwanaland supercontinent and the gradual drying up of the region left high levels of inorganic mineral deposits along fissures in the geological formations. Heavy metals such as gold aggregated and accumulated in the rock seams, and have been mined successfully. Other elements percolated through the fissures into aquifers and gathered elements from the surrounding geology, imparting a particular character to the water of the aquifer. In addition, aquifers have interesting characteristics of either being isolated (dammed in by geological dykes) or interconnected, allowing flows and mixing of water.

The inorganic elements in the water as dissociated elements or conjugated molecules are of varying density, causing a separation: denser molecules settle deeper and lighter molecules settle closer to the upper layers in the aquifer. The releasing or bonding of H ions affects the pH of the water, which has implications on the dissociation or conjugating of elements.

As a result, water from the upper layers in still aquifers can have a different inorganic WQC profile than the deeper water as well as a differing TDS reading. As the upper water is pumped out, an influx of water from adjoining aquifers can change the WQC profile and the TDS. Similarly, as the upper water is used and the replenishment rate cannot balance the abstraction of water, either the water table drops and a deeper well is required (that could have an altered WQC profile and TDS), or as has been found in Australia, an influx of seawater into aquifers close to the coast. The Overstrand Municipality around Hermanus where several subterranean water well fields supplement the water to Hermanus and the adjoining localities closely monitors this phenomenon.

These conditions of varying WQC of groundwater gave rise to the high range of inorganic WQC that might affect livestock and rural human populations (Casey *et al.,* 1996a, 1996b, 1996c, 1998a, 1998b, 1998c, 2001, 2006; WRC 2175 Volume 1: Part 2).

3.6.1 Defined user-group: Livestock

The agro-ecological features of southern Africa determine the suitability of ecological regions to types of livestock farming (Tainton *et al.,* 1993; De Jager, 1993). Extensive livestock farming across the country, with the exception of some communal systems, is not entirely free-range. Extensive livestock enterprises are therefore often restricted to limited use of the natural veld and are dependent on seasonal rainfall with precarious distribution. In intensive systems, such as pig, poultry and ostrich production, the possibility to move animals in the dry season or times of drought is virtually impossible. GW is the obvious alternative across the region in all aspects of livestock production.

The extent of health and production risks due to WQC in GW and the risks posed by COC/PHCC have been shown through surveys and controlled experiments.

The most likely factors to predispose livestock to inorganic WQC becoming hazardous are:

- Exposure: The exposure of animals to the WQC where exposure is:
    - Concentration (WQC mg/L) x Time (period of exposure) x Intake (L/period).
- Chronological age: The physiological age of animals is important where young animals with a high growth rate of muscle have relatively high WI. An example is the high rate of WI of chickens in the first week may be equivalent to 73.5% of live mass (Casey *et al.,* 1998a).
- Production status/Physiological stage: The production status of the animal, such as lactation, that requires a high WI.
- Environment: Demands of the environment where temperatures are high and feed is dry.
- Physiological water conservation: The inherent water turnover rates of the species or breed within species that includes the physiological capability to conserve water.
- Health: Animals in poor health as with digestive disturbances (scours) or a fever have higher demands for WI.

- Interactions between WQC: WQC such as $MgSO_4$ can cause diarrhoea and high TDS values can be diuretic and stimulate increased WI.
- Bioavailability of WQC: The bioavailability of WQC may be influenced by TDS, the pH of the digestive tract, and by dissociation and speciation under the influence of sunlight in open reservoirs or water troughs.

The exposure of livestock to WQC that might be potentially hazardous varies:

- Short-term exposure is associated with young growing animals, where the stock turnover is high.
- Long-term exposure is associated with breeding animals, where the replacement rates are slower.

Short-term exposure however of young growing animals to PHCC may affect the animals' physiology as an endocrine disruptor and limit the production, hence profitability (Du Toit and Casey, 2010; 2012).

A survey of GW revealed that 37.2% of the boreholes could be considered unfit for livestock watering due to WQC being in the category of PHCC, while other WQC had levels close to the level for PHCC. A typical incidence of PHCC in GW could be F 38%, TDS 19.1%, and Cl 24.8 with Na, SO_4, Mg, NO_3 and Ca at < 10% (Casey, *et al.,* 1996). Further surveys included trace minerals and were over a wider set of regions, including the Western Cape, the Great Karoo, the Little Karoo and the Kalahari region, and a more recent survey over a wider range across South Africa. Values published by Coetzee *et al.* (2000), Casey *et al.,* (2001) and Casey and Meyer (2006), show a high range of WQC throughout South Africa and that these can differ markedly between regions. It emerged that the mean values for As, F, Hg, NO_3, Se, Sr, U, V and TDS are COC throughout South Africa, but not necessarily in the Western Cape.

3.6.2 Defined user groups: Domestic use

Similar biological and environmental factors to those that can influence WQC being potentially hazardous to livestock prevail regarding humans. Humans are monogastric, as are pigs and with similar kidney functions. An exception would be ruminants that have a digestive system different to humans. Humans are more likely to be sensitive to aesthetic parameters such as smell caused by H_2S, soapy feel of water with high carbonate levels ($^{2-}CO_3$) and metallic taste due to Fe, compared to livestock.

In considering domestic use in general and not as potable water, inorganic WQC can contribute to degradation of appliances, as with the precipitation of $CaCO_3$ when heated causing clogging of hot water systems, or Fe in both the ferrous and ferric states reacting with metal surfaces. Water with $CaCO_3$ will not lather with soaps, but cause a scum, which is mainly aesthetically unacceptable.

3.6.3 Pathogens and organic compounds in GW

Pathogens in GW present a health risk for humans and livestock, in particular monogastric livestock, pigs and poultry. Livestock have been shown to be vectors of pathogens (*E. coli* bacteria for example) that are documented causes of critical outbreaks of illness and mortalities. In the South African context, GW is susceptible to contamination by pathogens due to the large number of informal settlements and the lack of sewage services in these settlements and on farms. Since investigating pathogens in GW was not an objective of this project, no problem statement is formulated. However, an opinion is given in the Discussion.

3.7 Problem statement and hypothesis

Problem statement

The problem statement, therefore, is that a single value WQG system for inorganic WQC is restrictive and ineffective in accommodating the complex, multiple conditions and interactions that prevail in livestock, people and household settings.

Hypothesis

The hypothesis is that a variable WQG system that is user and site-specific has the greatest probability of alleviating the effects of PHCC in water.

3.8 Current water quality guidelines pertaining to inorganic water quality constituents

Published WQG include single value systems, a range for specified users, a TWQR and a risk-based structured system, which are illustrated in the tables and text boxes.

Table 3.3 shows comparative WQG for organoleptic and physical factors and inorganic WQC in the seven WQG documents referred to above. Table 3.4 is a collated presentation of these WQG values for humans and livestock. Table 3.5 presents WQG for livestock on magnesium (Mg) as WQC. Table 3.6 shows comparative WQG for salinity as it may affect livestock. Models for WQG are presented in Box 3.1 to 3.3.

Table 3.3 Comparative water quality guidelines (WQG) for organoleptic and physical factors and inorganic water quality constituents (WQC) referring to humans, livestock and irrigation for selected WQC

WQC	Value mg/L (unless otherwise stated)													
	Australia 2004	Canada 2015		EPA 1986	EPA (1)	EPA (2)	EU 2014	FAO 1985	NRC, 2001. (MAL, dairy cattle)	WHO WQG 4th ed.	South Africa TWQR		Miscellaneous references	
		Short-term	Long-term								Human	Livestock	WQG range of maximum acceptable levels	
Organoleptic and physical factors														
Alkalinity														
Electrical Conductivity S/m														
Colour (true)	15 HU MAL			< 15 HU		15 HU	Consumer dependent			< 15 TCU				
Dissolved oxygen	>85% saturation									N/E, but not "too high or too low"				
Hardness (Calcium carbonate, CaCo3)	200			< 300					NOAEL	N/E*	n/a	n/a		
pH	6.5-8.5			5-9		6.5-8.5	6.5-9.5		N/A	6.5-8.5	6-9	n/a		
Salinity								See Table 6					3000	6
Taste and odour	Should be acceptable					3 TON	Consumer dependent				1 TON	n/a		
TDS	500	1 000-3 000 – Livestock, species dependent		< 500		500			< 5000	N/E*	0-450	0 – 1000 (a)		
		500-3 500 – Irriga-tion, crop tolerance							> 7000 Unsuitable for cattle	< 1000 Taste		0-2 000 (b)		
												0-3 000 (c)		
Turbidity	5 NTU	10 NTU — Wildlife					Consumer dependent			< 5 NTU (MAL)	0-1 NTU	n/a		
		5 NTU — Livestock								< 1 NTU Preferable				
Inorganic WQC														
Macro-minerals / Anions														
Bicarbonate (HCO3-)														
Calcium (Ca)													600- 200	1; 4; 5; 8.

Carbonate (CO3)2-													500 – 98	5
Chloride (Cl-)	250	100 — Irrigation		250	n/a	250	250			N/E*	0-100	0-1 500 (a)		
		600 — Wildlife and livestock								200-300 Taste		0-3 000 (b)		
Fluoride (F)	1.5	1.5 — Marine			4	2	0.8 — Fluoridated supply	2	2	1.5	0-1	0-2 (a)	4-0.06	1; 4; 5; 6; 8; 10.
wildlife ©		1.5	1				1.5 — sources naturally high in F					0-6 (b)		
dairy cows, breeding stock, long-lived animals ©		1.5	1											
livestock, high F diets ©		2	1											
other livestock ©		4	2											
irrigation ©		2	1											
Nitrate/Nitrite (NO_3/NO_2)	50 NO_3 MAL Infants <3mo	100/10 — Wildlife		10 mg/L of nitrate nitrogen			50 Nitrate	100 total	< 10 Nitrate	< 50 Nitrate Infants	0-6 (NO_3 + NO_2)	0-100 (NO_3)	200-10	2; 3; 4; 5; 6; 7; 9; 10.
	100 NO_3 MAL Infants >3mo	100/10 — Livestock					0.5 Nitrite	10 Nitrite	< 44 Nitrite	< 3 Nitrite Infants		0-10 (NO_2)	4-1	2; 6; 7; 9; 10.
	3.0 NO_2													
Phosphate (PO_4)													5-0.7	1; 4.
Phosphorus (P)											n/a	n/a		
Sulphates (SO_4)	250 Aesthetic	1 000 — Livestock		250		250	250		< 500 (calves)	N/E*	0-200	0-1 000		
									< 1000* Adult cattle	250 – 1000 Taste				
Cations														
Calcium (Ca)		1 000 — Livestock									0-32	0-1 000		
Magnesium (Mg)											0-30	0-500	350-50	1; 2; 4; 5; 7; 8; 9.
Magnesium sulphate ($MgSO_4$)													200-400	4
Potassium (K)	n/a				n/a	n/a			n/a	N/E*	0-50	n/a		
Sodium (Na) / Sodium sulphate (Na_2SO_4)	180 Aesthetic						200			N/E*	0-100	0-2 000		
										200 Taste			200 – 50	2; 5.

Micro-minerals													
Aluminium (Al)	0.2 MAL	5					0.2	5	0.5	0.9	0-0.15	0-5	5-0.25	4; 6; 10.
	0.1 TWQR													
Ammonia (NH_3)	0.5						0.3			N/E				
										1.5 Odour threshold at alkaline pH	0-1	n/a		
										35 (taste threshold				
Antimony (Sb)	0.003			0.146	0.006		0.005			0.02			0.006	10
										6 µg/kg Body mass, human, TDI				
Arsenic (As)	0.007		25 µg/L Wildlife and livestock	0.22-22ng/L	0.01		0.01	0.2	0.05	0.01 Provisional	0-0.1	0-1	1-0.05	1; 4; 5; 6; 8; 10.
			100µg/L Irrigation		0 — TWQR									
Barium (Ba)	0.7			1	2					0.7			1 – 2	8; 10.
										7.3 NOAEL humans				
Beryllium (Be)	Insufficient data	0.1 Livestock and irrigation		68ng/L	0.004			0.1		N/E	n/a	n/a	0.004	10
Bismuth (Bi)														
Boron (B)	4.0		5 Wildlife and livestock	750µg/L Irrigation	n/a		1	5	5	2.4	n/a	0-5	5	6
			<0.5-15 Irrigation							0.17/kg BW human				
Bromate (BrO_3)	0.02				0.01		0.01			0.01				
Bromide (Br)	n/a				n/a					N/E*				
Cadmium (Cd)	0.002	0.08 — Livestock		0.01	0.005		0.005	0.05	0.005	0.003	0-5	0-10	50-0.005	4; 6; 10.
Cesium (Cs)														
Chlorine (Cl)	5.0	1.0 — Hydroponic irrigation			4 MRDL					5			1500 – 200	1;2; 4; 5; 7; 8; 9; 10.
Chromium (Cr)	0.05	0.05 — Livestock		0.05	0.1		0.05	1	0.1	0.05	0-0.05	0-1	5-0.05	4; 8; 10.
Cobolt (Co)		0.001 — Livestock						1	1	n/a	n/a	0-1	1	4; 6.
Copper (Cu)	2.0 Health	0.2 — irrigation		n/a	1.3 AL		2	0.5	1	2	0-1	0-0.5 (a)	2.5-0.06	1; 4; 2; 3; 4; 5; 6; 7; 8; 9; 10.

	1.0 Aesthetic	0.3 Wildlife and livestock		< 1 taste		1				> 1 may cause staining.		0-1 (b)		
												0-5 (c)		
Hydrogen Sulphide (H_2S)	0.05 Aesthetic			0.002						0.05 – 1 Odour threshold				
Iodide (I)	0.1				N/A	N/A			N/A	N/E*				
Iron (Fe)	0.3 Aesthetic			0.3		0.3	0.2	N/E	N/A (may cause aesthetic problem)	N/E*	0-0.1	0-10	6-0.3	2; 4; 5; 7; 8; 9.
Lanthanum (La)														
Lead (Pb)	0.01			0.05	0.015 AL		0.01	0.1	0.015	0.01	00.01	0-0.1 (a)	0.5 – 0.015	1; 2; 4; 5; 6; 7; 8; 9.
marine life ©		0.14										0-0.5 (b)		
wildlife ©		0.1												
livestock ©		0.1												
Lithium (Li)											n/a	n/a		
Manganese (Mn)	0.1 Aesthetic	<1 µg/L	<0.8 µg/L	0.05		0.05	0.05	0.05	0.05	0.4	0-0.05	0-10		
	0.5 Health	0.2 — Irrigation								> 0.1 Taste and staining			4.6-0.05	1; 4; 5; 8.
Mercury (Hg)	0.001	0.003 — Livestock		144ng/L			0.001	0.01	0.01	0.006	0-0.001	0-1.0	10-0.0021	4; 6; 8; 10.
Molybdenum (Mo)	0.05	<0.08	<0.03							N/E*	NA	0-0.01	10	4
Nickel (Ni)	0.02	0.001 — Livestock		0.013			0.02		0.25	0.07	NA	0-1	1-0.001	6; 10.
Platinum (Pt)														
Radionuclides	0.5 Bq/L									0.1-100 Bq/L Natural occurring radionuclide species	0-11 isotope and ions dependent (a)	n/a		
Rubidium (Rb)														
Selenium (Se)	0.01			0.001			0.01	0.05	0.05	0.04	0-0.02	0-50	0.05-0.01	4; 6; 8; 10.
wildlife©			0.002-0.006											
livestock©			0.03											
irrigation©			0.01											
Silica (SiO_2)											n/a	n/a		
Silver (Ag)	0.1			0.05		0.1				N/A			0.05	8
hardness <100mg/L©		0.1	0.05											
hardness >100mg/L©		3	1.5											
Strontium (Sr)														

Tellurium (Te)														
Thallium (Tl)													0.002	10
Tin (Sn)	n/a	0.25 — Livestock								N/E*				
Tungsten (W)														
Uranium (U)	0.02	0.01 — Irrigation								0.03	NA	NA		
		0.2 — Livestock												
Vanadium (V)		0.1 — Irrigation						0.1	0.1		0-0.1	0-1	0.1	6
		0.1 — Livestock												
Zinc (Zn)	3 Aesthetic	2 — Livestock		< 5 Taste		5		24	5	N/E*	0-3	0-20	25-1.5	1; 2; 5; 6; 7; 8; 9.
		1-5 — Irrigation, pH dependent								< 4 Taste				
	Australian WQG 2004, based on a 70kg adult consuming 2L/day H_20	Fluoride short-term goal is dependent on water hardness							* > 500 mg/L $^-SO_4$ may be deleterious to cattle depending on the type of $^-SO_4$ present	* Bromide N/E because " levels occur well below the threshold for human health concern				

Table 3.4 Collated TWQG values (mg/L) from the cited WQG documents

WQC mg/L	Collated TWQR				Comment
	Humans		Livestock		
	Max	Std	Max	Std	
Anions					
Bicarbonate (HCO_3)	n/a		n/a		
Calcium (Ca)	250		3000	1500	
Carbonate (CO_3)			500	100	Livestock type dependent
Chloride (Cl)					
Fluoride (F)	4	1.5	6	2	
Nitrate/Nitrite (NO_3/NO_2)	50				Infants <3mo
	100				Infants >3mo
			10		Monogastric < ruminants
Phosphate (PO_4)	n/a		n/a		
Phosphorus (P)	n/a		0	5	Livestock type dependent
Sulphates (SO_4)	250		1000		
			500		Calves
Cations					
Calcium (Ca)	32		1000		
Magnesium (Mg)	30		500		Livestock type dependent
Potassium (K)	50		n/a		
Sodium (Na) / (Na_2SO_4)	200	100	1000		
Aluminium (Al)	0.2	0.1	5		
Antimony (Sb)	0.003		0.006		Highly variable recommendations
Arsenic (As)	0.007		1		Highly variable recommendations
Barium (Ba)	7.3		2	1	7.3 NOAEL, WHO (2011)
Beryllium (Be)	n/a		0.1		Highly variable recommendations
Bismuth (Bi)	n/a		n/a		
Boron (B)	4	2.4	n/a		0.17/kg BM humans, WHO (2011)
Bromate (BrO3-)	0.02	0.01	n/a		
Bromide (Br-)	n/a		N/E		Not considered PHCC
Cadmium (Cd)	0.01		50	10	
Cesium (Cs)	n/a		n/a		
Chlorine (Cl)	5		1500		
Chromium (Cr)	0.05		n/a		
Cobolt (Co)			0.001		
Copper (Cu)	2		2.5	1	Livestock type dependent
Iodide (I)	0.1		N/E		
Iron (Fe)	0.3		10	<6	Livestock type dependent
Lanthanum (La)	n/a		n/a		
Lead (Pb)	0.01		0.01		
Lithium (Li)	n/a		n/a		
Manganese (Mn)	0.05		10		Livestock type dependent
Mercury (Hg)	0.001		0.003		
Molybdenum (Mo)	0.05		10	0.3	Highly variable recommendations
Nickel (Ni)	0.02		0.001		
Platinum (Pt)	n/a		n/a		
Radionuclides (not included)					
Rubidium (Rb)	n/a		n/a		
Selenium (Se)	0.04		50		Highly variable recommendations

WQC mg/L	Collated TWQR				Comment
	Humans		Livestock		
	Max	Std	Max	Std	
Silica (SiO_2)	n/a		n/a		
Silver (Ag)					
Strontium (Sr)	n/a		n/a		
Tellurium (Te)	n/a		n/a		
Thallium (Tl)	n/a		0.002		
Tin (Sn)	n/a		0.25		
Tungsten (W)	n/a		n/a		
Uranium (U)	0.03		0.2		
Vanadium (V)	n/a		0.1		
Zinc (Zn)	n/a		n/a		

Table 3.5 Water quality guidelines (WQG) for livestock on magnesium (Mg) as a water quality constituent (WQC)

Livestock	Magnesium (mg/L)
Poultry	<250
Swine	<250
Horses	250
Cows (lactating)	250
Ewes with lambs	250
Beef cattle	400
Adult sheep on dry feed	500

Magnesium guidelines (FAO) – intake to cause physiological disturbance is dependent on water salinity

Table 3.6 Total water quality range (TWQR) for salinity applicable to livestock

Water salinity ranges (EC) (dS/m)	Rating / Risk	Remarks
<1.5	Excellent	Usable for all classes of livestock and poultry.
1.5-5.0	Very Satisfactory	Usable for all classes of livestock and poultry. May cause temporary diarrhoea in livestock not accustomed to such water; watery droppings in poultry.
5.0-8.0	Satisfactory for Livestock	May cause temporary diarrhoea or be refused at first by animals not accustomed to such water.
	Unfit for Poultry	Often causes watery faeces, increased mortality and decreased growth, especially in turkeys.
8.0-11.0	Limited use for Livestock	Usable with reasonable safety for dairy and beef cattle, sheep, swine and horses. Avoid use for pregnant or lactating animals.
	Unfit for Poultry	Not acceptable for poultry.
11.0-16.0	Very limited use	Unfit for poultry and probably unfit for swine. Considerable risk in using for pregnant or lactating cows, horses or sheep, or for the young of these species. In general, use should be avoided although older ruminants, horses, poultry and swine may subsist on waters such as these under certain conditions.
>16.0	Not Recommended	Risks with such highly saline water are so great that it cannot be recommended for use under any conditions.

Water quality guide for livestock and poultry uses: Salinity (FAO, 1985)

Box 3.1 Target water quality range (TWQR, mg/L) based formats of the water quality guidelines

Arsenic	Medium incidence
TWQR mg/L	Effects – all livestock
0-1.0	No adverse effects.
1.0-1.5	Adverse acute effects, e.g. anaemia, incoordination, haemorrhagic diarrhoea and dehydration may occur in sensitive species (pigs and poultry), although short-term exposure is usually tolerated. Acute effects are unlikely in larger animals (cattle, sheep, goats and horses), but may occur if arsenic feed concentrations are elevated and could be tolerated in long-term exposure according to SSF.
> 1.5	Adverse acute effects may occur, particularly in more sensitive species (pigs and poultry), although short-term exposure could be tolerated according to SSF.
Boron	Low incidence
TWQR mg/L	Effects – all livestock
0-5	No adverse effects.
5-50	Adverse chronic effects (decrease in feed intake and weight loss) may occur, but are unlikely if feed concentrations are normal, and exposure is short-term. Ruminants may be more tolerant than monogastrics. Could be tolerated in the long-term according to SSF.
> 50	Adverse chronic effects may occur (see above), although short-term exposure may be tolerated according to SSF.
Cadmium	
TWQR mg/L	Effects – all livestock
0-0.01	No adverse effects.
0.01-0.02	Adverse chronic effects such as anaemia, testicular degeneration, reduced feed intake and milk production and reduced growth may occur, but are unlikely if exposure is short-term, dietary protein, calcium and phosphorus intake is adequate, and feed concentration of cadmium is normal. Adverse acute effects such as abortions, still births, hepatotoxicity and nephrotoxicity may occur, but suckling and pregnant livestock are principally at risk. Could be tolerated in the long-term depending on Ca: P ratio present and SSF.
> 0.02	Adverse chronic and acute effects (as above) may occur, although short-term exposure could be tolerated depending on feed concentrations of Cd, adequate intake of dietary protein, Ca and P, and according to SSF.

(Casey and Meyer, 1996d)

Box 3.2 Target water quality range (TWQR, mg/L) based formats of the water quality guidelines

Chloride	High incidence					
TWQR mg/L	Effects					
	Sheep	Cattle	Dairy cattle, pregnant and lactating cattle	Ruminants	Monogastrics	Poultry
0-1500	○○○	○○○	○○○	○○○	○○○	○○○
1500-2000	○○○	○○○	○○○	○○○	○○●	○○●
2000-3000	○○○	○○○	○○○	○○○	○●●	●●●
3000-4000	○○●	○○●	○○●	●●●	●●●	●●●
4000-5000	○●●	○●●	●●●	●●●	●●●	●●●
5000-6000	○●●	●●●	●●●	●●●	●●●	●●●
> 6000	●●●	●●●	●●●	●●●	●●●	●●●
Key for Cl ○○○ TWQR. No adverse effects.						

○○● Adverse chronic effects such as decreased feed and WI and a decline in productivity may occur, but are unlikely. Adverse effects that do occur will most likely be temporary and normal production should continue once stock are adapted (see TDS). ○●● Adverse chronic effects such as decreased feed and WI, weight loss and a decline in productivity may occur, but will most likely be temporary and normal production should continue once stock are adapted (see TDS). ●●● Adverse chronic (as above) and acute effects such as osmotic disturbances, hypertension, dehydration, renal damage and salt poisoning may occur. May be tolerated for shorter exposure time ▾ depending on site-specific factors and adaptation. Stock may subsist under certain conditions, but production will in all likelihood declines (see TDS).

Copper	Medium incidence		
TWQR mg/L	Effects		
	Horses, pigs and poultry	Cattle	Sheep and pre-weaned calves
0-0.5	○○○	○○○	○○○
0.5-1	○○○	○○○	○○●
1-2	○○○	○●●	●●●
2-5	○○○	●●●	●●●
5-10	○●●	●●●	●●●
> 10	●●●	●●●	●●●

Key for Cu
○○○ TWQR No adverse effects.
○○● Adverse chronic effects such as diarrhoea and liver damage may occur, but may be tolerated if there is adequate Mo and S intake, feed concentrations are normal, and exposure is short-term. Could be tolerated in the long-term according to SSF.
○●● Adverse chronic effects (as above) may occur, but are unlikely if there is adequate Mo and S intake, — feed concentrations are normal and exposure is short-term. Could be tolerated in the long-term according to SSF.
●●● Adverse chronic (as above) and acute effects such as liver damage haemolytic jaundice may occur, although short-term exposure could be tolerated according to SSF.

Fluoride	High incidence		
TWQR mg/L	Effects		
	Horses, pigs and poultry	Cattle	Sheep and pre-weaned calves
0-2	○○○	○○○	○○○
2-4	○○○	○○○	○○●
4-6	○○○	○●●	○●●
6-12	○○●	●●●	○●●
> 12	○●●	●●●	○●●

Key for F
○○○ TWQR. No adverse effects.
○○● Adverse chronic effects associated with dental fluorosis in young livestock and skeletal fluorosis In mature livestock such as mottling of teeth and enamel hypoplasia, a decrease in feed and WI and a decline in productivity may occur, with continuous long-term exposure, but are unlikely if feed concentrations are normal, and exposure is short-term. Could be tolerated in the long-term according to SSF.
○●● Adverse chronic (as above) and acute effects such as crippling, lameness and weight loss may occur, although short-term exposure could be tolerated according to SSF.

(Casey and Meyer, 1996d)

Box 3.3 Example of water quality guideline for a water quality constituent in South African Water Quality Guidelines for Livestock Watering (1996) pertaining to fluoride (F) and selenium (Se)

Fluoride (F)
Incidence in GW: High

Description Excessive F results in tooth damage in growing animals and bone lesions resulting in crippling of older animals, especially in cattle (Canadian Guidelines, 1987). F is a cumulative toxin and signs of fluorosis may only be observed in the second and third year of exposure to high levels. Toxic effects include anorexia, hyperostosis, pitting and erosion of teeth, loss of appetite, decreased feed intake and performance. Breeding sheep should tolerate a diet with < 60 mg F on a dry matter (DM) basis.

Occurrence in the aquatic environment F, a relatively common element, comprises approximately 0.3 g/kg of the Earth crust. It exists as F in a number of minerals, including fluorspar, cryolite and fluorapatite. Fluorides are also present in numerous industrial products (phosphate fertilisers, bricks, tiles, and ceramics) and in a wide range of pharmaceutical products. Traces of F occur in many waters and higher concentrations are often associated with ground water. In areas rich in fluoride-containing minerals, ground water may contain levels in excess of 20 mg/F. F concentrations in most surface waters are > 1 mg/L. F may enter rivers as a by industrial discharge or the use of rock phosphate fertilisers. Levels of around 50 mg/F and higher have been recorded. F concentrations in surface and ground water are high in some areas in South Africa, such as the Karoo. Occurrence of fluorspar deposits is of relevance, particularly those occurring in the north-western Cape and parts of the Transvaal (previous province in pre-1994 Republic of South Africa and is the extensive region north of the Vaal River).

Interdependence with other constituents and properties F is thought to be one of the main ions responsible for solubilising Be, Sc, Nb, Ta and Sn in natural waters. Occurrence of Ca together with F limits fluoride toxicity. Fluorosis is less severe when drinking water is hard, rather than soft, and the presence of Ca and Cl reduces the toxicity of F to fish. Aquatic plants and animals accumulated F (Canadian Guidelines, 1987). Aluminium-fluoride complexes are likely to occur in water with pH levels of below neutral.

Guideline range
Non-ruminant target guideline range: 0-2 mg/L
Ruminant target guideline range: 0-6 mg/L
Potential effects in non- ruminants: At > 2 mg/L, long-term exposure could result in fluorosis developing.
Potential effects in ruminants: At > 6 mg/L, assess site-specific factors that may influence F toxicity before allowing long-term watering.

Selenium (Se)
Incidence: Low

Description Chronic selenium poisoning causes "alkali disease", of which the symptoms include a loss of hair (principally the mane and tail), lameness and decreased feed intake. Death may occur from starvation. Acute selenium poisoning causes "blind staggers", with symptoms such as impaired vision, decreased feed intake, weakened front legs and paralysed tongue and throat. Death may occur from respiratory failure. Young animals are more susceptible to selenium poisoning.

Maximum and toxic levels of selenium (Se) for livestock (NRC, 1980)

Livestock	Maximum total recommended by US FDA (mg/head/day)	Toxic level in feed (mg/kg)	Toxic level (mg/head/day)
Beef'	1	10-30	100-300
Dairy	2	3-5	30-60
Sheep	0.23	3-20	7-50

Swine	-	5-10	8-16
Chicken	-	2	-
All species	2 mg/kg	-	-

The lethal dose of Se salts for cattle is taken to be 4.4 mg/kg body mass. An estimated threshold level of 5 mg/kg feed of dietary Se is required to induce Se poisoning. Plants can concentrate Se from irrigation and soils. Se protects against Hg toxicity, and may be an anti-carcinogen. High SO_4 intakes can increase Se requirement.

Occurrence in the aquatic environment Surface and subterranean waters usually contain less than 0.05 mg/L. Se occurs in the stable anion form of selenite in aerated water at pH 6.6.
Guideline range The target guideline range for selenium in livestock drinking water is 0.05 mg/L

South African Water Quality Guidelines for Livestock Watering (1996)

A selection of organic WQC shown in Table 3.7, are the ones most often referred to in WQG and many more can occur. However, they are unlikely to occur in GW.

Table 3.7 Comparative water quality guidelines (WQG) for organic compound water quality constituents (WQC) from selected published WQG sources

Organic compound											
Acrylamide (C_3H_5NO)	0.0002		0 - TWQR	0.05-0.2	0.1µg/L	0.5 µg/L					
Asbestos	Insufficient data	3 000-30 000 fibres/L	7 MFL			N/E	0-1 MFL				
Atrazine ($C_8H_{14}ClN_5$)	0.04		0.003			0.1	0-0.002	NA	NA	< 0.0002	
hydroxyatrazine ($C_8H_{15}N_5O$)						0.2					
Benzene (C_6H_6)	0.001	0.0066	0.005		0.001	0.01					
Carbon-Cl4 (CCl_4)	0.003	0.004	0.005			0.004					
Cyanide (CN-)	0.08	0.2	0.2		0.05	N/E*	NA	NA	NA	≤ 0.05	0.2
DDT ($C_{14}H_9Cl_5$)	0.02	0.24ng/L				0.001					
Organic Carbon							0-5	NA	NA	NA	
Phenol (C_6H_6)							0-1	NA	NA	≤ 1 000	

3.9 Biological applications of water quality guidelines pertaining to inorganic wqc

The reference documents for this study are a set of script-based WQG. The range of values in the WQG shown in Table 3.3, illustrate the lack of conformity between published WQG of the selected reference countries. It is claimed in each of the documents that the best available scientific information was applied in deriving the values. However, the documents also present values that had been taken from other WQG publications (some quite old); the scientific source is not noted. The reason for the variance may be ascribed to the dearth of controlled experiments to verify the potentially hazardous levels. The values are likely to have been derived from water quality analyses with no associated adverse condition arising in the user-group. On that basis, a NOAEL is observed. The value is then adjusted along the principles of an additional margin for safety.

A few values only and for specific WQC, differentiate between ages of people (infant vs. adult) and body mass as a reference, and in livestock between adult cattle and calves, or on the basis of mg/kg body mass. Examples of these are:

- TDS: Human taste threshold = 1000mg/L; unsuitable for cattle > 7000mg/L.
- Nitrate (NO_3)/ nitrite (NO_2): maximum allowable level (MAL) for infants <3mo = 50 mg/L NO_3
- Antimony (Sb): 6 µg/L/kg body mass.
- Boron (B): 0.17/kg body mass humans.
- Zinc (Zn): Reference is a 70kg man.

Simple single values for Mg are given for different livestock types with a differentiation between lactating and non-lactating cattle and cattle on dry rations in Table 3.5. Salinity in Table 3.6 is given in the form of ranges and associated risk for types of livestock, with accompanying notes. Similar approaches are illustrated in Boxes 3.1 and 3.2: TWQR for WQC and categories of livestock, with accompanying notes. Box 3.3 offers more information as a reference text than a concise set of guidelines values applicable to categories of livestock. WQG for a selection of organic WQC are shown in Table 3.7, which is similar in format to the inorganic WQG presented in Table 3.3.

The glaring deficiency of the reference documents for this study is the generic nature of the guidelines. Although the deductions from the reference documents are to take into consideration as many factors affecting the users (humans and livestock) to formulate WQG, these recommendations are not apparent, although as noted, some user-specific recommendations are made. The WQG are not sufficiently discriminatory between people of different ages and physiological status, while WQG for livestock are extensively discriminatory between types of livestock.

The WQG do not relate the recommended WQC level or exceeding the recommended WQC in which it may become a PHCC to WI and total exposure. The data set in Tables 3.8 and 3.9 illustrate that WI (L/day) has a significant effect on the amount taken in and subsequently, total exposure.

Table 3.8 Estimated bromine (Br) intake through water

Persons	**WQG**	**Br in water mg/L**		**WI**	**Br intake mg/day**		**Comment**
	0.01	Max	Mean	(L) / Day	Max	Mean	
Adults and adolescents		0.842	0.525	2.3	1.937	1.2075	Max > WQG; mean > WQG
Children: both sexes 4-12 years		0.842	0.525	0.55	0.463	0.28875	Max > WQG; mean > WQG
Children: both sexes 0-3 years		0.842	0.525	0.4	0.337	0.21	Max > WQG; mean > WQG

(WRC 2175 Volume 1, Part 2)

Table 3.9 Estimated Zinc (Zn) intake through water as a dietary supplement

Persons	RDA mg/d	Zn in RRWH (mg/L)			WI	Zn / day by WI (mg)			Supplementation consequences**
		Max	Min	Mean	(L) per day*	Max	Min	Mean	
Males: Adults and adolescents	11	9.60	0.646	2.713	2.3	22.09	1.486	6.241	Max > RDA; mean < RDA
Children: both sexes 4-12 yr	6	9.60	0.646	2.713	0.55	5.283	0.355	1.493	Max = RDA; mean < RDA
Children: both sexes 0-3 yr	3	9.60	0.646	2.713	0.40	3.842	0.258	1.086	Max > RDA; mean < RDA
Women: Pregnancy <18 years	12	9.60	0.646	2.713	2.3	22.09	1.486	6.241	Max > RDA; mean < RDA
Women: Pregnancy 19-50 yr	11	9.60	0.646	2.713	2.3	22.09	1.486	6.241	Max > RDA; mean < RDA
Women: Lactating <18 yr	13	9.60	0.646	2.713	2.9	27.85	1.873	7.870	Max > RDA; mean < RDA
Women: Lactating 19-50 yr	12	9.60	0.646	2.713	2.9	27.85	1.873	7.870	Max > RDA; mean < RDA

*Assumed for normal healthy people of moderate lifestyle at 95% of the empirical distribution (EPA, 2004).
**No conclusive evidence on MTL for Zn in humans but is an interpretation in terms of the RDA and WQG values.
(WRC 2175 Volume 1, Part 2)

It is deduced that the WQG in the given format, with the exception of those illustrated in Table 3.5 and Boxes 3.1 and 3.2, have limited application value. As noted in the WHO (2011) WQG, the guideline values must not be interpreted as the MAL or threshold value to which WQC could be lowered in order to comply.

3.10 Application of water quality guidelines according to biological reference criteria

It is noted in the text that the WQG documents referred to are limited in recommending WQG in terms of biological reference criteria. The preceding text shows that linear discrimination between people of different ages and physiological status (e.g. pregnant and lactating women and the level of physical activity can be included) are subjected to different potential total exposures of WQC.

In humans, the reference body mass (BM) is standardised at 70kg for men and 60kg for women. This is applied to estimate the NOAEL for adults and various chemicals. A number of biases are in the BM reference since it does not accommodate accurately differences in MBM in relation to BM.

3.10.1 Metabolic body mass (MBM) in mammals

In mammals, basal metabolic rate (BMR) is proportional to body mass ($kg^{0.76}$). The relationship is allometric and applies to humans and livestock. MBM is the proportion of BM reliably related to energy metabolism of the body in a resting state (BMR). The relationship is exponential where MBM = $BMkg^{0.76}$. Table 3.10 and Figure 3.3 illustrate the relationship between BM and MBM. Figure 3.4 illustrates the log relationship between MBM and BM and Figure 3.5 illustrates the relationship between MBM as percentage of BM.

Table 3.10 Body mass, metabolic body mass (MBM) and metabolic body mass as percentage of body mass (MBM/BM)%

Body mass	MBM	(MBM/BM)%
5	3.34	66.87
10	5.62	56.23
15	7.62	50.81
20	9.46	47.29
25	11.18	44.72
30	12.82	42.73
35	14.39	41.11
40	15.91	39.76
45	17.37	38.61
50	18.80	37.61
55	20.20	36.72
60	21.56	35.93
65	22.89	35.22
70	24.20	34.57
75	25.49	33.98
80	26.75	33.44
85	27.99	32.93
90	29.22	32.47
95	30.43	32.03
100	31.62	31.62
105	32.80	31.24
110	33.97	30.88
115	35.12	30.54
120	36.26	30.21
125	37.38	29.91
130	38.50	29.62
135	39.61	29.34
140	40.70	29.07
145	41.79	28.82
150	42.86	28.57

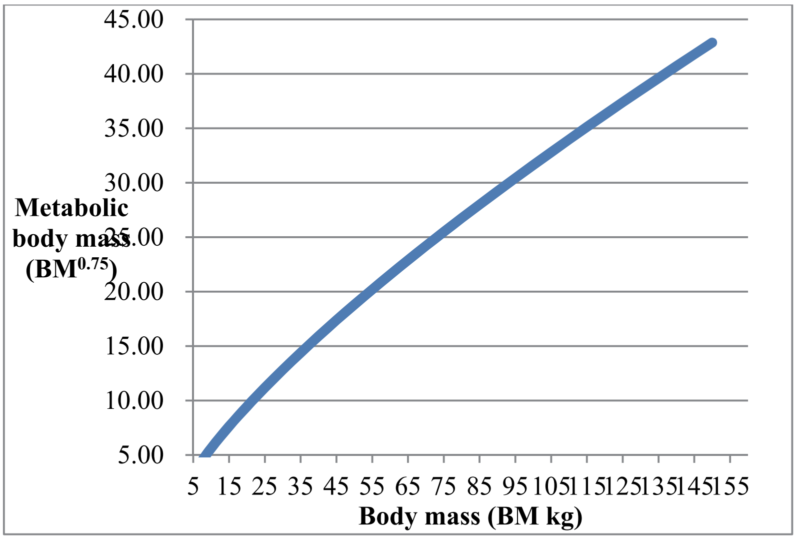

Figure 3.3 Relationship between body mass (kg) and metabolic body mass ($BM^{0.75}$).

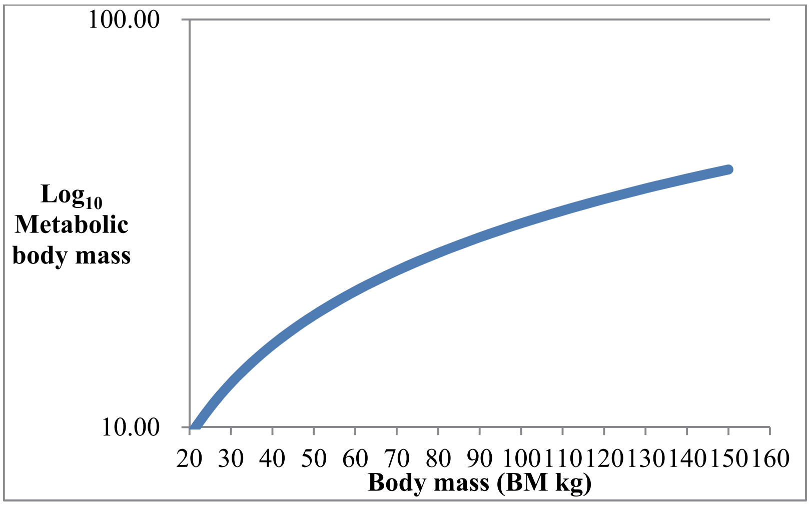

Figure 3.4 Relationship between body mass (kg) and log metabolic body mass (log $BM^{0.75}$).

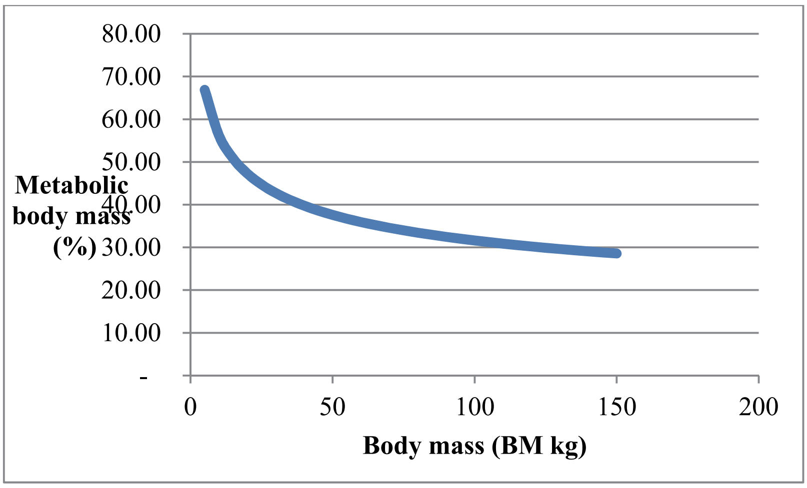

Figure 3.5 Relationship between body mass and metabolic body mass as percentage of body mass.

The guidelines give WQC values of mg/L, but do not place this in relation to BM or MBM. Tables 3.8 and 3.9 show the estimated relative WI rates of various categories of people without a reference to metabolic rates. The WI rates in Table 3.9 show differences between women in different physiological states. The estimates are very broad assumptions. If the WI, and thereby exposure to WQC, were calculated in terms of BM or MBM, the potential of a WQC being considered a COC or PHCC is more accurate, since it is assessed against a biological standard.

Table 3.11 illustrates that based on the standard WI of 2.3 L/d for adults and adolescents the exposure to a WQC is linear between BM categories. If the WI is related to activity level, for example, low and high at 80% and 120% of the standard, respectively, the relationships decrease or increase linearly.

Calculating the intake and exposure per MBM, the relationship is exponential decreasing. Since MBM decreases exponentially against BM, the risk associated with a WQC decreases exponentially. The calculated MBM for very young children of 5 kg BM is 3.34 or 66.87% of BM; in a teenager of 45 kg, MBM is 17.37 with the ratio decreasing to 38.61%, and in an adult of 80 kg, MBM is 26.75, which is 33.44% of BM.

The assumption is based on MBM calculated on a BMR. Activity and muscle type influence MBM, which could be taken into consideration, but would add a more complex dimension to the assessment of risk. Activity is taken into account in the illustration as a factor of WI, where low activity is calculated at 80% of the reference value (2.3 L/d) and the high activity at 120% of the reference value.

The principles illustrated would apply to mammalian livestock (cattle, sheep, goats, pigs, horses and others).

Table 3.11 Water quality constituent (WQC) intake based on body mass (BM) and metabolic body mass (MBM) and relative level of activity

Persons	**WQG value for a WQC**	**BM kg**	**WI L/d**	**WI L/kg BM/d**	**WQC intake mg/d**	**WQC intake/kg BM/d**
Based on BM	0.01					
Adults and adolescents 50kg (Average, index 1)		50	2.3	0.0460	0.0230	0.00046
Adults and adolescents 50kg (Low activity, index 0.8)		50	1.84	0.0368	0.0184	0.00037
Adults and adolescents 50kg (High activity, index 1.2)		50	2.76	0.0552	0.0276	0.00055
Adults and adolescents 80kg (Average, index 1)		80	3.68	0.0460	0.0230	0.00046
Adults and adolescents 80kg (Low activity, index 0.8)		80	2.94	0.0368	0.0184	0.00037
Adults and adolescents 80kg (High activity, index 1.2)		80	4.42	0.0552	0.0276	0.00055
Based on MBM	**WQG value for a WQC**	**MBM**	**WI L/d**	**WI L/MBM/d**	**WQC intake mg/d**	**WQC intake/MBM/d**
Adults and adolescents 50kg (Average, index 1)		18.80	2.3	0.1223	0.0230	0.00122
Adults and adolescents 50kg (Low activity, index 0.8)		18.80	1.84	0.0979	0.0184	0.00098
Adults and adolescents 50kg (High activity, index 1.2)		18.80	2.76	0.1468	0.0276	0.00147
Adults and adolescents 80kg (Average, index 1)		26.75	3.68	0.0860	0.0230	0.00086
Adults and adolescents 80kg (Low activity, index 0.8)		26.75	2.94	0.0688	0.0184	0.00069
Adults and adolescents 80kg (High activity, index 1.2)		26.75	4.42	0.1032	0.0276	0.00103

3.10.2 Constituent Intake Rate Risk Assessment model (CIRRA)

The CIRRA model was proposed in 1989 for the WRC project. It took much research into WI studies and the responses of various categories of livestock to WQC as well as extensive literature studies to set the foundations contained in WRC reports to develop the CIRRA model (Meyer, 1998; Casey and Meyer, 1998d; Meyer and Casey, 2012).

The model is based on Equation 1:

$$Y \text{ (risk factor)} = X_1[\text{Animal (or person) type}] * X_2[\text{Animal (or person)'s physiological status}] * X_3[\text{environmental demands}] * X_4[\text{water (PHCC) intake and turnover rate}] * X_5[\text{level of PHCC}] * X_6[\text{physiological effect of PHCC}] * \ldots X_n \times e$$

The CIRRA model is based on biological reference criteria such as animal type, physiological status, WI and turnover rates; and then evaluates the risk imposed by other factors that are either aggravating or mitigating. This is essentially a metric system to estimate more accurately the probability of a WQC becoming a PHCC.

The publication of Meyer and Casey (2012) follows on the preceding publications noted and describes the development of risk assessment. It was noted that even with a software-based tool for risk assessment, general preceding observations are made. A risk assessment is generally done either when (i) an analysis of water has revealed a COC or PHCC, or (ii) either subclinical (loss in production) or clinical (pathological condition) toxicity symptoms have been observed. For the latter, before starting the risk assessment, the user would first need to (i) do a clinical examination of the affected animals and to establish the incidence of the problem within the group or region and (ii) eliminate other known causes of both subclinical and clinical observations (See (WRC 2175 Volume 1, Part 2).

The risk assessment would be conducted as described in Boxes 3.4 and 3.5. The CIRRA model would ask the user to enter choices for each variable, such as the livestock type, the physiological status of the animal, the type of ration fed, the characteristics of the range, the season, etc. The system uses algorithms to estimate the risk for each of the constituents in the sample. The reference values in the model are published values obtained, for example, from the National Research Council (USA) tables or based on published studies. The assessment is within an accuracy range of > 70%, but is largely depend on the accuracy of the information provided by the user.

Application of the CIRRA model was limited however. The model had emerged from WRC-funded projects and used as a tool by the developers in helping the livestock industry, including farmers, veterinarians and feed companies in water quality management for livestock. The risk is not updating the model or its perpetuity on a national scale.

Box 3.4 Procedural steps in assessing risk due to water quality constituents (WQC)

Procedural steps
1. Sample water at the source and at the point of use
2. Use correct preservation methods for water samples
3. Use standardised analytical techniques
4. Focus analyses on constituents that have a bearing on livestock (e.g. F, Se) and watering facilities (e.g. Fe)
5. Review each of the constituents in the analysis - Concentration (mg /L) - Potential physiological effect of the constituent - Possible alleviatory factors such as total dissolved solids, competitive constituents
6. Note the source of the sample
7. Note the water user-group (example: sheep – lactating, broiler chickens – one week old, horses – endurance).
8. Note the site-specific factors that can influence WI - Dry matter content of the rations - High physiological demand increasing WI as with young animals, lactation, high physical activity, etc. - Environmental factors such as high altitude, etc.

Meyer and Casey, 2012.

3.10.3 Assessment of health risks due to WQC

Health risk assessment for inorganic WQC is aimed at setting TWQR values for risk categories shown in Box 3.5. Risk assessment is done at the generic level similar to the WQG cited. Assessment in terms of biological impact of WQC can be expanded to include exposure rates to WQC, with subdivisions, speciation and bioavailability of ingested WQC, environmental effects, nutritional sources of elements ingested via water, clinical effects and in the case of livestock, transfer to consumer of animals' products of chemicals that had been retained in organs and tissues.

Health risk assessment for pathogens would be based in the 98% confidence level of samples being free of pathogens. The vulnerability of humans and livestock to pathogens would be constructed as shown in Box 3.5. An important aspect, however, of vulnerability is physiological adaptation to potential pathogens where chronic exposure may contribute to a tolerance. Exposure exceeding tolerances, or other pathogenic conditions, might tip the balance towards the negative, initiating an expressed pathogenic effect.

Box 3.5 Health risk assessment by categories in terms of vulnerability

Health risk assessment is aimed at setting TWQR values for the risk categories	
Livestock watering	**Domestic use**
Generic: WQC as COC and PHCC Biological impact: Exposure rates to WQC Categories of livestock Metabolic mass criterion Proportional water intake Gender, age Suckling Growing Adult Production status Lactation Growing young Conception / fertility Gestation Teratogenesis Epigenetic effects Transplacental effect on foetus Speciation and bioavailability of ingested WQC Environment effects Nutritional sources Clinical effect: Diarrhoea, etc. Subclinical effect Unthriftiness Growth, milk, wool, etc. Immunity Metabolic effect Skeletal abnormalities Teeth, hooves (laminitis) EDC effects on TSH, GH, androgens oestrogens, cortisols, etc. Transfer to consumers of animal products	Generic: WQC as COC and PHCC Biological impact: Exposure rates to WQC Categories of consumer Metabolic mass criterion Proportional water intake Gender, age Adults, M and F Young adults Prime adults Seniors (60+) Juveniles (12 to 20) Children (4-11) Toddlers (2 to 3) Infants (0 to 24 mo) Physiological status Sedentary vs Active Lactating Conception rates / fertility Gestation Teratogenesis Epigenetic effects Transplacental effects on foetus Speciation and bioavailability of ingested WQC Environment effects Nutritional sources Clinical effect: Diarrhoea, etc. Mental impairment Subclinical effect Unthriftiness Growth Immunity Metabolic effect Skeletal abnormalities Hairs, skin, nails, teeth EDC effects on TSH, GH, androgens, oestrogens, cortisols, etc.

3.11 Proposed revision of the South African Water Quality Guidelines: Volume 5 Agricultural use: Livestock watering, 1996

3.11.1 Livestock watering

The SAWQG Vol. 5: Livestock watering (1996) was presented as comprehensive document in a generic approach to water quality for livestock. The proposed changes to WQG are aimed at GW, which would exclude only the biological WQC noted in the 1996 WQG, namely algae.

The 1996 WQG were part of a set of 8 volumes:

- Volume 1: South African Water Quality Guidelines – Domestic Water Use
- Volume 2: South African Water Quality Guidelines – Recreational Water Use
- Volume 3: South African Water Quality Guidelines – Industrial Water Use
- Volume 4: South African Water Quality Guidelines – Agricultural Water Use: Irrigation

- Volume 5: South African Water Quality Guidelines – Agricultural Water Use: Livestock Watering.
- Volume 6: South African Water Quality Guidelines – Agricultural Water Use: Aquaculture
- Volume 7: South African Water Quality Guidelines –Aquatic Ecosystems
- Volume 8: South African Water Quality Guidelines – Field Guide

Any critique on Vol.5: Livestock Watering, would invariably apply to the whole set. Considered, however, as a stand-alone volume aimed at a defined user-group, the comments are intended to improve WQG for livestock, with the particular emphasis on GW.

Positives are that the 1996 WQG document explained the application of the concept of water quality. Background information was given to inform users of characteristics of each WQC in the guideline. These include occurrence, interactions, measurement, data interpretation and treatment options, and the effects in terms of norms, possible mitigation and TWQR as the criterion. The assumption of treatment is that if the WQC exceeds the TWQR and becomes a PHCC, treatment options can be exercised by changing the character of the water or by changing the way in which the water is used. These are useful to have in a guideline.

Negatives of the 1996 WQG Livestock Watering are the cumbersome extended layout and the continuous repetition of the bibliography at each WQC. Up to seventeen repetitions occurred. These references were highly relevant at the time, but in most cases, revised editions of reference books have been published. An example is the NRC (2005) standards for Mineral Tolerance of Domestic Animals. An update of the literature would be needed.

Research on micro-minerals and macro-minerals that have relevance on GW has advanced considerably since the 1996 WQG. Examples are the effects of TDS on WQC becoming PHCC and links between WQC in GW and the geology of regions with the potential to predict the occurrence of specific WQC from the geology.

Other examples of additional information are the effects of WQC on species of livestock not listed such as ostriches; and the spatial distribution of WQC that was gained from sampling GW in many regions of the country. Information has been gained on the distribution, risk and biological effects of WQC occurring in GW that were not included in the 1996 WQG such as F (Coetzee *et al.,* 1997; 2000) and Br (Du Toit and Casey, 2010; 2012; Meyer (2015). This new South Africa-generated knowledge would make the WQG more applicable to livestock production in South Africa.

3.11.2 Domestic use

The 1996 WQG Vol. 1 Domestic Use follows the same format as Vol. 5 for Livestock. The bibliography is similar and the same form of repetition occurs. Comments in this regard are therefore the same as for livestock.

The data gained on spatial distribution of WQC and the effects noted on livestock can be extrapolated to humans as a moral imperative. Many people share the same GW sources as livestock, and the sensitivity of livestock can be interpolated to humans. The MBM biological reference would be applicable to humans and form a common denominator.

3.11.3 Pathogens
The current WQG do not address potential pathogens in GW, which should be included given the health risk posed by settlement conditions lacking sewage services around South Africa.

3.12 Discussion
The problem statement that a single value WQG system is restrictive and ineffective in accommodating the complex, multiple conditions and interactions that prevail in livestock, people and household settings is elucidated. A WQG cannot be a stand-alone approach to managing health risks pertaining to water – my statement. However, it seems that single value WQG systems are the norm in the WQG of the countries and organisations reviewed. The reason is the relative simplicity of producing single value guidelines. In order to reduce risk to vulnerable users, some differentiation was introduced. Examples of these are: TDS: Threshold value for human taste is 1000 mg/L; the threshold unsuitable for cattle is 7000 mg/L; Nitrate (NO_3)/ Nitrite (NO_2): The MAL for infants <3 mo is 50 mg/L NO_3; Antimony (Sb): 6 µg/L/kg body mass; Boron (B): 0.17/kg body mass humans; Zinc (Zn): Reference is a 70 kg man.

The recommended WI (WI L/d) for people of different ages and physiological status shown in Tables 3.8 and 3.9, show that people can be exposed in varying degrees to WQC. The duration of the exposure may then become critical, noted in the WHO (2011) WQG. This would also apply to livestock.

The single value system was expanded to a risk-based TWQR shown in Tables 3.4 and 3.5 and Boxes 3.1 and 3.2. The TWQR would appear to be close to the most applicable user-friendly, scientific, text-based system. However, as noted by Meyer and Casey (2012), it would still require that the user must assess other factors subjectively to complete the assessment.

Age and BM are limiting biological reference criteria due to their variability. Estimation of health risk depends on how the body deals with the foreign or excess chemicals ingested into the digestive tract and, if this occurs, absorbed into the circulatory system. Once in the system, the chemical might enter the metabolic pathway or becomes competitive with essential elements in metabolism. An example is Br becoming a thyroid endocrine disruptor by displacing I and affecting the physiological function determined by thyroid hormone (Du Toit and Casey (2010, 2012). Table 3.9 demonstrates a case in which GW can be a conduit for dietary supplementation of elements.

Figures 3.1 and 3.2 show the allometric relationship between BM and MBM and Figure 3.5 shows MBM decreases as a percentage of BM with increasing BM. MBM is an accurate estimation of the true of metabolic mass of mammals. This is based on the BMR (ml O_2/h) (White and Seymour, 2003). Table 3.10 shows (1) the linear relationship between BM and intake or exposure even when the variance of activity is introduced, and (2) the nonlinear relationship when intake is calculated against MBM (L/MBM/d). The latter demonstrates that lighter (and younger) animals and people might be at higher risk to PHCC than heavier (and more adult) people and animals.

The CIRRA model is built on Equation 1, accommodating variables that contribute in the multi-factorial assessment of health risk. The model has been shown to effectively accommodate animal and site-specific variables. MBM would fit into the model.

Box 3.5 illustrates an expansion into categories for health risk assessment, which can be accommodated in an expanded text-based WQG. The cited WQG have limited divisioning of this nature.

According to the WQG reviewed, these list the most likely WQC to appear in water and most likely to be PHCC under specified circumstances and users.

As noted, a new text-based compilation of WQG for livestock would bring updated and new information to the attention of livestock producers and professional persons. The possible effect of climate change on GW is not yet clear. What remains clear and of growing concern is the continued exposure of livestock and people to PHCC. A new text-based system should address this from a health risk aspect. The more interactive system CIRRA would be complementary management tool.

Regarding potential pathogens in GW, this would require urgent attention. The reason is that and the fast expanding informal highly concentrated human settlements where no sewage services are available pose a threat to the quality and health-risk of GW. A search of the WRC website a search of the WRC's Knowledge Hub revealed no projects on the topic.

3.13 Conclusion and recommendation

The hypothesis that a variable WQG system, which is user and site-specific, has the greatest probability of alleviating the effects of PHCC in water is sustained. There appear to be two practical options, however. Option 1 is to develop WQG as shown in Tables 3.4 and 3.5 and Boxes 3.1, 3.2 and 3.5. Option 2 is to follow a software-based system similar to the CIRRA model. The information captured in the text-based system should include data on spatial distribution of WQC, alleviatory mechanisms for PHCC and data on WQC that were not in the 1996 WQG. PHCC in RRWH and GW and the development of standards require urgent attention. The CIRRA model should be revised and made available on a national scale. This may best be achieved through a centralised reference centre for water quality management.

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CHAPTER FOUR

CONCLUSIONS AND RECOMMENDATIONS

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4.1 Introduction

The project assessed the potential for using two important water sources, RRWH and GW, in domestic settings and for livestock watering. Using either of these water sources in the context noted is not new: Harvesting rainwater from roofs for domestic purposes and using groundwater for domestic purposes and livestock watering are well-established practices. In an overall water-scarce country such as South Africa, rural and farming communities who do not have water utility services are reliant on these sources. In addition, the inability of some local authorities to manage and supply water to communities necessitates that local residents seek alternative water sources.

The questions that arose regard the safety of the water in terms of microbial and inorganic chemical standards. The concept of safety, however, has broad parameters. Water becomes unsafe when it poses a potential health risk to consumers, whether people or livestock. In both cases, ensuring minimum risk to health and wellbeing is a moral imperative. For people, safety and minimum exposures to health risks are basic human rights, while for livestock safety and minimum exposure to health risk are both of primary and secondary concerns. Primary concerns relate to livestock developing debilitating sub-clinical and clinical physiological and anatomical pathologies that can reduce the production potential of the livestock. The consequences would be the economic viability of farming enterprises. Secondary concerns are where the livestock products become conduits for the transfer of potentially hazardous inorganic water quality constituents (WQC) to consumers of livestock products.

Determining risks to health and wellbeing by biological or chemical WQC does not depend on simple linear relationships between a constituent in water and the consumer. The expression of risk or the expression of either sub-clinical or clinical pathology is the subject of multifactorial interactions, and within these, the weighting or relative contribution of a constituent is either mitigated or aggravated by the consumer's physiological condition or by environmental influences. An example would be that children or lactating mothers are in different physiological states compared with adults or non-lactating mothers and hence children and lactating mothers would have higher risk profiles to potentially hazardous water constituents. Biological adaptation to potentially hazardous biological constituents (e.g. *E. coli* bacteria) could mitigate the debilitating responses of consumers to ingested organisms whereas un-adapted persons are highly susceptible to ingested potentially hazardous biological constituents.

In terms of inorganic WQC, the potential effect on consumers may be acute such as the ingestion of $MgSO_4$ causing digestive disturbances or may be chronic as in the case of ingesting endocrine disrupting chemicals over a long period. The effect of the latter is at first sub-clinical and not easily observed until clinical conditions begin to emerge.

The challenge therefore is to construct WQG that are either generic in their application or are specific taking into account the physiological conditions of consumers or contributing environmental conditions.

According to the WHO (2011), guidelines should be considered in the context of local or national environmental, social, economic, cultural conditions and user in deriving local guideline values. The Australian Drinking Water Guidelines (ADWG, 2011, updated 2016), are intended to provide a framework for good management of drinking water supplies. The ADWG notes that WQG are not mandatory standards, but are intended provide references for determining the quality of water for consumers taking into consideration the diverse array of regional or local factors, and economic, political and cultural issues, including consumer expectations.

The overall aim of the project was to evaluate risks associated with the use of RRWH for domestic use and homestead food gardens; and GW for domestic use and livestock watering. The aspect of evaluating RRWH for food gardens was not addressed largely because this water source is considered too scarce and precious to use directly on household gardens. The aims were accomplished by addressing specific objectives as reported in Volume 1, Chapters 4 to 9 and in the present Volume 2, Chapters 2 and 3.

4.2 Volume 1: Microbial quality of roof harvested rainwater

The results noted the potential health risks associated with pathogens in RRWH are either due to contamination of the roof-surfaces from animal sources such as birds and livestock, or due to organisms in the rainwater tanks. Despite the reports from research projects done elsewhere on the levels of contamination that may give rise to or are associated with health risks, no consensus has been reached on standards. However, pathogens that are transferred into rainwater storage tanks can survive and persist in biofilms and shed into the water.

Potentially pathogenic bacteria were detected in stored RRWH that had been presumed to have been decontaminated by traditional methods such as exposure to UV-sunlight. Although a total microbial count has value, it is important to differentiate between indicator species of faecal pollution and other potential pathogens. For example, *E. coli* may be outlived by a number of pathogens including *Salmonella*, *Campylobacter* and *Enterococcus* species, which means risk assessment should not be based on *E. coli* and extrapolated to the generic presence of pathogens, which is the practice regarding RW systems. A quantitative microbial risk assessment would be determined by the abundance of individual pathogenic bacterial species.

Faeces were a major source of microbial contamination. The most prevalent faecal indicators in 365 water samples from various water sources (3 GW, 5 ground harvested rainwater tanks, 5 RW, 80 RRWH and 1 spring) were measured as concentrations of *E. coli* (29.1%) and enterococci (19.5%) within 1-10 cfu/100mℓ, whereas that for faecal coliforms was (36.6%) were within 100-1000 cfu/100mℓ. Evaluation of the microbial quality of RW used by the villagers as an alternative water source revealed that 79% had enterococcus, 39% *E. coli* and all samples had faecal coliforms. The majority of the samples that tested positive for enterococcus (32%) and *E. coli* (16%) had a concentration of 10-100 cfu/100mℓ. However the majority of the concentrations for faecal coliforms detected (48%) were of concentrations greater than 1000 cfu/100mℓ.

As indicators of microbial quality RRWH and ground surface runoff, the concentrations of *Escherichia coli,* faecal coliforms, enterococci and *Pseudomonas aeruginosa. E. coli* and enterococci were detected in 44.8% of the RRWH tanks although enterococci concentrations were several times higher than those for *E. coli*. Urban pigeons are the likely sources of contamination since enterococci were detected in pigeon faecal samples. Of the various enterococci detected, the four dominant species in faecal samples were *E. faecalis* (20.5%), *E. mundtii* (20.51%), *E. faecium* (23.1%) and *E. casseliflavus* (17.3%) and the dominant species in RRWH were *E. casseliflavus* (34.6%) and *E. mundtii* (33.2%).

Pathogen detection remains critical in determining the fitness-for-use of water sources. The prevalence of pathogenic bacteria and specific virulence genes were detected in samples of the water sources using Real-Time PCR. All the samples tested negative for the *Shigella* spp. ipaH gene, while five tested positive for *Salmonella* ipaB gene. No samples tested positive for stx1 and stx2, and only two tested positive for the eaeA gene.

The formation of biofilms in water storage tanks may become causes for concern due to the biofilms having the potential to be sinks for pathogens, while the formation of biofilms are associated with the characteristics of the tank. Water stored in low-density polyethylene storage tanks had deteriorated microbiologically to levels considered unfit for human consumption within 15 days, which was associated with the formation of biofilms. Imperfections in the UV resistant inner lining of the tanks revealed to be ecological niches for microbial colonisation and biofilm development.

Establishing the microbial populations, their diversity and detecting pathogens are essential in establishing WQG control measures. In this research, bacterial diversity in RRWH and RW was determined through pyrosequencing. The structure of bacterial communities clearly showed significant similarities between RRWH and differences with the RW, suggesting different levels and/or sources of contamination and environmental factors affecting the various water sources. Signatures of potential pathogens included *Legionella*, *Acinetobacter, Pseudomonas, Clostridia, Chromobacterium, Yersinia*, *Serratia* and *Legionella* suggesting a potential health risk to households using RRWH. The MALDI-TOF-MS technique characterised *Escherichia coli* isolated from RRWH and distinguished 31 strain groups.

The global concern for anti-biotic resistance in human and animal health management programmes should be extended to the prevailing microbial populations in animal contamination sources to comprehend the risks in microbial water quality management. The current research showed that in a total of 239 *Escherichia coli* isolated from fresh pigeon faecal samples (130 isolates), resistances to anti-biotic were: ampicillin (27.9%), gentamicin (23.6%), amikacin (24%), tetracycline (17.4) and amoxicillin (16.9%). The highest number of phenotypes was observed for single antibiotics and no single antibiotic resistance was observed for chloramphenicol, ceftriaxone, gentamicin, cefoxitin, cotrimoxazole, although they were detected in multiple antibiotic resistance (MAR) phenotypes. The highest multiple antibiotic resistance (MAR) phenotypes were observed for a combination of four antibiotics, on isolates from JHB (18.8%), pigeon faeces (15.2%) and Pretoria (5.1%). The most abundant resistance phenotype to four antibiotics, Ak-Gm-Cip-T was dominated by isolates from pigeon faeces (6.8%) with Pretoria and Johannesburg isolates having low proportions of 1.3% and 3.1%, respectively. It would appear that various environmental settings where RRWH is practiced might affect the characterisation of the antibiotic resistance determinant genes among the isolates.

WQG for microbial risk assessment need to include the source of water, the collection system, the characteristics of the storage tanks, especially in terms of biofilm formation, and the potential for contamination prior to harvesting and post-harvesting. The microbial risk assessment (MRA) procedure was applied to compile guidelines on rainwater harvesting and the use of harvested rainwater. The guidelines identify critical practices or points of concern that may serve as a source of contamination and suggests the appropriate mitigation strategies to minimise adverse health effects.

4.3 Conclusions and recommendations on microbial quality of roof harvested rainwater

The following recommendations are formulated from the research results:

The contamination of RRWH appears to be strongly influenced by environmental settings especially the presence of a faecal source in the form of nearby animal housing. While little can be done to the presence of a faecal source around rural households, practicing good animal husbandry and ensuring appropriate RRWH-system maintenance should be some of the minim aspects put in place to lessen the levels of contamination. This should also include regular cleaning of the roofs and gutters especially before rainfall events or prior to the start of the rainfall season.

Although the levels of contamination in RRWH were significant, some levels of indicator bacterial presence in such sources may be tolerated. However, tolerable levels of contamination will depend on water use and can only be established where good RRWH practices are being implemented. That is, after all has been done to harvest clean rainwater, contaminant levels detected in the water may be normal for the area.

Since the presence of pathogens cannot be correlated to faecal indicators in RRWH, the recommendation is to develop a system based on the dual prevalence of *E. coli* and enterococci as sanitary indicator bacteria. Further research should focus on establishing the applicabilities of *E. coli* and enterococci to show levels of contamination and potential health-risk as applied to stored harvested rainwater.

Biofilms can develop in both untreated and treated water sources on the interior of low density polyethylene water storage tanks as early as one day after collection. However, the storage period and the microbial quality of the source water influences water quality deterioration and the rate of biofilm formation. Biofilm development is further enhanced by crevices in the interior surface of storage tanks. Effective management of biofilms in water storage systems is a critical part of RRWH quality management.

Given the lack of standards, knowledge of contamination and complexity of the problem with RRWH, guidance information is required on best practices and risks associated with harvesting rainwater. The guidance information should give a description of the chemical and biological constituents that can potentially affect water quality, their occurrence in the harvest water interdependence with other constituents, and their properties. These should also include standardised methods for measurement. For each contaminant, the guidance information on risks that are site-specific should be provided in addition to generic guidance information for RRWH practices. While the guidance information may not be completely accurate, it should provide improvement over the current non-specific systems. The information should allow users to obtain information on risks more easily by explaining RRWH sampling procedures and how to interpret the results according to the RHRnW system, general environment, and site or homestead specific factors. This guidance information more specifically should specify the TWQR in which infection or adverse effects are unlikely to occur. Current Australian data suggests that even when concentrations exceed the upper safety limit and are likely to result in infection, diseases may not always develop in the prevailing community.

The response to risks depend on site-specific factors, synergistic and antagonistic interactions between food and water contaminants, the age of the person, and the actual water intake that determines the ingestion rate of the contaminant. However, a precise way to evaluate the risk has limitations in that tools to measure RRWH specific factors may not be easily available. In this case, impact factors may have to be estimated, making it still precarious. Given this scenario, an interactive WQG in the form of computer software system that would have programmed references, by which risk assessment could be done for a specific RRWH system, environment, site or homestead specific factors and extent of exposure, should be developed.

In an attempt to mitigate these risk factors, the government has embarked on distribution of RRWH systems to communities without access to piped water. Rainwater harvesting has traditionally been practiced by a number of households in these communities without any reports of diseases emanating from its use. It cannot be ignored that there is a body of evidence, which undoubtedly shows the link between diseases associated with the use of harvested rainwater. In order to empower communities and counter the potential negative effects of contaminated water, community-based workers should be trained on how to advise rural communities in the maintenance of RRWH systems. The knowledge package should incorporate cultural norms and practices in RRWH and handling within the communities. The challenge in most of these communities is the presence of animal faeces in close proximity to the households. This may be in the form of animal housing, of which for security reasons are built near households.

Research in South Africa on harvested rainwater in rural settings is limited. Data from other situations cannot be directly extrapolated to rural settings. Research is required on the actual levels of risks in these communities.

Data is required on the reliability of the various water sources including chemical and microbiological safety from which algorithms can be constructed to determine critical parameters for risk assessment. These would be useful tools for following or predicting trends, real-time scenario analyses and for developing appropriate management strategies and treatment systems.

4.4 Volume 2: Chemical quality of groundwater for potable use and livestock watering
In complementing the objectives of Volume 1, Volume 2 focused on the inorganic WQC with the aim of investigating the occurrence of inorganic WQC in RRWH, ground harvested rainwater, GW and RW to estimate whether risk to livestock and people might occur from these sources singularly or in combination. This information were intended to be collated into the WQG for livestock and rural communities.

The WQC-profiles differed between GW, RRWH, RW and MW samples drawn from various localities. GW had the highest content of inorganic elements. Contamination of roofs mainly by wind increases the amount of selected inorganic WQC in RRWH depending on the locality. Household settings close to mining activities have a high probability of PHCC (for example Cd or Cr) contaminating RRWH. WQG should include measures to limit the contamination such as discarding the first flushes after the dry period.

Apart from risks associated with the presence of inorganic PHCC, the research showed water sources may be supplementary dietary sources for various essential elements. It occurred that RRWH was characterised by high levels of Zn that is ascribed to the zinc-galvanised sheet-iron used for roofing material. Zn in RRWH could be a source to supplement dietary Zn in humans. The inorganic WQC in the water sources varied marginally over season.

An important result was the presence of Br, a halogen-class element. Controlled research has revealed that Br may become a potential endocrine disruptor. Levels of Br exceeding the current WQG value of 0.01 mg/l were measured in GW and in RRWH at a locality close to the coast, which means those communities and their livestock are exposed to Br as a PHCC. Br is currently not in the SA WQG.

The results elucidated the problem that a single value WQG system is restrictive and ineffective in accommodating the complex, multiple conditions and interactions that prevail in livestock, people and household settings. A WQG cannot be a stand-alone approach to managing health risks pertaining to water. However, it seems that single value WQG systems are the norm in the WQG of the countries and organisations reviewed. The reason is the relative simplicity of producing single value guidelines.

In order to reduce risk to vulnerable users, some differentiation was introduced in livestock according to type and physiological status. In terms of people, the published recommended WI (WI L/d) for people of different ages and physiological status showed that people could be exposed in varying degrees to WQC, which may become critical. In a similar context, chronological age and BM could be limiting biological reference criteria due to their variability.

Considering the relationships between BM and MBM based on the BMR (ml O_2/h), lighter (and younger) animals and people might be at higher risk to PHCC than heavier (and more adult) people and animals.

4.5 Conclusions and recommendations on chemical quality of groundwater for potable use and livestock watering

Due to differences in the profiles of WQC from RRWH, GW and RW and the occurrence of inorganic WQC that are COC or PHCC, water from these sources should be monitored to assess their human and livestock health-related risk.

The WQG and recommendations for these emanating from the report are text-based WQG systems using Target Water Quality Range (TWQR) values as handy quick reference systems, but have limited value. A WQG system should differentiate between types of livestock and people according to their vulnerability and that MBM be applied as the biological reference criterion. WQC previously excluded from the South African Water Quality Guidelines (SAWQG), (e.g. Br) must be included in a new text-based publication. The limitations of such systems must be recognised and a software-based interactive, health risk assessment system be developed.

It remains challenging to manage an interactive software-based system as was experienced with the CIRRA model. This could be overcome with the development of a centralised reference centre for water quality management.

4.6 Overall recommendations

The project addressed the aspect of water quality from two diverse positions: microbiological WQC and inorganic WQC. The commonalities that emerged are:

- Contamination (biological or chemical) may be a random or predictable, consistent event.
- WQC undoubtedly determine the status of water quality.
- The presence of a WQC does not necessarily indicate that the WQC is potentially hazardous to people in a domestic setting or to livestock.
- Environmental factors could determine the nature of a contaminant.
- The relationship between the ingestion of a contaminant and the expression of a pathological condition, whether sub-clinical or clinical, is multifactorial.
- The susceptibilities of people and livestock to potentially hazardous WQC are dependent on their physiological status.
- WQG are presented in text-based format either as recommended values that exceed the NOAEL, moving towards COC and PHCC, or as the more accommodating TWQR-values.

The overall recommendations are therefore:

- Maintain research on PHCC WQC to people and livestock.
- Update and published the 1996 SAWQG.

- Develop algorithms to determine critical parameters for risk assessment.
- Establish a National Water Quality Reference Centre.

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