# THE APPLICATION OF RISK ASSESSMENT MODELLING IN GROUNDWATER FOR HUMANS AND LIVESTOCK IN RURAL COMMUNAL SYSTEMS

Report to the

**Water Research Commission**

By

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# EXECUTIVE SUMMARY


**Motivation**

Previous water quality guideline research conducted since 1990 for the Water Research Commission (WRC) and Department of Water Affairs and Forestry (DWAF) had focused on establishing scientifically based guidelines for livestock watering relevant in South Africa, predominantly for the commercial sector (WRC Final Reports 301/01/1; 644/1/98; 644/2/98; 857/1/01 and 857/2/01). The emphasis during this process was to progress from static concentration-based guidelines to a flexible ingestion-based risk assessment modelling software program, named CIRRA (constituent ingestion rate risk assessment), and led later to the inclusion of different user categories, including wildlife and rural communal production systems.

The research conducted into water resource management in rural communal livestock production systems observed the occurrence of geochemical anomalies, assessed as potentially hazardous chemical constituents (PHCC), in predominantly groundwater used for agricultural and domestic uses. Associated hazard and risk assessments indicated that communities were exposed to hazardous concentrations of elements, such as bromide, selenium, lead, cadmium, strontium, fluoride, nitrate and iodine, with an environmental component of causation through multiple routes of ingestion, including agricultural products. Shared utilization of water sources and common exposure to geochemical anomalies with documented adverse health impacts between domestic and agricultural users, coupled to the inherent difficulties in applying primary prevention to community health, formed the motivation to develop and propose a mechanism to implement a process that utilizes water quality as a departure point, with geochemistry and biological monitoring as indicators for human health hazards, within a cost-effective multidisciplinary approach, to identify and propose management options for key water quality hazards in rural communities.

**Problem identification**

Problems regarding safe use of available water sources within rural communities are complex and multi-faceted, however, three broad areas may be identified. The first area concerns the presence of PHCC and constituents of concern (COC) that are present in water sources and the second area deals with the context of use within rural communal systems. The first area introduces the complexities of environmental toxicology and the impact of water quality constituents (WQC) on multiple norms for each water user. The second area incorporates the dynamics of site-specific factors that significantly alter the outcome of exposure through numerous components of hazard and risk equations. These two areas significantly influence the third broad area that is centered within difficulties in diagnosing disorders and diseases. These difficulties are largely due to direct factors affecting the developmental, chronic, subclinical route and latent presentation followed of adverse effects attributed to the constituents, and indirect environmental factors primarily responsible for observational challenges.

Accordingly, the problem may be stated as a need for measures that not only assess country-specific health problems correlated primarily to naturally occurring water quality

hazards within rural communities, but also for measures that acquire sufficient site-specific information to formulate viable actions to reduce risk and cope with the challenges in integrating varied specializations within environmental health assessments.

Within these broad problem statements, specific problem statements relate to constituent dependant toxicodynamic and toxicokinetic features where risk factors are associated with rural communal agricultural production systems. These problems all relate to critical knowledge gaps with reference to low-level, long-term, concurrent multiple hazard exposures in different sensitive user groups and may be addressed by identifying geochemical anomalies affecting community health using water quality and rural agricultural risk factors to enable differentiation between necessary and sufficient causation. The specific areas targeted are environmental controls and protection from natural hazards, with the preclinical phase assisted by the quantification of baseline conditions and developmental toxicity.

**Study objectives**

The initial objective of the study was to utilize the platform presented in CIRRA Version 2.03 to develop formal procedures for addressing water quality related hazards and risks for humans and livestock in rural communities within rural communal production systems. Following the severity of the PHCCs observed in selected rural communities, an additional investigation into the fitness for use of groundwater for domestic uses and animal uses in groundwater in rural communities throughout South Africa was also conducted. This was made possible by a collaborative investigation between the Agricultural Risk Assessment Division at Business Enterprises at the University of Pretoria, the Institute for Soil, Climate and Water at the Agricultural Research Council, and the Directorate for Land Use and Irrigation Development at the National Department of Agriculture.

The development of the formal procedures required sought not only to investigate the benefits of using biological monitoring as an integral aid for assessing related hazards and risks for humans in these communities, but also to assess which biological and environmental sampling was most appropriate. Although the main focus was intended to be on subterranean water this was expanded to include other water used as different water sources are at times mixed and groundwater often not utilized by a community in an attempt to maintain an adequate supply during dry conditions.

The methodology sequence was to conduct sampling, to perform biological experiments, investigate the extent of the hazards in groundwater in other communities in South Africa, and to develop and propose a system for managing naturally occurring water related hazards in rural communities. Where feasible capacity building initiatives were addressed in all aspects, as was international collaboration and consultation with different specialists in relevant fields.

As a final objective this project not only developed and proposed mechanisms for implementation of a tool that addresses aspects of water resource management, as it pertains to public health issues for rural communities within the context of water quality

related health hazards, but to acknowledges the increasing recognition of geochemistry and water quality as a valuable component in the rapidly growing field of environmental epidemiology.

The model proposed in this report is seen as a fundamental requirement that ensures that efforts by Water Service Authorities, Water Service Providers and Village Water Committees do not result in preventable direct and/or indirect adverse effects on human and animal users.

Further evidence supporting the concerns raised in the selected communities was obtained from a survey of the fitness for domestic and agricultural use of groundwater throughout South Africa conducted during 2005 for the National Department of Agriculture, Directorate of Water Use and Irrigation Development. Additional concerns regarding inorganic endocrine disrupting contaminants (EDCs) have also been subsequently raised. Discussions were held with relevant departments in the Limpopo and North-West Provinces during which these results and other aspects regarding water quality in rural communities were presented. Apart from the primary concerns regarding direct and indirect adverse effects to human health in the communities, the successful implementation of various agricultural initiatives and sustainable production at household and village level were also stated as having a high research priority.

**Results and conclusions**

The most significant conclusion is that the observations of PHCCs in point of use samples in rural communities at concentrations that exceed the local and international guideline limits by several order of magnitude pose significant hazards to the recognized norms for water use for both domestic and animal uses. This extends to multiple user categories within user types, for example, drinking, food preparation and bathing for domestic use, and use for household layers, broilers and crops.

The vast majority of household and village drinking water was classified as completely unfit for domestic purposes. The potentially fatal consequences of the excessive nitrate values warrant intervention, and a report detailing the hazards was submitted to the Limpopo Provincial authorities at Polokwane. The contribution of fertilizer applications and housing small stock on the household premises where hand pumps were located, in addition to natural occurrence in the aquatic environment, is well documented in the scientific literature, and management strategies concerning water sources and commuity agricultural practices need to be implemented. This extends to the village poultry and vegetable projects as they may serve as a significant source of potentially hazardous element intake in community members

Significant differences between villages were noted for elements reflected in different tissue types that accorded with the water chemistry observed. Differences in the presence of sensitive user groups (pregnant women, breastfeeding mothers, infants) and varying routes of exposure and dosages necessitate that the detection of PHCCs be used as an action level on which site-specific investigations commence.

It was found that liver samples predicted the variability between elements the best. Environmental samples did not describe element variance significantly and the collection of poultry specimens, either household or project sourced, appears to be the most reliable biological indicator.

The formulation of risk management strategies requires appropriate management that can reduce the risk to allow production and safe groundwater use to continue. However, failure to measure and monitor water quality prevents any successful management programme from being implemented. Failure to adequately describe water chemistry consequently reflects in uncertainty regarding adequate description of baseline conditions, a necessary step in fundamental epidemiological studies.

A generic level water quality risk assessment is recommended as the first step in determining baseline exposures required for the identification of constituents in the geochemical environment that may contribute to adverse effects on health, productivity, and product quality in animal users, and for health-related norms for domestic users.

Any potential hazards identified then require further investigation regarding the water, user, environment and nutrition in order to ascertain the hazard posed by the presence of toxic constituents at concentrations that exceed the various forms of recommended guidelines, and in so-doing acquire relevant site-specific risk factor information required for risk management strategies to be formulated.

This approach is addressed in detail by a proposed model that is a tool for Hazard Management for Rural Water Sources, referred to as HMRWS, and functions as a multidisciplinary effort between groups with specializations and commonalities, within a discreet functioning units that may be linked for various reasons (geographical and technical) referred to as a HUB.

The main components of the HMRWS are:

- A series of parent-child software programs
- A Central Administrator that receives, processes and directs information between five Specialist Groups:
    - Analytical Group
    - Animal Health Group
    - Geochemistry Group
    - Community Health Group
    - Rural Groundwater Implementation and Monitoring Group

The main processes within the HMRWS occur as four phases:

- Hazard Identification Phase (HIP)
- Exposure Assessment Phase (EAP)
- Toxicity and Risk Assessment Phase (TA & RA)
- Risk Management Strategy Phase (RMSP)

The HMRWS objectives are:

- Generic Objectives: For sustained water resource management issues in rural communal agricultural systems.
- Specific Objectives: For community-dependent risk factors that may range from agricultural productivity to safe household food preparation of high-risk agricultural products.

The benefits of biological and environmental sampling in acquiring site-specific data are further illustrated in the results presented later from the NDA Groundwater Project where the majority of the PHCCs reported were within 50% of the guideline thresholds. Risk for incurring both false negatives and false positives may be reduced by the acquisition of site-specific data.

The planning and implementation of community agricultural projects, typically poultry and food gardens, must take into account the role these projects may play in contributing to ingestion routes and total exposure of communities to PHCC in order to prevent a positive intention from having a potentially irreversible negative health impact.

It is suggested that the HMRWS should be implemented on a national scale, but initially commence as a single unit (HUB) that could serve to assess the most appropriate means for future expansion, and may consist of various stakeholders identified on a regional or provincial level. Primary stakeholders are specialist groups, whilst recipients of group outputs vary according to need, and level of application (local or provincial). The stakeholders presented in this chapter should not be seen as prescriptive, but rather as an example of viable working groups. The allocation of various stakeholders to groups is based on the facilitation of processes in the different phases, with flexible involvement in multiple phases suggested. Several protocol specific Research Partnerships may be incorporated where appropriate.

The current reality for the communities investigated for this report is that groundwater classified as potentially hazardous and/or completely unfit for use by animal and domestic users is still being used for these purposes, and continues to be a significant and at time critical water source. The effect of groundwater quality on the relationship between the fitness for use of animal products, various additional affected exposure routes and community health is of serious concern for both household consumption and community agricultural projects. These concerns are promoted by the irreversible developmental insults characterised for many of the constituents involved and firmly place responsibility on the various specialist fields to proactively seek to reduce the risk as much as possible, as opposed to simply complying with upper threshold limits. In contrast to endocrine disrupting effects that currently receive much attention, the physiological significance and well established cause and effect relationships following exposure to the majority of potentially hazardous chemical constituents presented in this report are known and accordingly warrants research attention and priority.

Following a collaborative and participatory approach, a model was developed and is presented in this report. Major stakeholders and individual participants indicated a strong interest to participate in the implementation thereof.

This approach is seen as integral to fundamental epidemiological principles applicable to human and animal studies. The role of groundwater in assisting the diagnostic and clinical interpretations for diseases and disorders should be seen as an opportunity.

The presence of the specific PHCCs and COCs in rural groundwater supplies presented in this report should be seen as worthy of receiving urgent attention on a National scale. The potential for *in utero* and neonatal insults suggest that a conservative approach be adopted.

**Achievements**

The 9th World Conference on Animal Production (WCAP) was held in 2003 in Porto Alegre, Rio Grande do Sul State, Brazil, from October 26 – 31. Professor NH Casey, Dr JA Meyer and Mr K Holele, were invited by the World Association for Animal Production (WAAP) to organise and chair a conference entitled "Water Use, Availability and Quality". Each member of the research team presented papers during the plenary session on the first morning of the conference. Additional papers were presented at other local and international conferences during the period of 2000 to 2005 by the researchers. Several popular articles were also produced and over 50 technical water quality assessment reports were produced for the commercial sector. A tender to assess the fitness for use of groundwater for domestic and animal use throughout South Africa was granted to the project team in 2004 from the National Department of Agriculture with a consultancy to monitor new groundwater points subsequently also awarded.

Academic achievements were:

| | |
|---|---|
| Mr D Vilakazi: | MSc (AnimSci) UP – Awarded 2003 |
| Mr K Holele: | MInstAgrar UP (submitted February 2006) |
| Mr C Mamabolo: | MSc (AnimSci) UP – (submission due June 2006) |

The following students were involved in capacity building initiatives for the project:

| | |
|---|---|
| Ms M Reuver: | MSc (Landou Universitiet Wageningen) |
| Mrs A Bichard: | PhD (Dept of Consumer Science – Developing viable production and marketing channels for cultural food products in rural communities) |
| Mr M Ramushu | Head of the Outreach Programmes – MSc (University of the North – community participation and safe agricultural programmes). |

Numerous students and community members engaged in the Outreach Programmes for Poultry Production at Tompi Seleka Agricultural College were involved in the research process, as were extension officers in the Limpopo and North West Provinces. .

During the 9th WCAP conference closing ceremony it was announced that the 10th WCAP, to be held in 2008, was awarded to South Africa, with Professor NH Casey elected at the President of the Conference. This affords African scientists an excellent opportunity to showcase research achievements and to expand on water related research, with the HMRWS an appropriate vehicle for presenting research outputs for the 2008 conference.

# ACKNOWLEDGEMENTS

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The Steering Committee, consisting of the members listed below, provided essential specialist input towards the completion of this study.

| | |
|---|---|
| Dr K C Pietersen (Chair) | Water Research Commission (WRC) |
| Mrs APM Moolman | Water Research Commission |
| Dr MM Ehlers | University of Pretoria (UP) |
| Prof TE Cloete | University of Pretoria |
| Dr HH Meissner | Agricultural Research Council (ARC) |
| Dr CHM de Brouwer | Dept. of Agriculture, Conservation and Environment |
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| Prof H Vermaak | University of Pretoria |
| Mr DJ Marais | Water Research Commission (Committee Secretary) |

The valuable inputs of Dr J Myburgh (UP) in conducting fieldwork is gratefully acknowledged. Messrs J Kruger (Delftzyl Agricultural Research Station), I Sheela (Jericho Agricultural Development Office, North West Province) and MEJ Ramushu (Tompi Seleka Agricultural College) are thanked for their assistance with fieldwork and extensive region experimentation. The North West Province and Limpopo Province Departments of Agriculture are thanked for providing extension officers for the rural community investigations. The Directorate of Water Use and Irrigation Development (National Department of Agriculture) is thanked for granting financial support for groundwater investigations. Mr A Loocke and Ms A van Rooyen of the Institute for Soil, Climate and Water (ARC) are thanked for their guidance in performing analytical work.

Mr J Mulder and Mrs Z Karparov of the National Department of Agriculture are thanked for their assistance with the preparation of several maps for the report. Mr JH Elsenbroek of the Council for Geoscience is thanked for his assistance with regard to geochemistry aspects in this report. Mr T Marias of Incasu (Pty) Ltd is thanked for his inputs regarding software programming. Mr R Coertzer of the University of Pretoria is gratefully acknowledged for assisting with statistical work and several experiments.

The experimentation conducted for the project was made possible by the following postgraduate students: Mr KK Holele (UP); Mr C Mamabolo (UP); Ms M Reuver (Landbou Univeriteit Wageningen) and Mr D Vilakazi (UP).

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## Acronyms

| | |
|---|---|
| ADI | Average daily intake |
| ADG | Average daily gain |
| ARAD | Agricultural Risk Assessment Division |
| ARC | Agricultural Research Council |
| AV | Antagonistic variable |
| CIRRA | Constituent Ingestion Rate Risk Assessment |
| COC | Constituent of concern |
| DMI | Dry matter intake |
| DWAF | Department of Water Affairs and Forestry |
| EAP | Exposure Assessment Phase |
| HMRWS | Hazard Management for Rural Water Supplies |
| HIP | Hazard Identification Phase |
| ISCW | Institute for Soil, Climate and Water |
| MAC | Maximum Acceptable Concentration |
| PHCC | Potentially hazardous chemical constituent |
| RA | Risk Assessment |
| RMSP | Risk Management Strategy Phase |
| TA | Toxicity Assessment |
| TSAC | Tompi Seleka Agricultural College |
| TWQR | Target Water Quality Range |
| TWI | Total Water Intake |
| USDA | United State Department of Agriculture |
| WQC | Water Quality Constituent |
| WI | Water intake |

# 1. INTRODUCTION

## 1.1 Background

Previous water quality guideline research conducted since 1990 for the Water Research Commission (WRC) and Department of Water Affairs and Forestry (DWAF) had focused on establishing scientifically based guidelines for livestock watering relevant in South Africa, predominantly for the commercial sector (WRC Final Reports 301/01/1; 644/1/98; 644/2/98; 857/1/01 and 857/2/01). The emphasis during this process was to progress from static concentration-based guidelines to a flexible ingestion-based risk assessment modelling software program, named CIRRA (constituent ingestion rate risk assessment), and led later to the inclusion of different user categories, including wildlife and rural communal production systems. A significant portion of the fundamental basis of this project rests on the investigations, experimental evidence and modelling that led to the development of CIRRA and the reader is referred to the WRC Final Reports 857/1/01 and 857/2/01 for supporting evidence and background information pertaining these aspects.

The research conducted into water resource management in rural communal livestock production systems observed the occurrence of geochemical anomalies, assessed as potentially hazardous chemical constituents (PHCC), in water used for agricultural and domestic uses with associated hazard and risk assessments indicating that communities were exposed to essentially hazardous elements with an environmental component of causation through multiple routes of ingestion, including agricultural products. Shared utilization of water sources and common exposure to geochemical anomalies with documented adverse health impacts between domestic and agricultural users, coupled to the inherent difficulties in applying primary prevention to community health, formed the motivation to develop and propose a mechanism to implement a process that utilizes water quality as a departure point, with geochemistry and biological monitoring as indicators for human health hazards, within a cost-effective multidisciplinary approach, to identify and propose management options for key water quality hazards in rural communities.

## 1.2 Problem identification

Problems regarding safe use of available water sources within rural communities are complex and multi-faceted. As the issue of land use and agricultural production systems in rural communities has received much research attention over the last decade and is too complex to be presented in this report the reader is referred to the relevant references provided in the chapters. Three broad areas may however be identified. The first area concerns the presence of PHCC and constituents of concern (COC) that are present in water sources and the second area deals with the context of use within rural communal systems. The first area introduces the complexities of environmental toxicology and the impact of water quality constituents (WQC) on multiple norms for each water user. The second area incorporates the dynamics of site-specific factors that significantly alter the outcome of exposure through numerous components of hazard and risk equations. These two areas significantly influence the third broad area that is centered within difficulties in diagnosing disorders and diseases. These difficulties are largely due to direct factors

affecting the developmental, chronic, subclinical route and latent presentation followed of adverse effects attributed to the constituents, and indirect environmental factors primarily responsible for observational challenges. Accordingly, the problem may be stated as a need for measures that not only assess country-specific health problems correlated primarily to naturally occurring water quality hazards within rural communities, but also for measures that acquire sufficient site-specific information to formulate viable actions to reduce risk and cope with the challenges in integrating varied specializations within environmental health assessments.

Within these broad problem statements, specific problem statements relate to constituent dependant toxicodynamic and toxicokinetic features where risk factors are associated with rural communal agricultural production systems. These problems all relate to critical knowledge gaps with reference to low-level, long-term, concurrent multiple hazard exposures in different sensitive user groups and may be addressed by identifying geochemical anomalies affecting community health using water quality and rural agricultural risk factors to enable differentiation between necessary and sufficient causation. The specific areas targeted are environmental controls and protection from natural hazards, with the preclinical phase assisted by the quantification of baseline conditions and developmental toxicity.

### 1.3 Study objectives

The initial objective of the study was to utilize the platform presented in CIRRA Version 2.03 to develop formal procedures for addressing water quality related hazards and risks for humans and livestock in rural communities within rural communal production systems. Targets were set to investigate the possible benefits of applying a generic level assessment followed by site-specific sampling in order to achieve this. These targets were:

1. To quantify and substantiate the risk posed to animals in selected communities due to the presence of potentially hazardous concentrations of identified water quality constituents within the production environment.
2. To quantify the risk posed to humans in selected communities due to the ingestion of water, food, milk, meat, organs and other livestock products.
3. To substantiate the risk posed to humans based on the results from targets (1) and (2) above by the use of community health procedures.
4. To formalize procedures involving the use of animal tissues and histopathological data for identifying potential risk for humans associated with hazardous water quality constituents.
5. To develop another version of the software program CIRRA to cater specifically for risk assessment procedure and solution driven management options viable for both humans and livestock in the communal livestock production system context.
6. To update version of CIRRA, and substantiate case study evidence of applications.

These targets were all addressed but due to the extent of the hazardous constituents identified in (1) and (2), the use of community health procedures in point (3) did not occur, as greater emphasis was placed on investigating the extent to which geochemical anomalies presented in South African groundwater in rural communities. An additional target was thus formulated, namely:

7. To investigate the fitness for use of groundwater for domestic uses and animal uses in groundwater in rural communities throughout South Africa.

Addressing this last target was made possible by a collaborative investigation between the Agricultural Risk Assessment Division at Business Enterprises at the University of Pretoria, the Institute for Soil, Climate and Water at the Agricultural Research Council, and the Directorate for Land Use and Irrigation at the National Department of Agriculture.

### 1.4 Methodology and report layout

The process followed in order to achieve the study objectives accords with the increasing application of epidemiology to non-infectious diseases and is integral to placing health care services in a position where multiple causation aspects can be assessed in order to progress from secondary and tertiary prevention to primary prevention. The development of the formal procedures required sought not only to investigate the benefits of using biological monitoring as an integral aid for assessing related hazards and risks for humans in these communities, but also to assess which biological and environmental sampling was most appropriate. Although the main focus was intended to be on subterranean water this was expanded to include other water used as different water sources are at times mixed and groundwater often not utilized by a community in an attempt to maintain an adequate supply during dry conditions.

The methodology sequence was to conduct sampling, to perform biological experiments, investigate the extent of the hazards in groundwater in other communities in South Africa, and to develop and propose a system for managing naturally occurring water related hazards in rural communities. The sampling was divided into an initial water quality phase in broad communities followed by biological and environmental sampling in selected villages within these communities. Broad community selection was defined and based on previous research (Casey *et al*., 2001a). Additional communities were incorporated following discussions held with provincial government departments where the results from targets (1) and (2) were presented and were influenced by existing community outreach programs. The biological experimentation was divided into intensive and extensive trials conducted in poultry and sheep, and addressed the aspects relating to the fitness of use of animal products for human consumption and the testing of alleviator treatments. The investigation of hazards in groundwater throughout South Africa involved the acquisition of samples from existing boreholes and the drilling of new boreholes in areas selected by the National Department of Agriculture (NDA). The results from the sampling, biological experimentation, and groundwater investigations were used to guide the proposed system developed.

Sampling schedules and extensive region biological experimentation were influenced by environmental factors, infrastructure problems and sociopolitical variables that are presented in the relevant chapters. Where feasible capacity building initiatives were addressed in all aspects, as was international collaboration and consultation with different specialists in relevant fields.

This project attempts to not only develop and propose mechanisms for implementation of a tool that addresses aspects of water resource management, as it pertains to public health issues for rural communities within the context of water quality related health hazards, but to also acknowledge the increasing recognition of geochemistry and water quality as a valuable component in the rapidly growing field of environmental epidemiology.

The model proposed in this report is seen as a fundamental requirement that ensures that efforts by Water Service Authorities, Water Service Providers and Village Water Committees do not result in preventable direct and/or indirect adverse effects on human and animal users.

# 2. HAZARDOUS CONSTITUENTS IN WATER, BIOLOGICAL AND ENVIRONMENTAL SAMPLES IN DIFFERENT RURAL COMMUNAL PRODUCTION SYSTEMS

## 2.1 Introduction

As detailed in previously (Casey *et al*., 1998; Casey *et al*., 2001a; Casey and Meyer, 2003; Meyer *et al*., 2000; 2003a; 2003b; 2004) concerns were raised about the presence of potentially hazardous chemical constituents (PHCC), predominantly in groundwater, used by multiple sensitive user groups associated with high risk factors within in a rural communal context, including different categories within agricultural and domestic user groups. Adverse effects predicted at the concentrations observed referred to the following recognized norms:

| | | | |
|---|---|---|---|
| Agricultural: | Livestock: | Health: Drinking: | Toxicity & Palatability |
| | | Product Quality: | Price & Fitness for use of consumers |
| | | Watering systems: | Production & Replacement costs |
| | | Ecological: | Impact on environment |
| | Aquaculture: | Production | |
| | | Product Quality: | Price & Fitness for use of consumers |
| | Irrigation: | Crop quality: | Price & Fitness for use of consumers |
| | | Crop production | |
| | | Soil quality | |
| Domestic: | Drinking: | Health & Aesthetic | |
| | Food Preparation | | |
| | Bathing | | |
| | Laundry | | |

Further evidence supporting the concerns raised in these reports obtained from a survey of the fitness for domestic and agricultural use of groundwater throughout South Africa conducted during 2005 for the National Department of Agriculture, Directorate of Water Use and Irrigation Development, is presented later in this report. Additional concerns regarding inorganic EDCs have also been subsequently raised and partially addressed in a report for the WRC EDC programme (Burger *et al*., 2005). Discussions were held with relevant departments in the Limpopo and North-West Provinces during which these results and other aspects regarding water quality in rural communities were presented. Apart from the primary concerns regarding direct and indirect adverse effects to human health in the communities, the successful implementation of various agricultural initiatives and sustainable production at household and village level were also stated as having a high research priority. Within the stated aims of the project two key areas were identified for further investigations that would follow the procedure of investigating site-specific variables following a generic indication of potential hazards. These areas were the Jericho District in the North-West Province and the Immerpan District and associated Tompi Seleka Agricultural College (TSAC) associated village poultry projects. Due to the greater amount of agricultural projects in the form of poultry production houses and vegetable gardens in the Immerpan District and TSAC associated areas it was decided to

follow an agricultural project approach there, and a household collection approach in the Jericho District. These different approaches would assist in identifying the most appropriate agricultural water and animal product use practices for rural communities. The objective was not to establish comprehensive cause and effect relationships, nor to produce new constituent information on an intermediate metabolic level, but to investigate appropriate procedures for investigating potential water quality hazards and management thereof within the context of rural communal production systems.

## 2.2 Jericho District

### 2.2.1 Methods

All experimentation conducted for this report was granted approval by the Ethics Committee of the University of Pretoria. Following the presentation of the results from previous sampling conducted (Casey *et al*., 2001a) to the head of the Jericho Agricultural Division Extension Office and all the Animal Technicians working in the district, nine villages were scheduled for an initial water sampling phase, the results of which would be used to select seven key villages for water and site-specific sample collections. Heavy rainfalls and subsequent delays in rebuilding access roads delayed this phase by several months. The end results of the sampling were used to identify key villages whose communities were also willing to participate in further biological and environmental sampling. Results from the initial sampling and from other areas investigated are presented later in this report. The villages selected for sampling are briefly presented in Table 2.1, with the following codes applicable:

Rantlapane = RP
Kalkbank Trust = KBT
Kalkbank Private = KBP
Koedoespoort = KP
Aasvogelboom = AVB
Rooiwal = RW
Wilgerkuil = WK
Fafung West = FF1
Fafung East = FF2

The objective of the sampling procedure was to obtain water samples from villages in consultation with the Animal Technicians and community forums (usually the general secretary of the village agricultural forum) in a manner that could be reproduced by similar persons through the province. This included completing draft data capturing guides intended to form part of the software support system described later in this report. As the sampling objective was to obtain information regarding fitness for use and not to describe subterranean water dynamics, point of use samples were collected when possible. Experiences in conducting case-study investigations into animal health have successfully used point of use samples as a starting point from which further investigations into water storage, delivery and source, provided information integral to risk management strategy formulation. Due to water system effects on concentrations and element speciation, investigations where the water source (borehole output or

reservoir input) was used to determine fitness for use often failed to adequately represent associated hazards.

As the key PHCC were trace element related, a concern was to limit analytical variability whilst at the same time obtaining analytical information on a comprehensive array of constituents. The laboratory also needed to be capable of handling a potential flow of samples from all regions of South Africa with a price structure that was not prohibitive. The Institute for Soil, Climate and Water at the Agricultural Research Council (ISCW) was selected as it fulfilled these requirements and had been used consistently in previous WRC projects. A further benefit was that new laboratory equipment was installed as part of a comprehensive analytical capability upgrade. The laboratory is part of AGRILASA (Agricultural Laboratory Association of Southern Africa) and certified on a yearly basis for quality assurance and requirements as part of the Water Scheme. The purposes for using the ICP-AES and ICP-MS methods are threefold. Firstly, from a cost-efficiency perspective the procedure provides approximate values for a large number of elements. Due to numerous physiologically significant trace element interactions the assessment of at least twenty-eight trace elements in a sample is a critical component required to perform hazard and risk assessments and is an essential aspect of environmental toxicological investigations that is often overlooked. Secondly, full quantitative confirmation of the values repeatedly returns values within 10% of the ICP-MS value, with the ICP-MS values providing a more conservative estimate. Thirdly, the use of ICP methods is advocated in geochemistry and the approach allows for multiple environmental sample types to be submitted to the same laboratory with similar procedures employed. Reducing inter-and intra-laboratory variation is seen as important for identifying long-term trends in environmental data.

Collection of the water samples took place in accordance with the methods recommended for the type of water samples collected for inorganic chemistry (Quality of Domestic Water Supplies, Volume 2, 2001). Two sampling phases were conducted on each of the key villages, but sample sets were not balanced, mainly due to drought (earth dams dry) or borehole pumps being stolen. Due to the importance of obtaining results for nitrate, no nitric acid preservative was used and for similar reasons mercury chloride was also not used. An additional concern raised by the Agricultural Forums was the ability to collect a sample with ease when problems were noted by the responsible persons in the village forums, as opposed to waiting for specific collection bottles and animal technicians. The collection phases thus form part of a generic tier 1 investigation whereby additional confirmation sampling may be recommended. Sample bottles were prepared (acid-washed) at the ISCW and delivered to the ISCW within 48 hours of collection.

Chemical analysis of the water samples provided were conducted by ICP-AES techniques (inductively coupled plasma atomic emission spectrometry) by the Institute for Soil Climate and Water at the Agricultural Research Council, Pretoria, using full quantitative and semi-quantitative procedures (ISCW, 2001; Eaton et al., 1995).

Fitness for use for livestock watering is assessed using CIRRA Version 1.03 software developed for the Water Research Commission (WRC Final Reports 644/1/98, 644/2/98,

644/3/98 and 857/1/01, 857/2/01) on a generic guideline application level. This level is concentration-based, as opposed to ingestion based, and is therefore conservative in risk estimation. Where appropriate, poultry water quality guidelines are used for assessing fitness for use (Casey *et al*., 2001b). A more accurate risk assessment may be performed when intake of a constituent is known from feed, water and other sources, and combined with site-specific risk factors that may increase, or decrease, the concentration at which a constituent in the water source may have an adverse effect. Use of specific information in this manner forms part of an ingestion-based specific guideline application level and hence involves site investigations with various data capturing procedures, and is a necessary step in the formulation of risk-management strategies. Although most appropriate from an animal health perspective in commercial production systems, a similar approach was employed for environmental samples in the key villages by the collection of bovine faecal, surface soil and grass sample collections. Two sets of three samples per sample type were collected within 30 m of the water sample site and each set pooled prior to laboratory submission. Standard ICP-MS techniques were employed in the analysis of the environmental samples (ISCW, 2001; Chao-Yong Luh Huang and Schulte, 1985).

Different types of biological samples were collected initially, including sheep, goats, bovine blood and indigenous poultry. Due to difficulties in obtaining specimens at all the key villages, indigenous poultry were chosen as the most appropriate type. An additional reason for this was that most were kept at a village and/or household level in a scavenging and partial feeding context, and consequently geophagia and other dietary contributions were influenced predominantly by local geochemistry. A further reason was the significant contribution to household dietary intake of poultry and poultry products. Milk samples were not collected due to the availability and consumption thereof being highly variable between households and across seasons. Several bovine blood collections were conducted from herds within separate villages and grazing areas, but collections could not be arranged from all the key villages due to a number of constraints, the main ones being lack of adequate crush and holding facilities and difficulties in herding the animals. Samples were collected from adult bovines via the jugular vein or the median caudal artery using lithium heparinized vacutainers, kept on ice, frozen within 24 hours and kept frozen until submitted for ICP-MS analyses (see below). The results are presented in Chapter 5 in conjunction with the blood results from the Immerpan District. Where possible households within key villages were also interviewed regarding water use practices and dietary profiles. As part of a collaborative project with Wageningen University in the Netherlands, a focused study was performed in the Fafung village in the Jericho District (Braker, 2002).

A minimum of two sets of three poultry specimens per set were collected from different households in each village where the predominant drinking water source for both animal and domestic use was groundwater. Each poultry specimen was sacrificed without the loss of blood volume by severing the cervical vertebrae and central nervous system. Each specimen was dissected at the Anatomy Dissection Hall at the Department of Animal and Wildlife Science at the University of Pretoria. Heart, liver, thyroid, back feather tract and brain samples were collected, and duplicate (left and right) femur, deep pectoral and total

thigh muscles were sectioned from each specimen. Each set was then pooled with the left side submitted for all specimens, yielding two observation points per village for each tissue type. Right side samples were retained for possible further analysis. Where more than two sets were collected, samples were pooled to deliver the same observation number based on proximity (closest sets pooled). Samples were pooled in this manner to obtain sufficient mass for analytical purposes. Pooled samples were dried at 60 degrees Centigrade for 48 hours prior to delivery to the ISCW where each observation set was ground and analyzed using standard ICP-MS techniques to determine trace element concentrations (ISCW, 2001; Chao-Yong Luh Huang and Schulte, 1985).

Fitness for use for domestic uses was determined on a similar basis to that for livestock with concentration-based water quality guidelines being applied. A combination of local and international guidelines (Quality of Domestic Water Supplies, Volume 1, 1998; DWAF, 1996; US EPA, 2005; WHO, 2000) were used for domestic uses in order to provide statements on the increasing number of water quality constituents recognized as impacting on the norms affected. The domestic assessments are provided later in this report in conjunction with the results from the DOA Groundwater Project.

Throughout this report an analysis of variance with the GLM model (Statistical Analysis System, 2001) was used to determine the significance of the observations made. Differences were determined within district collections using least squares means and standard deviations for different elements within sample types, with significant differences predominantly determined using the Fischer Test (Samuels, 1989).

The following acronyms apply:
Concentrations recorded which exceed the Department of Water Affairs and Forestry (DWAF, 1996) guideline for the category C, or the internationally recommended upper guideline limit, are reported as potentially hazardous chemical constituents (PHCC). Constituents that recorded values within 10% of a guideline limit are reported as constituents of concern (COC). Definitions of these terms appear below.

| | |
|---|---|
| **WQC**: | Water quality constituent, e.g. Arsenic. |
| **PHCC**: | Indicates that exposure to the WQC in question is likely to result in adverse effects. |
| **COC**: | Indicates that the WQC in question could conceivably become a PHCC due to concentration variations, such as seasonal fluctuation in the water source or evaporative effects, and should therefore be monitored. |

| | |
|---|---|
| MPL | maximum permissible level (Kempster *et al*., 1985; Smith, 1988) |
| RL | recommended level (Kempster *et al*., 1985; Smith, 1988) |
| CL | crisis level (Smith, 1988) |
| Cat C | risk of adverse effects in sensitive user groups |
| Cat D | risk of adverse chronic effects in all users |
| Cat E | risk of adverse chronic and acute effects in all users (Quality of Domestic Water Supplies, 1998) |
| MRL | maximum recommended limit (WHO, 1996) |
| TWQR | target water quality range (DWAF, 1996); Casey and Meyer (1996) |
| AV | antagonistic variable (Underwood and Suttle, 1999) |
| MCL | Maximum Contaminant Level (USEPA, 1998) |
| HA | health advisory (USEPA, 1998) |

**Table 2.1. Collection of samples from the Jericho District.**

| Sample Site | Sample Location | Water Samples Collected | Water User Groups |
|---|---|---|---|
| RP1<br>Rantlapane Village | E 27 58 42.1<br>S 25 18 29.1 | Earth Dam<br>(borehole fed) | Livestock |
| RP2<br>Rantlapane Village | E 27 58 18.9<br>S 25 18 27.1 | Earth Dam<br>(borehole fed) | Domestic, household livestock and crops |
| RP3<br>Rantlapane Village | E 27 58 26.3<br>S 25 18 22.3 | Tap – Dry (no sample)<br>(borehole fed) | Domestic, household livestock and crops |
| KBTBHT<br>Kalkbank Trust Village | E 27 59 02.4<br>S 25 17 30.2 | Tap - Village Borehole | Domestic, household livestock and crops |
| KBP1<br>Kalkbank Private Village | E 27 59 09.3<br>S 25 17 03.7 | Earth Dam<br>(borehole fed) | Domestic, household livestock and crops |
| KBP2<br>Kalkbank Private Village | E 27 59 04.7<br>S 25 17 03.9 | Tap for main village borehole - main collection point | Domestic, household livestock and crops |
| KBP3<br>Kalkbank Private Village | E 27 58 44.3<br>S 25 17 09.6 | Tap for second village borehole (supplies for school) | Domestic, household livestock and crops |
| KP1<br>Koedoespoort Village (Mmakgabetlwane) | E 27 56 00.9<br>S 25 16 21.1 | Tap for Poultry Project, Vegetable Garden Project (first village borehole) | Livestock and crops |
| KP2<br>Koedoespoort Village (Mmakgabetlwane) | E 27 56 12.4<br>S 25 16 38.5 | Tap for Clinic<br>(second village borehole) | Domestic and Livestock |
| KP3<br>Koedoespoort Village (Mmakgabetlwane) | E 27 55 55.5<br>S 25 16 12.5 | Earth Dam<br>(borehole fed) | Domestic and Livestock |
| KP4<br>Koedoespoort Village (Mmakgabetlwane) | E 27 55 54.9<br>S 25 16 15.2 | Earth Dam<br>(borehole fed) | Livestock |
| KP5<br>Koedoespoort Village (Mmakgabetlwane) | E 27 55 57.9<br>S 25 16 13.0 | Earth Dam<br>(borehole fed) | Livestock |
| KP6<br>Koedoespoort Village (Mmakgabetlwane) | E 27 55 56.5<br>S 25 16 14.7 | Earth Dam<br>(borehole fed) | Livestock |
| AVBRW1<br>Aasvogelboom Village | E 27 54 43.4<br>S 25 14 36.1 | Tap for main village borehole – locked – sample mainly collected rainwater (tanks)<br>Second sampling – borehole functioning | Domestic, household livestock and crops |
| AVBRW2<br>Aasvogelboom Village | E 27 54 50.6<br>S 25 14 06.2 | House - mainly rainwater | Domestic, household livestock and crops |
| AVBRW3<br>Aasvogelboom Village | E 27 54 17.5<br>S 25 14 33.2 | Earth Dam (borehole fed) | Livestock |
| WK1<br>Wilgerkuil Village | E 27 44 05.3<br>S 25 15 10.3 | Earth Dam<br>(Borehole fed) | Livestock |
| WK2<br>Wilgerkuil Village | E 27 44 21.1<br>S 25 15 08.2 | Tap for main village borehole | Domestic, household livestock and crops |
| WK3<br>Wilgerkuil Village | E 27 44 05.3<br>S 25 15 10.3 | Drinking trough<br>(Borehole fed) | Livestock |
| WK4 | E 27 44 21.3 | Hand pump | Domestic, household |

| | | | |
|---|---|---|---|
| Wilgerkuil Village | S 25 15 12.5 | (Borehole fed) | livestock and crops |
| FF11<br>Fafung Village | E 27 44.975<br>S 25 11.474 | Earth dam<br>(borehole fed) | Livestock and crops |
| FF12<br>Fafung Village | E 27 46.556<br>S 25 11.542 | Earth dam<br>(borehole fed) | Mainly livestock and domestic |
| FF13<br>Fafung Village | E 27 48.381<br>S 25 11.187 | Earth dam<br>(borehole fed) | Mainly livestock and domestic |
| FF14<br>Fafung Village | E 27 48.572<br>S 25 11.057 | Reservoir<br>Second collection point<br>(borehole fed) | Domestic, household livestock and crops |
| FF15<br>Fafung Village | E 27 46.954<br>S 25 11.753 | Main village reservoir<br>central collection point<br>(borehole fed) | Domestic, household livestock and crops |
| FF21<br>Fafung Village | E 27 48.401<br>S 25 12.684 | Dam<br>Next to school<br>(borehole fed) | Mainly livestock and domestic |
| FF22<br>Fafung Village | E 27 48.401<br>S 25 12.684 | Tap near school<br>(borehole fed) | Domestic, household livestock and crops |
| FF23<br>Fafung Village | E 27 48.401<br>S 25 12.684 | Second Earth Dam<br>Next to school<br>(borehole fed) | Mainly livestock and domestic |
| RW1<br>Rooiwal Village | E 27 45 19.6<br>S 25 18 48.0 | Tap in Village<br>(main borehole) | Domestic, household livestock and crops |
| RW2<br>Rooiwal Village | E 27 43 47.6<br>S 25 19 18.5 | Earth dam<br>(borehole fed) | Livestock |
| RW3<br>Rooiwal Village | E 27 44 50.9<br>S 25 19 06.5 | Earth dam<br>(borehole fed) | Livestock |
| RW4<br>Rooiwal Village | E 27 45 46.6<br>S 25 18 49.6 | Drinking trough<br>Household in Village<br>(borehole fed) | Domestic, household livestock and village vegetable garden project |
| RW5<br>Rooiwal Village | E 27 45 46.6<br>S 25 18 49.6 | Drinking trough<br>Household in Village<br>(borehole fed) | Domestic, household livestock and village vegetable garden project |
| RW6<br>Rooiwal Village | E 27 45 46.6<br>S 25 18 49.6 | Hand pump in Village<br>(low pressure borehole fed) | Mainly livestock and village vegetable garden project |
| RW7<br>Rooiwal Village | E 27 45 46.6<br>S 25 18 49.6 | Main Hand pump in Village<br>(high pressure borehole fed) | Mainly Domestic |
| RW8<br>Rooiwal Village | E 27 45 46.6<br>S 25 18 49.6 | Hand pump in Village<br>(low pressure borehole fed) | Mainly livestock |

### 2.2.2 Results

#### 2.2.2.1 Water quality

The main PHCCs and COCs observed for each point of use sample collected are presented next.

##### 2.2.2.1.1 Summer sampling phase

The results for samples collected during mid- to late summer are presented in the Tables 2.2.1 to 2.2.35.

Table 2.2.1 Sample ID: RP1

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.048 | 0.01 – MCL | V | 0.031 | 0.1 - TWQR |
| Pb | 0.01 | 0.01 - TWQR | | | |
| As | 0.035 | 0.01 – TWQR | | | |
| Hg | 0.017 | 0.001 - TWQR | | | |
| Se | 0.275 | 0.02 - TWQR | | | |
| Ti | 0.798 | 0.2 – CL | | | |
| Cr | 0.058 | 0.05 - TWQR | | | |
| Ni | 0.038 | 0.02 - TWQR | | | |

Table 2.2.2 Sample ID: RP2

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.055 | 0.01 – MCL | Pb | 0.004 | 0.01 - TWQR |
| Hg | 0.013 | 0.001 - TWQR | V | 0.014 | 0.1 - TWQR |
| Ti | 0.164 | 0.2 – CL | Cr | 0.017 | 0.05 - TWQR |
| Mn | 0.896 | 0.1 - TWQR | Sr | 0.102 | 0.1 - AV |
| | | | Cd | 0.003 | 0.005 - TWQR |

Table 2.2.3 Sample ID: KBTBHT

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| As | 0.013 | 0.01 – TWQR | Sr | 0.945 | 0.1 - AV |
| Ca | 113 | 75 - TWQR | Zn | 1.223 | 0.1 - AV |
| I | 0.167 | 0.1 - TWQR | Pb | 0.004 | 0.01 - TWQR |
| Na | 205 | 50 – TWQR | V | 0.030 | 0.1 - TWQR |
| TDS | 1170 | 500 – TWQR | Cr | 0.017 | 0.05 - TWQR |
| Ti | 0.364 | 0.2 – CL | | | |
| Cl | 245 | 200 – TWQR | | | |
| U | 0.04 | 0.02 - TWQR | | | |
| Mg | 63 | 50 – TWQR | | | |
| $NO_3$ | 106 | 25 - TWQR | | | |

Table 2.2.4 Sample ID: KBP1

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.607 | 0.01 – MCL | Sr | 1.131 | 0.1 - AV |
| As | 0.01 | 0.01 – TWQR | Pb | 0.004 | 0.01 - TWQR |
| Ca | 76 | 75 - TWQR | Zn | 0.255 | 0.1 - AV |
| Mn | 0.155 | 0.1 - TWQR | V | 0.047 | 0.1 - TWQR |
| I | 0.291 | 0.1 - TWQR | Cr | 0.047 | 0.05 - TWQR |
| $NO_3$ | 43 | 25 - TWQR | Cd | 0.004 | 0.005 - TWQR |
| Na | 147 | 50 – TWQR | | | |
| TDS | 751 | 500 – TWQR | | | |
| Ti | 0.273 | 0.2 – CL | | | |
| Hg | 0.001 | 0.001 - TWQR | | | |

Table 2.2.5 Sample ID: KBP2

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.755 | 0.01 – MCL | Sr | 0.911 | 0.1 - AV |
| I | 0.175 | 0.1 - TWQR | Pb | 0.004 | 0.01 - TWQR |
| $NO_3$ | 46 | 25 - TWQR | Zn | 0.527 | 0.1 - AV |
| Na | 138 | 50 – TWQR | V | 0.027 | 0.1 - TWQR |
| TDS | 710 | 500 – TWQR | Cr | 0.011 | 0.05 - TWQR |
| Ti | 0.263 | 0.2 – CL | As | 0.007 | 0.01 – TWQR |
| | | | Ca | 64 | 75 - TWQR |

Table 2.2.6 Sample ID: KBP3

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.743 | 0.01 – MCL | Sr | 1.100 | 0.1 - AV |
| As | 0.01 | 0.01 – TWQR | Ca | 72 | 75 - TWQR |
| I | 0.189 | 0.1 - TWQR | Zn | 0.807 | 0.1 - AV |
| $NO_3$ | 50 | 25 - TWQR | V | 0.028 | 0.1 - TWQR |
| Na | 136 | 50 – TWQR | Cr | 0.011 | 0.05 - TWQR |
| TDS | 744 | 500 – TWQR | | | |
| Ti | 0.342 | 0.2 – CL | | | |
| Hg | 0.007 | 0.001 - TWQR | | | |

Table 2.2.7 Sample ID: AVBRW1

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.152 | 0.01 – MCL | Cd | 0.001 | 0.005 - TWQR |
| | | | Zn | 2.181 | 0.1 - AV |

Table 2.2.8 Sample ID: AVBRW2

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| | | | Sr | 0.232 | 0.1 - AV |
| | | | Zn | 0.793 | 0.1 - AV |

Table 2.2.9 Sample ID: AVBRW3

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| I | 0.142 | 0.1 - TWQR | Sr | 0.567 | 0.1 - AV |
| Ti | 0.202 | 0.2 – CL | V | 0.013 | 0.1 - TWQR |

Table 2.2.10 Sample ID: KP1

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.407 | 0.01 – MCL | Sr | 0.280 | 0.1 - AV |
| As | 0.017 | 0.01 – TWQR | V | 0.017 | 0.1 - TWQR |
| Se | 0.052 | 0.02 - TWQR | | | |
| I | 0.129 | 0.1 - TWQR | | | |
| $NO_3$ | 29 | 25 - TWQR | | | |
| Ti | 0.238 | 0.2 – CL | | | |
| Hg | 0.008 | 0.001 - TWQR | | | |

Table 2.2.11 Sample ID: KP2

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.132 | 0.01 – MCL | V | 0.030 | 0.1 - TWQR |
| As | 0.011 | 0.01 – TWQR | Cr | 0.038 | 0.05 - TWQR |
| Pb | 0.017 | 0.01 - TWQR | $NO_3$ | 18 | 25 - TWQR |
| Se | 0.026 | 0.02 - TWQR | Ni | 0.019 | 0.02 - TWQR |
| Ti | 0.595 | 0.2 – CL | | | |
| Hg | 0.006 | 0.001 - TWQR | | | |

Table 2.2.12 Sample ID: KP3

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 1.109 | 0.01 – MCL | Sr | 0.524 | 0.1 - AV |
| As | 0.01 | 0.01 – TWQR | Mg | 41 | 50 - TWQR |
| I | 0.449 | 0.1 - TWQR | V | 0.027 | 0.1 - TWQR |
| Cl | 292 | 200 - TWQR | | | |
| Na | 220 | 50 – TWQR | | | |
| TDS | 874 | 500 – TWQR | | | |
| Ti | 0.131 | 0.2 – CL | | | |

Table 2.2.13 Sample ID: KP4

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 1.131 | 0.01 – MCL | Sr | 0.268 | 0.1 - AV |
| As | 0.012 | 0.01 – TWQR | V | 0.024 | 0.1 - TWQR |
| I | 0.226 | 0.1 - TWQR | | | |
| $NO_3$ | 48 | 25 - TWQR | | | |
| Na | 177 | 50 – TWQR | | | |
| TDS | 678 | 500 – TWQR | | | |
| Hg | 0.002 | 0.001 – TWQR | | | |
| Cl | 210 | 200 - TWQR | | | |

Table 2.2.14 Sample ID: KP5

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.114 | 0.01 – MCL | Sr | 0.100 | 0.1 - AV |
| Pb | 0.047 | 0.01 – TWQR | V | 0.027 | 0.1 - TWQR |
| Mn | 0.761 | 0.1 - TWQR | | | |
| Hg | 0.055 | 0.001 – TWQR | | | |
| Ti | 0.114 | 0.2 - CL | | | |

Table 2.2.15 Sample ID: KP6

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.134 | 0.01 – MCL | Sr | 0.190 | 0.1 - AV |
| Pb | 0.020 | 0.01 – TWQR | V | 0.036 | 0.1 - TWQR |
| Mn | 0.156 | 0.1 - TWQR | Cr | 0.018 | 0.05 - TWQR |
| Hg | 0.010 | 0.001 – TWQR | | | |
| Ti | 0.462 | 0.2 - CL | | | |

Table 2.2.16 Sample ID: FF11

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 1.668 | 0.01 – MCL | Sr | 1.140 | 0.1 - AV |
| As | 0.027 | 0.01 – TWQR | V | 0.074 | 0.1 - TWQR |
| I | 1.188 | 0.1 - TWQR | Zn | 1.839 | 0.1 - AV |
| Cr | 0.06 | 0.05 - TWQR | Cd | 0.003 | 0.005 – TWQR |
| Ca | 157 | 75 - TWQR | | | 0.01 - TWQR |
| Na | 257 | 50 – TWQR | | | |
| TDS | 1245 | 500 – TWQR | | | |
| Hg | 0.001 | 0.001 – TWQR | | | |
| Ti | 0.475 | 0.2 – CL | | | |
| Cl | 405 | 200 - TWQR | | | |

Table 2.2.17 Sample ID: FF12

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 1.228 | 0.01 – MCL | Sr | 0.320 | 0.1 - AV |
| As | 0.032 | 0.01 – TWQR | V | 0.075 | 0.1 - TWQR |
| I | 0.403 | 0.1 - TWQR | Zn | 0.108 | 0.1 - AV |
| Cr | 0.076 | 0.05 - TWQR | Pb | 0.006 | 0.01 - TWQR |
| Mo | 0.026 | 0.01 - TWQR | | | |
| F | 6.24 | 1 - TWQR | | | |
| Cd | 0.005 | 0.005 – TWQR | | | |
| TDS | 764 | 500 – TWQR | | | |
| Hg | 0.002 | 0.001 – TWQR | | | |
| Cl | 228 | 200 - TWQR | | | |
| Ti | 0.318 | 0.2 – CL | | | |

Table 2.2.18 Sample ID: FF13

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.185 | 0.01 – MCL | V | 0.028 | 0.1 - TWQR |
| Pb | 0.016 | 0.01 - TWQR | Cr | 0.035 | 0.05 - TWQR |
| Hg | 0.008 | 0.001 – TWQR | As | 0.006 | 0.01 – TWQR |
| Ti | 0.290 | 0.2 – CL | Cd | 0.004 | 0.005 – TWQR |

Table 2.2.19 Sample ID: FF14

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.835 | 0.01 – MCL | Sr | 0.135 | 0.1 - AV |
| Se | 0.027 | 0.02 – TWQR | V | 0.011 | 0.1 - TWQR |
| I | 0.582 | 0.1 - TWQR | As | 0.008 | 0.01 – TWQR |
| Mn | 0.123 | 0.1 - TWQR | | | |
| Pb | 0.015 | 0.01 - TWQR | | | |
| Hg | 0.002 | 0.001 – TWQR | | | |

Table 2.2.20 Sample ID: FF15

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.448 | 0.01 – MCL | Sr | 0.258 | 0.1 - AV |
| F | 4.37 | 1 - TWQR | V | 0.017 | 0.1 - TWQR |
| Se | 0.180 | 0.02 – TWQR | Cd | 0.002 | 0.005 – TWQR |
| I | 0.717 | 0.1 - TWQR | Pb | 0.004 | 0.01 - TWQR |
| TDS | 506 | 500 - TWQR | Cr | 0.016 | 0.05 - TWQR |
| Na | 119 | 50 – TWQR | | | |
| As | 0.041 | 0.01 – TWQR | | | |
| U | 0.022 | 0.02 - TWQR | | | |
| Hg | 0.011 | 0.001 – TWQR | | | |
| Ti | 0.271 | 0.2 – CL | | | |

Table 2.2.21 Sample ID: FF21

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.140 | 0.01 – MCL | Sr | 0.216 | 0.1 - AV |
| I | 0.150 | 0.1 - TWQR | V | 0.014 | 0.1 - TWQR |
| Pb | 0.011 | 0.01 - TWQR | Cr | 0.021 | 0.05 - TWQR |
| Mn | 0.946 | 0.1 - TWQR | Cd | 0.004 | 0.005 – TWQR |
| Hg | 0.001 | 0.001 – TWQR | | | |
| Ti | 0.191 | 0.2 – CL | | | |

Table 2.2.22 Sample ID: FF22

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.543 | 0.01 – MCL | Sr | 0.108 | 0.1 - AV |
| I | 0.408 | 0.1 - TWQR | V | 0.061 | 0.1 - TWQR |
| As | 0.014 | 0.01 - TWQR | Se | 0.016 | 0.02 - TWQR |
| Pb | 0.136 | 0.01 - TWQR | Ni | 0.017 | 0.02 - TWQR |
| Mn | 0.668 | 0.1 - TWQR | | | |
| Cr | 0.058 | 0.05 - TWQR | | | |
| Ti | 1.021 | 0.2 – CL | | | |

Table 2.2.23 Sample ID: FF23

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.347 | 0.01 – MCL | As | 0.006 | 0.01 - TWQR |
| I | 0.683 | 0.1 - TWQR | Se | 0.018 | 0.02 - TWQR |
| Mn | 0.993 | 0.1 - TWQR | Pb | 0.005 | 0.01 - TWQR |
| Hg | 0.005 | 0.001 – TWQR | | | |
| Ti | 0.185 | 0.2 – CL | | | |

Table 2.2.24 Sample ID: WK1

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.149 | 0.01 – MCL | Cr | 0.008 | 0.05 - TWQR |
| I | 0.141 | 0.1 - TWQR | | | |
| F | 1.87 | 1 - TWQR | | | |
| Ti | 0.201 | 0.2 – CL | | | |

Table 2.2.25 Sample ID: WK2

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.127 | 0.01 – MCL | Pb | 0.004 | 0.01 - TWQR |
| Hg | 0.010 | 0.001 - TWQR | Cd | 0.002 | 0.005 - TWQR |
| As | 0.024 | 0.01 - TWQR | Cr | 0.010 | 0.05 - TWQR |
| F | 1.64 | 1 - TWQR | | | |
| Se | 0.151 | 0.02 - TWQR | | | |
| Mn | 0.177 | 0.1 - TWQR | | | |
| Ti | 0.232 | 0.2 – CL | | | |

Table 2.2.26 Sample ID: WK3

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.396 | 0.01 – MCL | Pb | 0.004 | 0.01 - TWQR |
| I | 0.101 | 0.1 - TWQR | | | |
| As | 0.021 | 0.01 - TWQR | | | |
| Se | 0.102 | 0.02 - TWQR | | | |
| Hg | 0.006 | 0.001 - TWQR | | | |
| Ti | 0.152 | 0.2 – CL | | | |

Table 2.2.27 Sample ID: WK4

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.058 | 0.01 – MCL | Sr | 0.107 | 0.1 - AV |
| F | 2.15 | 1 - TWQR | | | |
| Ti | 0.172 | 0.2 – CL | | | |

Table 2.2.28 Sample ID: RW1

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.150 | 0.01 – MCL | V | 0.014 | 0.1 - TWQR |
| Hg | 0.001 | 0.001 - TWQR | Cd | 0.004 | 0.005 - TWQR |
| I | 0.110 | 0.1 - TWQR | Sr | 0.268 | 0.1 – AV |
| F | 3.76 | 1 - TWQR | | | |
| Pb | 0.057 | 0.01 - TWQR | | | |
| Na | 67 | 50 – TWQR | | | |
| Mn | 0.223 | 0.1 - TWQR | | | |
| Ti | 0.222 | 0.2 – CL | | | |

Table 2.2.29 Sample ID: RW2

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.437 | 0.01 – MCL | Cd | 0.004 | 0.005 - TWQR |
| Pb | 0.051 | 0.01 - TWQR | Cr | 0.02 | 0.05 - TWQR |
| As | 0.014 | 0.01 - TWQR | V | 0.028 | 0.1 - TWQR |
| F | 1.65 | 1 - TWQR | Ni | 0.018 | 0.02 - TWQR |
| Mn | 0.858 | 0.1 - TWQR | Sr | 0.198 | 0.1 – AV |
| Ti | 1.015 | 0.2 – CL | | | |

Table 2.2.30 Sample ID: RW3

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.049 | 0.01 – MCL | Cr | 0.035 | 0.05 - TWQR |
| Pb | 0.051 | 0.01 - TWQR | V | 0.029 | 0.1 - TWQR |
| Cd | 0.005 | 0.005 - TWQR | Ni | 0.017 | 0.02 - TWQR |
| Mn | 0.254 | 0.1 - TWQR | | | |
| Ti | 1.525 | 0.2 – CL | | | |

Table 2.2.31 Sample ID: RW4

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.292 | 0.01 – MCL | As | 0.007 | 0.01 - TWQR |
| Pb | 0.005 | 0.01 - TWQR | | | |
| Hg | 0.004 | 0.001 - TWQR | | | |
| Se | 0.033 | 0.02 - TWQR | | | |

Table 2.2.32 Sample ID: RW5

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 2.140 | 0.01 – MCL | As | 0.050 | 0.01 - TWQR |
| Se | 0.025 | 0.02 - TWQR | V | 0.055 | 0.1 - TWQR |
| Ti | 0.252 | 0.2 – CL | Zn | 0.148 | 0.1 - AV |
| | | | Sr | 0.384 | 0.1 - AV |

Table 2.2.33 Sample ID: RW6

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.440 | 0.01 – MCL | V | 0.040 | 0.1 - TWQR |
| As | 0.029 | 0.01 - TWQR | Zn | 0.649 | 0.1 - AV |
| Ti | 0.147 | 0.2 – CL | Sr | 0.739 | 0.1 - AV |
| Hg | 0.002 | 0.001 - TWQR | Se | 0.015 | 0.02 - TWQR |
| $NO_3$ | 27 | 25 - TWQR | | | |
| TDS | 835 | 500 - TWQR | | | |
| Na | 205 | 50 – TWQR | | | |
| Cl | 264 | 200 - TWQR | | | |

Table 2.2.34 Sample ID: RW7

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 1.617 | 0.01 – MCL | Ca | 68 | 75 - TWQR |
| As | 0.075 | 0.01 - TWQR | V | 0.080 | 0.1 - TWQR |
| Ti | 0.291 | 0.2 – CL | Zn | 0.181 | 0.1 - AV |
| Se | 0.025 | 0.02 - TWQR | Sr | 2.231 | 0.1 - AV |
| Hg | 0.003 | 0.001 - TWQR | | | |
| TDS | 1909 | 500 - TWQR | | | |
| Na | 476 | 50 – TWQR | | | |
| Cl | 1056 | 200 - TWQR | | | |

Table 2.2.35 Sample ID: RW8

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.895 | 0.01 – MCL | V | 0.028 | 0.1 - TWQR |
| As | 0.052 | 0.01 - TWQR | Zn | 5.701 | 0.1 - AV |
| Ti | 0.355 | 0.2 – CL | Sr | 2.194 | 0.1 - AV |
| Mn | 0.525 | 0.1 - TWQR | Se | 0.010 | 0.02 - TWQR |
| Hg | 0.002 | 0.001 - TWQR | | | |
| TDS | 2090 | 500 - TWQR | | | |
| Na | 514 | 50 – TWQR | | | |
| Cl | 1190 | 200 - TWQR | | | |
| Ca | 86 | 75 - TWQR | | | |

#### 2.2.2.1.2 Second sampling phase

The second sampling phase results for water chemistry conducted in early summer are presented in Tables 2.3.1 to 2.3.14.

Table 2.3.1 Sample ID: RP12

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.318 | 0.01 – MCL | V | 0.07 | 0.1 - TWQR |
| Pb | 0.037 | 0.01 - TWQR | Sr | 0.215 | 0.1 – AV |
| As | 0.021 | 0.01 – TWQR | Cd | 0.003 | 0.005 - TWQR |
| Hg | 0.002 | 0.001 - TWQR | | | |
| Mn | 1.476 | 0.1 - TWQR | | | |
| Ti | 2.266 | 0.2 – CL | | | |
| Cr | 0.072 | 0.05 - TWQR | | | |
| Ni | 0.075 | 0.02 - TWQR | | | |

Table 2.3.2 Sample ID: KBTBHT2

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Pb | 0.061 | 0.01 - TWQR | Sr | 0.832 | 0.1 - AV |
| Br | 0.242 | 0.01 - TWQR | Se | 0.017 | 0.02 - TWQR |
| Ca | 108 | 75 - TWQR | V | 0.013 | 0.1 - TWQR |
| I | 0.191 | 0.1 - TWQR | As | 0.005 | 0.01 – TWQR |
| Na | 103 | 50 – TWQR | | | |
| TDS | 641 | 500 – TWQR | | | |
| Ti | 0.670 | 0.2 – CL | | | |
| F | 1.52 | 1 – TWQR | | | |
| Hg | 0.002 | 0.001 - TWQR | | | |
| $NO_3$ | 30 | 25 - TWQR | | | |
| Cd | 0.006 | 0.005 - TWQR | | | |

Table 2.3.3 Sample ID: KBP12

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.162 | 0.01 – MCL | Sr | 0.125 | 0.1 - AV |
| As | 0.01 | 0.01 – TWQR | $NO_3$ | 15 | 25 - TWQR |
| Na | 102 | 50 – TWQR | V | 0.031 | 0.1 - TWQR |
| TDS | 453 | 500 – TWQR | Cr | 0.024 | 0.05 - TWQR |
| Ti | 0.159 | 0.2 – CL | Cd | 0.003 | 0.005 - TWQR |
| Hg | 0.001 | 0.001 - TWQR | | | |
| Mn | 0.298 | 0.1 - TWQR | | | |

Table 2.3.4 Sample ID: KBP22

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.190 | 0.01 – MCL | Sr | 0.139 | 0.1 - AV |
| I | 0.157 | 0.1 - TWQR | Cd | 0.004 | 0.005 - TWQR |
| $NO_3$ | 89 | 25 - TWQR | Zn | 2.592 | 0.1 - AV |
| TDS | 265 | 500 – TWQR | V | 0.017 | 0.1 - TWQR |
| Ti | 0.147 | 0.2 – CL | Cr | 0.016 | 0.05 - TWQR |
| Hg | 0.001 | 0.001 - TWQR | As | 0.005 | 0.01 – TWQR |
| Mn | 0.385 | 0.1 - TWQR | Ni | 0.015 | 0.02 - TWQR |

Table 2.3.5 Sample ID: AVBRW12

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.024 | 0.01 – MCL | Cd | 0.001 | 0.005 - TWQR |
| Pb | 0.011 | 0.01 - TWQR | Zn | 3.909 | 0.1 - AV |
| Hg | 0.001 | 0.001 – TWQR | | | |

Table 2.3.6 Sample ID: AVBRW22

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.022 | 0.01 – MCL | Zn | 6.165 | 0.1 - AV |
| | | | | | |

Table 2.3.7 Sample ID: KP23

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.226 | 0.01 – MCL | V | 0.040 | 0.1 - TWQR |
| As | 0.01 | 0.01 – TWQR | Cr | 0.040 | 0.05 - TWQR |
| Pb | 0.01 | 0.01 - TWQR | Sr | 0.205 | 0.1 – AV |
| I | 0.303 | 0.1 - TWQR | Ni | 0.012 | 0.02 - TWQR |
| Ti | 0.478 | 0.2 – CL | | | |

Table 2.3.8 Sample ID: FF152

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 2.140 | 0.01 – MCL | Sr | 0.384 | 0.1 - AV |
| F | 11.3 | 1 - TWQR | V | 0.055 | 0.1 - TWQR |
| Se | 0.025 | 0.02 – TWQR | Zn | 0.148 | 0.1 - AV |
| TDS | 805 | 500 - TWQR | Cr | 0.009 | 0.05 - TWQR |
| Na | 100 | 50 – TWQR | | | |
| As | 0.050 | 0.01 – TWQR | | | |
| $NO_3$ | 29 | 25 - TWQR | | | |
| Cl | 266 | 200 – TWQR | | | |
| Ti | 0.252 | 0.2 – CL | | | |

Table 2.3.9 Sample ID: FF222

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.410 | 0.01 – MCL | Sr | 0.555 | 0.1 - AV |
| I | 0.319 | 0.1 - TWQR | V | 0.01 | 0.1 - TWQR |
| Mn | 0.158 | 0.1 - TWQR | Ni | 0.015 | 0.02 - TWQR |
| Ti | 0.237 | 0.2 – CL | As | 0.006 | 0.01 - TWQR |
| | | | Pb | 0.008 | 0.01 - TWQR |

Table 2.3.10 Sample ID: WK22

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.075 | 0.01 – MCL | Zn | 0.102 | 0.1 - AV |
| F | 1.94 | 1 - TWQR | As | 0.005 | 0.01 - TWQR |
| Ti | 0.100 | 0.2 – CL | | | |

Table 2.3.11 Sample ID: RW12

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.086 | 0.01 – MCL | Zn | 0.794 | 0.1 - AV |
| F | 3.56 | 1 - TWQR | Sr | 0.240 | 0.1 – AV |
| Pb | 0.004 | 0.01 - TWQR | | | |
| Ti | 0.184 | 0.2 – CL | | | |

Table 2.3.12 Sample ID: RW22

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.090 | 0.01 – MCL | Sr | 0.121 | 0.1 – AV |
| Mn | 0.707 | 0.1 - TWQR | Cr | 0.011 | 0.05 - TWQR |
| Ti | 0.262 | 0.2 – CL | | | |

Table 2.3.13 Sample ID: RW32

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Pb | 0.005 | 0.01 - TWQR | | | |
| Mn | 0.149 | 0.1 - TWQR | | | |

Table 2.3.14 Sample ID: RW62

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 1.147 | 0.01 – MCL | As | 0.04 | 0.01 - TWQR |
| V | 0.124 | 0.1 - TWQR | Sr | 0.322 | 0.1 - AV |
| Ti | 0.294 | 0.2 – CL | I | 0.628 | 0.1 - TWQR |
| Hg | 0.001 | 0.001 - TWQR | Ca | 72 | 75 – TWQR |
| $NO_3$ | 324 | 25 - TWQR | Cr | 0.015 | 0.05 - TWQR |
| TDS | 826 | 500 - TWQR | | | |
| Mg | 68 | 50 – TWQR | | | |
| Na | 82 | 50 - TWQR | | | |

### 2.2.2.2 Biological and environmental samples

The results for the biological and environmental samples collected are presented in Tables 2.4.1 and 2.4.2.

**Table 2.4.1**. Biological tissue results in indigenous chickens collected in the Jericho District.

| Element* | Means & S.D. (mg/kg DM basis) | | | |
|---|---|---|---|---|
| | Liver | Thigh | Breast | Femur |
| **As** | | | | |
| RP | $1.075_{a}$ (0.318) | $0.75_{a}$ (0.212) | $1.1_{cd}$ (0.001) | $3.35_{b}$ (2.899) |
| KBT | $0.9_{a}$ (0.141) | $0.45_{a}$ (0.070) | $1.575_{c}$ (0.742) | $1.9_{ab}$ (0.707) |
| KBP | $1.15_{a}$ (0.212) | $5.4_{b}$ (0.141) | $0.4_{a}$ (0.001) | $1.55_{ab}$ (0.212) |
| FF1 | $2.25_{b}$ (1.202) | $1.05_{a}$ (0.919) | $0.4_{a}$ (0.001) | $0.95_{ab}$ (0.070) |
| KP | $0.5_{a}$ (0.141) | $0.45_{a}$ (0.070) | $0.6_{ad}$ (0.282) | $0.6_{a}$ (0.2820) |
| RW | $0.65_{a}$ (0.070) | $0.4_{a}$ (0.001) | $0.4_{a}$ (0.001) | $0.8_{a}$ (0.002) |
| FF2 | $1.3_{ab}$ (0.707) | $1.2_{a}$ (1.131) | $2.3_{b}$ (0.141) | $2.2_{ab}$ (0.848) |
| AVB | $0.55_{a}$ (0.212) | $0.65_{a}$ (0.353) | $0.5_{ad}$ (0.141) | $0.85_{a}$ (0.636) |
| WK | $0.5_{a}$ (0.001) | $0.75_{a}$ (0.070) | $0.4_{a}$ (0.001) | $0.55_{a}$ (0.212) |
| **Pb** | | | | |
| RP | $4.1_{ac}$ (0.989) | $4.4_{a}$ (4.808) | $2.25_{a}$ (1.626) | $17.45_{a}$ (0.636) |
| KBT | $7.15_{ac}$ (0.421) | $2.9_{ab}$ (2.969) | $4.350_{a}$ (1.484) | $36.0_{a}$ (26.870) |
| KBP | $23.5_{bc}$ (19.09) | $44.0_{c}$ (14.142) | $9.0_{a}$ (1.414) | $11.0_{a}$ (0.424) |
| FF1 | $15_{abc}$ (2.828) | $8.5_{ab}$ (0.707) | $6.0_{a}$ (1.414) | $29.5_{a}$ (20.506) |
| KP | $8.5_{a}$ (2.121) | $13.5_{ab}$ (4.949) | $8.0_{a}$ (8.485) | $10.0_{a}$ (5.656) |
| RW | $2.1_{a}$ (0.848) | $1.55_{a}$ (0.494) | $2.15_{a}$ (1.202) | $20.35_{a}$ (15.061) |
| FF2 | $18_{c}$ (8.485) | $21.5_{b}$ (10606.) | $22.0_{b}$ (7.071) | $41.0_{a}$ (15.556) |
| AVB | $0.4_{a}$ (0.001) | $1.95_{a}$ (0.212) | $7.8_{a}$ (4.525) | $30.0_{a}$ (36.769) |
| WK | $1.3_{a}$ (0.848) | $2.7_{a}$ (0.989) | $6.4_{a}$ (3.676) | $26.85_{a}$ (3.040) |
| **Se** | | | | |
| RP | $7.65_{b}$ (0.353) | $5.4_{a}$ (0.282) | $8.15_{d}$ (0.212) | $2.95_{abc}$ (2.333) |
| KBT | $6.85_{a}$ (0.777) | $4.85_{a}$ (0.636) | $11.05_{c}$ (0.636) | $6.85_{a}$ (0.636) |
| KBP | $8.9_{ab}$ (1.131) | $4.0_{a}$ (1.834) | $3.15_{a}$ (0.212) | $4.1_{abc}$ (2.828) |
| FF1 | $13.25_{b}$ (7.424) | $17.6_{b}$ (9.758) | $4.0_{a}$ (1.131) | $2.95_{ac}$ (0.494) |
| KP | $5.55_{a}$ (1.767) | $3.8_{a}$ (0.848) | $2.05_{a}$ (2.757) | $2.1_{c}$ (0.141) |
| RW | $5.75_{a}$ (0.070) | $3.45_{a}$ (0.212) | $3.55_{a}$ (0.494) | $8.05_{b}$ (4.596) |
| FF2 | $9.65_{ab}$ (3.181) | $8.4_{ab}$ (6.788) | $13.95_{b}$ (0.353) | $3.65_{abc}$ (0.919) |
| AVB | $4.3_{a}$ (1.131) | $4.2_{a}$ (1.838) | $2.65_{a}$ (1.767) | $2.35_{ac}$ (0.919) |

| | | | | |
|---|---|---|---|---|
| WK | 4.55 $_{a}$ (0.070) | 5.05 $_{a}$ (0.636) | 2.75 $_{a}$ (0.919) | 1.8 $_{ac}$ (1.555) |
| **Br** | | | | |
| RP | 93.5 $_{acd}$ (7.778) | 116 $_{ab}$ (2.828) | 262.5 $_{d}$ (36.062) | 84 $_{a}$ (2.828) |
| KBT | 80.5 $_{ac}$ (6.363) | 89.5 $_{ab}$ (2.121) | 220.5 $_{ad}$ (92.63) | 206 $_{ab}$ (166.8) |
| KBP | 131 $_{acd}$ (0.707) | 120 $_{ab}$ (11.313) | 115.5 $_{ad}$ (3.535) | 77.5 $_{ab}$ (16.263) |
| FF1 | 265.5 $_{b}$ (171.820) | 289.5 $_{ab}$ (147.78) | 689.5 $_{bc}$ (62.93) | 381 $_{ab}$ (371.93) |
| KP | 216 $_{bd}$ (67.882) | 485.5 $_{b}$ (458.9) | 107 $_{ad}$ (16.263) | 84.5 $_{ab}$ (9.192) |
| RW | 80.5 $_{ac}$ (3.535) | 64 $_{a}$ (11.313) | 718 $_{d}$ (151.32) | 245.5 $_{ab}$ (102.5) |
| FF2 | 195 $_{bc}$ (7.071) | 198 $_{ab}$ (77.781) | 267 $_{c}$ (97.580) | 110 $_{ab}$ (18.384) |
| AVB | 44 $_{a}$ (1.414) | 76.5 $_{a}$ (14.849) | 75 $_{a}$ (29.698) | 62.5 $_{ab}$ (28.99) |
| WK | 47 $_{a}$ (5.656) | 49.5 $_{a}$ (4.949) | 53.5 $_{a}$ (2.121) | 59.5 $_{b}$ (9.192) |
| **Cd** | | | | |
| RP | 0.2 $_{a}$ (0.001) | 0.1 $_{a}$ (0.001) | 1.0 $_{ab}$ (1.272) | 2.2 $_{bc}$ (1.131) |
| KBT | 0.25 $_{a}$ (0.141) | 0.1 $_{a}$ (0.001) | 0.5 $_{a}$ (0.282) | 2.35 $_{b}$ (1.060) |
| KBP | 0.2 $_{a}$ (0.141) | 0.25 $_{a}$ (0.212) | 0.1 $_{a}$ (0.001) | 0.35 $_{a}$ (0.212) |
| FF1 | 0.7 $_{a}$ (0.070) | 0.2 $_{a}$ (0.001) | 0.2 $_{a}$ (0.141) | 0.5 $_{a}$ (0.141) |
| KP | 0.3 $_{a}$ (0.141) | 0.3 $_{a}$ (0.282) | 0.3 $_{a}$ (0.282) | 0.5 $_{a}$ (0.282) |
| RW | 0.45 $_{a}$ (0.212) | 0.1 $_{a}$ (0.001) | 0.5 $_{a}$ (0.001) | 1.7 $_{ab}$ (0.989) |
| FF2 | 2.75 $_{b}$ (0.777) | 1.4 $_{b}$ (0.282) | 2 $_{b}$ (0.707) | 1.35 $_{ab}$ (0.353) |
| AVB | 0.1 $_{a}$ (0.001) | 0.1 $_{a}$ (0.001) | 0.3 $_{a}$ (0.141) | 0.6 $_{a}$ (0.141) |
| WK | 0.1 $_{a}$ (0.001) | 0.3 $_{a}$ (0.141) | 0.15 $_{a}$ (0.070) | 0.5 $_{a}$ (0.001) |
| **Cr** | | | | |
| RP | 3.3 $_{acd}$ (0.424) | 4.3 $_{a}$ (0.070) | 4.5 $_{a}$ (1.272) | 7.75 $_{a}$ (3.889) |
| KBT | 3.55 $_{acd}$ (0.070) | 3.1 $_{a}$ (0.424) | 4.95 $_{a}$ (0.494) | 5.45 $_{a}$ (0.636) |
| KBP | 3.65 $_{ad}$ (0.353) | 7.45 $_{a}$ (5.444) | 4.9 $_{a}$ (0.141) | 7.55 $_{a}$ (6.151) |
| FF1 | 4.45 $_{cd}$ (0.070) | 5.65 $_{a}$ (0.777) | 4.6 $_{a}$ (0.001) | 11.05 $_{a}$ (9.263) |
| KP | 7.3 $_{b}$ (1.555) | 7.85 $_{a}$ (5.444) | 6.4 $_{a}$ (0.919) | 46 $_{b}$ (0.001) |
| RW | 2.9 $_{ad}$ (0.282) | 2.95 $_{a}$ (0.353) | 4.75 $_{a}$ (0.070) | 6.75 $_{a}$ (2.050) |
| FF2 | 4.0 $_{d}$ (0.424) | 6.4 $_{a}$ (2.545) | 7.65 $_{a}$ (1.343) | 5.05 $_{a}$ (0.494) |
| AVB | 2.45 $_{a}$ (0.353) | 4.85 $_{a}$ (3.606) | 13.55 $_{b}$ (7.141) | 13.6 $_{a}$ (1.555) |
| WK | 3.25 $_{ad}$ (0.4945) | 3.65 $_{a}$ (0.070) | 6.6 $_{a}$ (0.141) | 10.6 $_{a}$ (2.404) |
| **V** | | | | |
| RP | 1.1 $_{ac}$ (0.001) | 1.7 $_{a}$ (0.424) | 0.4 $_{a}$ (0.001) | 0.7 $_{a}$ (0.424) |
| KBT | 1.2 $_{ac}$ (0.282) | 1.2 $_{a}$ (0.001) | 0.4 $_{a}$ (0.001) | 0.4 $_{a}$ (0.001) |
| KBP | 0.4 $_{b}$ (0.001) | 0.65 $_{a}$ (0.353) | 0.4 $_{a}$ (0.001) | 0.4 $_{a}$ (0.001) |
| FF1 | 0.4 $_{b}$ (0.001) | 0.4 $_{a}$ (0.001) | 0.4 $_{a}$ (0.001) | 0.6 $_{a}$ (0.282) |
| KP | 0.4 $_{b}$ (0.001) | 0.4 $_{a}$ (0.001) | 0.75 $_{a}$ (0.919) | 0.4 $_{a}$ (0.001) |
| RW | 0.95 $_{a}$ (0.070) | 1 $_{a}$ (0.141) | 0.4 $_{a}$ (0.001) | 0.4 $_{a}$ (0.001) |
| FF2 | 0.4 $_{b}$ (0.001) | 0.4 $_{a}$ (0.001) | 0.4 $_{a}$ (0.001) | 0.4 $_{a}$ (0.001) |
| AVB | 0.75 $_{b}$ (0.070) | 1.55 $_{a}$ (1.060) | 0.65 $_{a}$ (0.353) | 0.4 $_{a}$ (0.001) |
| WK | 1.5 $_{c}$ (0.565) | 1.25 $_{a}$ (0.070) | 0.4 $_{a}$ (0.001) | 0.4 $_{a}$ (0.001) |
| **Cu** | | | | |
| RP | 28 $_{ac}$ (1.414) | 15.65 $_{abc}$ (3.04) | 24.5 $_{c}$ (12.02) | 61 $_{bcd}$ (24.04) |
| KBT | 20.5 $_{ad}$ (3.535) | 8 $_{abc}$ (1.131) | 15 $_{ac}$ (0.001) | 35.5 $_{acd}$ (0.707) |
| KBP | 52.5 $_{bc}$ (9.192) | 57.5 $_{bc}$ (51.61) | 15.5 $_{ac}$ (0.707) | 31.5 $_{abcd}$ (3.535) |
| FF1 | 38 $_{bcd}$ (2.828) | 18 $_{abc}$ (1.414) | 12.5 $_{a}$ (3.535) | 30.5 $_{ac}$ (0.707) |
| KP | 28 $_{a}$ (4.426) | 11.4 $_{ab}$ (0.565) | 18 $_{ac}$ (1.414) | 46.5 $_{abc}$ (6.363) |
| RW | 24.5 $_{d}$ (2.121) | 8.65 $_{a}$ (0.771) | 16.5 $_{ac}$ (0.707) | 52 $_{abd}$ (15.556) |
| FF2 | 62 $_{b}$ (35.355) | 53 $_{c}$ (12.727) | 36 $_{b}$ (4.242) | 59 $_{bd}$ (7.071) |
| AVB | 7.5 $_{a}$ (3.535) | 7.6 $_{a}$ (4.384) | 10.5 $_{a}$ (3.535) | 26.5 $_{c}$ (3.535) |
| WK | 8.5 $_{a}$ (4.949) | 14.5 $_{abc}$ (0.565) | 14 $_{a}$ (0.001) | 53.5 $_{abcd}$ (13.43) |

* Means within a coloumn (tissue type) for each element bearing the same subscripts do not differ significantly at the $P< 0.05$ level.

** Where: RP = Rantlapane; KBP = Kalkbank Private; KBT = Kalkbank Trust; AVB = Aasvogelboom; KP = Koedoespoort; RW = Rooiwal; WK = Wilgerkuil; FF1 = Fafung 1; FF2 = Fafung 2.

**Table 2.4. 2**. Environmental sample results from rural communities in the Jericho District.

| Element* | Means & S.D. (mg/kg DM basis) | | |
|---|---|---|---|
| | **Soil** | **Faecal** | **Plant** |
| **As** | | | |
| RP | 1.65 $_{a}$ (0.212) | 0.7 $_{ac}$ (0.001) | 0.85 $_{a}$ (0.070) |
| KBT | 0.9 $_{a}$ (0.989) | 1.25 $_{abc}$ (0.070) | 0.63 $_{a}$ (0.230) |
| KBP | 1.45 $_{a}$ (0.777) | 1.9 $_{abc}$ (0.282) | 0.65 $_{a}$ (0.212) |
| FF1 | 1.15 $_{a}$ (0.636) | 2.85 $_{b}$ (2.192) | 5.4 $_{a}$ (6.646) |
| KP | 2.85 $_{a}$ (1.909) | 1.2 $_{abc}$ (0.141) | 0.7 $_{a}$ (0.141) |
| RW | 53.05 $_{b}$ (59.467) | 1.15 $_{abc}$ (0.494) | 0.6 $_{a}$ (0.001) |
| FF2 | 1.5 $_{a}$ (0.424) | 0.85 $_{c}$ (0.353) | 1.1 $_{a}$ (0.424) |
| AVB | 1.1 $_{a}$ (0.141) | 1.5 $_{abc}$ (0.707) | 21.5 $_{a}$ (2.121) |
| WK | 1.95 $_{a}$ (0.070) | 1 $_{abc}$ (0.001) | 0.6 $_{a}$ (0.141) |
| **Pb** | | | |
| RP | 11.55 $_{a}$ (3.323) | 6 $_{ab}$ (1.414) | 6 $_{a}$ (1.414) |
| KBT | 3.8 $_{a}$ (0.141) | 6.5 $_{ab}$ (0.707) | 8 $_{a}$ (4.242) |
| KBP | 8.35 $_{a}$ (0.353) | 4 $_{ab}$ (0.001) | 5 $_{a}$ (2.828) |
| FF1 | 8.75 $_{a}$ (6.010) | 9.1 $_{ab}$ (9.616) | 56.5 $_{b}$ (30.405) |
| KP | 8.6 $_{a}$ (1.414) | 2.5 $_{b}$ (0.707) | 2.55 $_{a}$ (0.070) |
| RW | 54.7 $_{a}$ (71.559) | 4 $_{ab}$ (0.001) | 3 $_{a}$ (1.414) |
| FF2 | 8.5 $_{a}$ (1.555) | 8 $_{ab}$ (4.242) | 4 $_{a}$ (0.001) |
| AVB | 10.65 $_{a}$ (0.353) | 4.85 $_{ab}$ (1.626) | 2.45 $_{a}$ (0.212) |
| WK | 42.79 $_{a}$ (11.582) | 11.5 $_{a}$ (3.535) | 26.5 $_{a}$ (12.020) |
| **Se** | | | |
| RP | 2.3 $_{a}$ (0.989) | 1.65 $_{ac}$ (0.353) | 2.9 $_{ab}$ (0.424) |
| KBT | 2.75 $_{a}$ (2.616) | 3.75 $_{abc}$ (0.353) | 2.2 $_{a}$ (0.848) |
| KBP | 2.2 $_{a}$ (1.272) | 2.95 $_{abc}$ (1.909) | 2.3 $_{a}$ (0.565) |
| FF1 | 1.3 $_{a}$ (0.424) | 9.85 $_{b}$ (3.040) | 30.85 $_{b}$ (30.981) |
| KP | 2.6 $_{a}$ (0.848) | 3.5 $_{abc}$ (1.979) | 2.2 $_{a}$ (0.565) |
| RW | 3.2 $_{a}$ (1.272) | 3.05 $_{abc}$ (1.909) | 2.3 $_{a}$ (0.282) |
| FF2 | 1.5 $_{a}$ (0.707) | 2.55 $_{c}$ (0.212) | 3.35 $_{ab}$ (1.484) |
| AVB | 1.05 $_{a}$ (0.353) | 65 $_{abc}$ (24.455) | 21.5 $_{ab}$ (4.949) |
| WK | 1.8 $_{a}$ (0.707) | 3 $_{abc}$ (0.565) | 0.7 $_{a}$ (0.707) |
| **Br** | | | |
| RP | 2.2 $_{a}$ (3.111) | 68 $_{a}$ (9.899) | 69.5 $_{a}$ (0.707) |
| KBT | 4.75 $_{a}$ (6.717) | 72.5 $_{a}$ (12.020) | 60.5 $_{a}$ (0.707) |
| KBP | 0 $_{a}$ (0) | 84.5 $_{a}$ (20.506) | 68 $_{a}$ (2.828) |
| FF1 | 0 $_{a}$ (0) | 29.2 $_{a}$ (39.315) | 162.5 $_{a}$ (227.62) |
| KP | 0 $_{a}$ (0) | 80.5 $_{a}$ (6.363) | 56 $_{a}$ (0.001) |
| RW | 0 $_{a}$ (0) | 67 $_{a}$ (12.727) | 70 $_{a}$ (1.414) |
| FF2 | 0 $_{a}$ (0) | 63 $_{a}$ (8.485) | 61.5 $_{a}$ (3.535) |
| AVB | 0 $_{a}$ (0) | 1.5 $_{a}$ (0.707) | 21.5 $_{a}$ (4.949) |
| WK | 0 $_{a}$ (0) | 73 $_{a}$ (7.071) | 14.5 $_{a}$ (14.849) |
| **Cd** | | | |
| RP | 0.335 $_{a}$ (0.190) | 0.20 $_{a}$ (0.001) | 0.20 $_{a}$ (0.001) |
| KBT | 0.35 $_{a}$ (0.353) | 0.20 $_{a}$ (0.001) | 0.20 $_{a}$ (0.001) |
| KBP | 0.4 $_{a}$ (0.141) | 0.20 $_{a}$ (0.001) | 0.25 $_{a}$ (0.070) |
| FF1 | 0.45 $_{a}$ (0.212) | 0.8 $_{a}$ (0.848) | 0.25 $_{a}$ (0.070) |
| KP | 0.3 $_{a}$ (0.141) | 0.20 $_{a}$ (0.001) | 0.25 $_{a}$ (0.070) |
| RW | 0.45 $_{a}$ (0.353) | 0.20 $_{a}$ (0.001) | 0.20 $_{a}$ (0.001) |

| | | | |
|---|---|---|---|
| FF2 | 0.42 $_{a}$ (0.098) | 0.20 $_{a}$ (0.001) | 0.4 $_{b}$ (0.141) |
| AVB | 0.2 $_{a}$ (0.001) | 0.5 $_{a}$ (0.282) | 0.20 $_{a}$ (0.001) |
| WK | 0.3 $_{a}$ (0.141) | 0.20 $_{a}$ (0.001) | 0.20 $_{a}$ (0.001) |
| **Cr** | | | |
| RP | 58.35 $_{ab}$ (21.001) | 11.3 $_{a}$ (2.54) | 6.35 $_{ac}$ (5.020) |
| KBT | 12.70 $_{a}$ (2.262) | 12.4 $_{a}$ (1.69) | 3.45 $_{ac}$ (0.070) |
| KBP | 51.95 $_{ab}$ (4.870) | 16.95 $_{a}$ (7.848) | 5.75 $_{ac}$ (1.767) |
| FF1 | 35.45 $_{a}$ (10.394) | 37.35 $_{a}$ (49.992) | 16.35 $_{b}$ (4.737) |
| KP | 110 $_{b}$ (79.903) | 12.15 $_{a}$ (11.263) | 3.05 $_{c}$ (0.212) |
| RW | 23 $_{a}$ (8.909) | 16.15 $_{a}$ (0.070) | 2.4 $_{ac}$ (0.141) |
| FF2 | 55.7 $_{ab}$ (5.656) | 15.2 $_{a}$ (16.122) | 6.55 $_{ac}$ (0.494) |
| AVB | 40.35 $_{a}$ (2.474) | 7.65 $_{a}$ (5.020) | 0.5 $_{ac}$ (0.001) |
| WK | 61.4 $_{ab}$ (5.232) | 16.25 $_{a}$ (4.596) | 11.1 $_{a}$ (6.788) |
| **V** | | | |
| RP | 48.9 $_{abc}$ (15.414) | 9.1 $_{a}$ (1.272) | 4.7 $_{ab}$ (3.636) |
| KBT | 17.25 $_{a}$ (9.687) | 9.2 $_{a}$ (1.838) | 2.4 $_{ab}$ (0.001) |
| KBP | 45.61 $_{abc}$ (13.420) | 9.25 $_{a}$ (2.899) | 3.95 $_{ab}$ (0.777) |
| FF1 | 30.77 $_{abc}$ (6.123) | 43.75 $_{b}$ (3.181) | 8.05 $_{b}$ (7.848) |
| KP | 61 $_{bc}$ (33.234) | 4.6 $_{a}$ (2.545) | 2.3 $_{ab}$ (0.001) |
| RW | 23.85$_{ac}$ (10.111) | 8.15 $_{a}$ (1.343) | 1.4 $_{ab}$ (0.282) |
| FF2 | 39.65 $_{abc}$ (5.586) | 7.15 $_{a}$ (7.424) | 4.3 $_{ab}$ (0.001) |
| AVB | 29.25 $_{abc}$ (3.040) | 152.5 $_{a}$ (3.535) | 35.5 $_{a}$ (6.363) |
| WK | 52.95 $_{c}$ (7.848) | 10.7 $_{a}$ (2.545) | 5.0 $_{ab}$ (3.535) |
| **Cu** | | | |
| RP | 14.55 $_{ac}$ (4.454) | 14.5 $_{a}$ (0.707) | 11.5 $_{a}$ (2.121) |
| KBT | 7.2 $_{a}$ (3.535) | 14.5 $_{a}$ (2.121) | 8 $_{a}$ (0.001) |
| KBP | 19 $_{bc}$ (12.727) | 10$_{a}$ (7.071) | 9 $_{a}$ (1.414) |
| FF1 | 13.05 $_{ac}$ (0.353) | 51.1 $_{a}$ (63.498) | 41.5 $_{b}$ (3.555) |
| KP | 11.35 $_{ac}$ (2.333) | 15.5 $_{a}$ (2.121) | 7.5 $_{a}$ (2.121) |
| RW | 12.45 $_{ac}$ (1.484) | 14.5 $_{a}$ (3.535) | 9.5 $_{a}$ (2.121) |
| FF2 | 11.9 $_{ac}$ (1.838) | 13.5 $_{a}$ (0.707) | 8 $_{a}$ (1.414) |
| AVB | 9.845 $_{ac}$ (1.06) | 24.5 $_{a}$ (7.778) | 0.35 $_{c}$ (0.212) |
| WK | 26.615 $_{bc}$ (5.960) | 27.05 $_{a}$ (13.93) | 19.5 $_{d}$ (2.121) |

* Means within a coloumn (tissue type) for each element bearing the same subscripts do not differ significantly at the P< 0.05 level.

** Where: RP = Rantlapane; KBP = Kalkbank Private; KBT = Kalkbank Trust; AVB = Aasvogelboom; KP = Koedoespoort; RW = Rooiwal; WK = Wilgerkuil; FF1 = Fafung 1; FF2 = Fafung 2.

### 2.2.3 Discussion

The main health hazard remains the observation that water classified as either poor or completely unacceptable for domestic and livestock consumption is used in these villages on an on-going basis. Subterranean water remains the primary source of water throughout the year, with earth dam contributions mainly subterranean with rainfall contributing seasonally to the earth dam recharge and for many households. Generally, the water chemistry anomalies in the form of PHCC and consistent COC were reflected with more certainty in the biological samples collected that the environmental samples. Given that soil samples were collected within close proximity to watering points in most cases, faecal contribution to surface soil would be likely. The surface soil does however provide some indication of key elements ingested via geophagia. This is an important consideration as geophagia may contribute up to 20 percent of dry matter intake in grazing herbivores. Household samples would be beneficial in terms of assessing the

impact on poultry product quality, as soil samples adjacent to the house have been significantly correlated to blood lead levels in children under 2 years of age (Mathee *et al.*, 2001). The variability in grass samples was most probably related to different grazing pressures, uneven rainfall patterns, seasonal and species differences. The faecal samples require input knowledge in the form of PHCC and COC in order to draw inferences on values outside normal ranges suggestive of inadequacies and excesses, specifically on the occurrence of synergists and antagonists (Spears, 1994; Underwood and Suttle, 1999). As such the sampling thereof with greater frequency may provide a means of assessing trends of certain trace elements. Although not herein discussed in great detail, significant differences were noted between villages with respect to different sample types and elements that are presented in Tables 2.4.1 and 2.4.2, and model analysis of variance revealed liver to be the most appropriate biological sample for the elements Br, Cr, Cd, Cu and V, whilst breast samples described the variability best for As, Pb and Se. Femur samples provided the least significant predictions for all elements except Cr. These and correlations between sample types are presented later.

The Rantlapane village relies predominantly on RP2 for over 15 household and community needs. The anomalies of Pb, Br, As, Cd and Se were all detected in the biological samples collected. Multiple tissue sample types assist in identifying long-term exposures that may otherwise not be detected in single water sample collections. Although water samples should be collected on at least a quarterly basis this is often not the case, even when the water is suspected of being the source of poor performance and/or health. This high femur Se and Cd for RP reflect the occurrence thereof in both the samples. The soil samples RP, together with those for KBT, were the only ones to reflect high Br. The general absence in the other village soil samples of Br would accord with the documented ease with which Br travels through soil towards subterranean water and perhaps attest to the use thereof as an aquifer tracer. The detection thereof in the RP village is possibly to be found in the fact that the earth dam of RP2 is unique in the Jericho District by being fenced-off. This is recommended in reducing faecal contamination of the earth dam, however, increases the time spent by herds in close proximity to the watering point in this instance due to RP2 being the main watering point as access to RP1 is made very difficult by steep banks. The pressure on RP2 led to visible erosion being observed in the second sampling phase and is also reflected in the high Ti, Mn and Ni observed in that water sample collected. The Br observation in KBT is probably due to the fact that as the only water source for the village the sacrifice zone extends more than 50 m due to the presence of large numbers of stock on a continual basis. Although not detected as a PHCC in the first sampling phase, a high Br concentration was detected in the second phase in KBT village, a factor further demonstrate by the high Pb values observed in both femur and both KBT sampling phases. The persistence of the $NO_3$ values over the sampling phases are also supportive of the statements made regarding density of stock around the watering point and the soil and faecal values observed. The village of KBP is adjacent to KBT, but has two functioning boreholes and one main earth dam, all of which display a similar trend of PHCC and COC. High $NO_3$ values observed in all the samples present a serious hazard to both domestic and animal users. The highest Pb value for the liver samples collected was noted for KBP, as was the highest thigh As value. Other tissue and environmental

samples were in the higher ranges and probably reflect the consistency of exposure to hazardous concentrations in terms of both element concentrations and localized exposure as the communities of KBT and KBP adhere strictly to village boundaries. Water is collected form KBP in plastic containers and sold elsewhere in the Jericho District.

The high Br concentrations observed in KP (KP3 & KP4 both > 1 mg/L) were reflected in the consistently high tissue concentrations and second highest faecal value. The high femur Cr value in only indicated by KP2 as a COC, but the highest soil Cr value obtained was from the KP village. The two earth dams KP3 and KP4 are similar, as are KP5 and KP6, both pairs being located near to one another. Use of the boreholes in KP is difficult to determine, as in some instances KP1 and KP2 were not functioning, and in other community members were collecting from KP1. The village clinic uses KP2 but also with the addition of rainwater when available. KP2 is also used for a poultry house, but stocking was very low at the time of sampling. Poultry were not collected from the poultry house, but rather from households in the village as was the case in the other villages.

Within the range of low observed constituent concentrations, observations in AVB for water chemistry were mostly well supported by the biological and environmental sample results. The lack of PHCC, aside from Br, observed in the water chemistry was reflected by the lowest liver values for Pb, Br and Cr being observed for AVB. Low values were also returned for As, Se and Cd. Similarly AVB returned the lowest values for faecal and plant Cr, faecal Br (with plant Br second lowest) and Se soil. High anomalies were observed for faecal and plant V and faecal As and Se. In addition to the documented interaction between As and Se and observation of these elements in other environmental samples, possible explanations may be found in the management on the water sources in AVB. The main borehole is used sparingly and presented with rainwater added. The second sampling phase increases observed in the WQC concentrations may be due to the long resident period resulting in deterioration of the borehole (possible contributions by plumbing fittings and fixtures). Utilization of the borehole increased due to the lack of rainfall.

The RW village observations for Pb in RW2 and RW3 are reflected in RW returning the highest soil Pb observations. These earth dams are over one kilometer from the village houses and heavily utilized for stock watering and fishing. Biological samples were collected within the villages and not in proximity to the earth dams. The high breast and bone Br, and femur Se were correlated to the drinking trough water chemistry fro RW4 and RW5. Increased concentrations are often noted in drinking troughs due to dust contamination and increased evaporative rates. Between the samples R6, R7 and R8, R7 is used the most, despite having a poor quality. The reason for this is that the hand pump for R8 is too hard for many of the elderly residents, and R6 does not deliver a strong pressure. As a result R7 is used for the village vegetable and poultry projects. High tissue results may also be due to the high TDS values noted and consequent increased water intakes and dose ingestion rates. The second sampling phase occurred after heavy rainfalls, with most of the earth dam samples showing some dilution. The drastically increased $NO_3$ of RW6 does however suggest rainfall related faecal contamination.

The generally low tissue concentrations returned for the WK village are also reflected in the water sample results, with the main hazard noted being F. As noted for WK arsenic concentrations in water and soil, similar trends were found between water and soil arsenic for the villages RW and KP. WK2 is the water source used the most for domestic use in the village, with WK4 used less often due to low water pressure. The livestock points of use are both WK1 and WK3, with the community members preferring to separate cattle watering points from those used by people. This was the only village were this practice was noted as an active strategy. Elevations in the drinking trough for WK3 were due to the poor design of the trough (low walled and large surface area). A similar pattern emerged for villages (AVB, WK & FF1) with water samples containing high Br concentrations where most biological tissues presented with low Cu values and associated high faecal values. Complexes may form extrahepatically (Kaneko, 1989) and are not necessarily confined to the digestive tract, but Cu deficiency problems associated with high Br in the drinking water have been noted in several game production system investigations (ARAD, 2004 & 2005).

The water samples that consistently presented with the highest hazards were obtained from the Fafung Villages, a pattern that was well supported by the biological and environmental samples. These are very large villages that consist of predominantly borehole supplied earth dams in the south, and central borehole supplied reservoirs from which water is collected for household use in the north. Fluoride anomalies were noted in some sampling points, and human and animals both present with enamel hypoplasia, exostoses and varying forms of skeletal defects documented with chronic fluorosis. The highest liver concentrations were observed for samples collected in these villages, with FF1 returning the highest for As, Se, Br, Cd, second highest for Cr and third highest for Pb (FF2 found to have the second highest liver Pb). Other tissues continued this trend, with the lower than expected femur values for some elements most probably attributed to displacement by fluoride. The highest observed values for plant samples for Se Cr, Pb and Br were from FF1 samples. The sample sites FF15 and FF14 are heavily utilized for domestic and animal purposes with strict times allocated for household collection and animal drinking. The palatability of these points are acceptable to the users and highlight the dangers of many PHCC such as F, As, and Se that do not impart any adverse aesthetic properties to the water. The samples collected from FF2 also highlight the need to assess trace element concentrations in drinking water as FF22 is a tap that provides the main schools with drinking water. The high lead concentration is most probably not due to contamination by fittings and fixtures, as similar concentrations were noted in the earth dams throughout the Fafung villages and also in other biological and environmental samples. The lower values for the two earth dams in FF2 were most probably attributed to size differences, with FF21 being a large dam with well-established aquatic vegetation, as opposed to FF23 which is a small earth dam with highly eroded animal access paths. As sample sites for FF2 are in close proximity to FF1, both presented similar constituent concentrations in the samples collected, with greater hazards noted for FF1.

## 2.3 Limpopo Province

### 2.3.1 Perspective

Observations of PHCC in the Immerpan District are presented in previous WRC Reports 644/1/98 and 857/1/01. The area is situated to the east of the Delftzyl Agricultural Research Station and was intended to form part of an initiative within the Limpopo Province Department of Agriculture whereby previously disadvantaged individuals from communities in the area would be able to rent farming units with the option to purchase later. As the previous reports indicate for the majority of these farms groundwater forms the only source of water and the quality thereof is classified as completely unacceptable for domestic and animal consumption. The initial aim for this project was to establish the extent to which the PHCC observed impacted on animal production and on human health due to the consumption of compromised animal products within this district. Successful alleviator treatments tested at the Delftzyl Agricultural Research Station and Hatfield Experimental Farm at the University of Pretoria, had been formulated for some of the main PHCC and the implementation and monitoring thereof on key selected farms was also planned.

However, due to the increased frequency of unlawful stocking of many of these units and the presence of illegal occupants it was not possible to complete the environmental and biological sampling programmes, nor to successfully implement alleviator treatments. Following discussions with the Director of Land Research and Training at the Limpopo Province Department of Agriculture, investigations proceeded in selected communities in the Polokwane District into groundwater quality used for human and animal use, specifically for poultry production projects. The main observation was that water quality was not considered during the planning and implementation of rural agricultural projects. It was therefore requested that the effects of groundwater on poultry production projects within selected communities in the Limpopo Province be conducted in association with the Tompi Seleka Agricultural College (TSAC), as the TSAC was involved in both practical and theoretical training of community members. The implementation of these poultry production projects was with the assistance of USDA funding.

### 2.3.2 Methods

#### 2.3.2.1 Communities in the Polokwane District

Water sample collection sites were located in two general areas, one south-west of Polokwane and the other north of Polokwane, and selected on the basis of complaints regarding poor animal performance and/or adverse health effects in people that the Land Research and Training Manager had received from various community forums. The same sampling, analytical and assessment procedures as described earlier for the Jericho District were followed. The following sampling was conducted:

**Table 2.5.1 Collection of samples from the Polokwane District in the Limpopo Province.**

| Sample Site | Sample Location | Water Samples Collected | Water User Groups |
|---|---|---|---|
| P1<br>Mashobohleng Village<br>Moletji Township | E 29 18 57.3<br>S 23 39 24.8 | Earth Dam following heavy rains (borehole fed) | Livestock |
| P2<br>Mashobohleng Village | E 29 19 32.1<br>S 23 39 41.8 | Household borehole hand-pump | Domestic, household livestock and crops |

| | | | |
|---|---|---|---|
| Moletji Township | | | |
| P3<br>Sekonye Village<br>Botlokwa Tribe | E 29 41 51.6<br>S 23 31 00.8 | Earth Dam following rains<br>(borehole fed) | Livestock and incidental domestic |
| P4<br>Sekonye Village<br>Botlokwa Tribe | E 29 41 37.2<br>S 23 31 04.6 | Household borehole hand-pump | Domestic, household livestock and crops |
| P5<br>Makgato Village<br>Klipplaat Drift Area | E 29 41 21.2<br>S 23 30 43.5 | Tap in village road<br>(borehole fed) | Domestic, household livestock and crops |
| P6<br>Makgato Village<br>Klipplaat Drift Area | E 29 40 05.3<br>S 23 30 35.4 | Household borehole hand-pump | Domestic, household livestock and crops |
| P7<br>Sekakene Village | E 29 41 01.6<br>S 23 27 15.16 | Village Tap<br>(Borehole fed) | Domestic, household livestock and crops<br>Vegetable Project and planned Poultry Production House |
| P8<br>Sekakene Village | E 29 41 41.9<br>S 23 27 42.7 | Communal Hand-pump | Domestic, household livestock and crops |
| P9<br>Mangatla Village | E 29 42 31.3<br>S 23 27 35.7 | Tap<br>(Borehole fed) | Poultry Project and Vegetable Project |
| P10<br>Mangatla Village | E 29 42 29.0<br>S 23 28 26.2 | Village Hand-pump | Domestic, household livestock and crops |

### 2.3.2.2 Immerpan District and TSAC Poultry Projects

Water, biological and environmental sampling and analytical methods employed were the same as presented for the Jericho District. Poultry specimens were collected from five poultry production houses in different villages and from the main poultry production house at the training facility at the TSAC. Environmental samples were collected from two sites (T3 and T4) due to the presence of vegetable plots and cattle (allowing for fecal sample collection). At the time of sampling only three farmers in the Immerpan Resettlement District were successfully occupying land and actively farming. Due to several constraints it was only possible to sample two of these units. These are included in the results presented. The following sampling was conducted:

**Table 2.5.2. Collection of samples from the Immerpan and adjoining Districts within the Limpopo Province.**

| Sample Site | Site Location | Water Samples Collected | Biological Samples Collected | Environmental Samples Collected |
|---|---|---|---|---|
| T1<br>Rehlakile PPH<br>Weltevreden<br>Mbozini Community | E 29 22 430.0<br>S 24 41 07.5 | Arabie Dam & Groundwater (mixed – one sample point of use) | Three Commercial Broilers | none |
| T2<br>Eenkantaan Village PPH | E 29 32 29.9<br>S 24 42 51.5 | River<br>(borehole not functioning) | Three Commercial Broilers | none |

| | | | | |
|---|---|---|---|---|
| T3<br>Batlabatale PPH & Vegetable Plot<br>Phokoane Village | E 29 45 00.0<br>S 24 51 30.7 | Groundwater | Three Commercial Broilers | Soil, Plant, Fecal |
| T4<br>Mamodi PPH & Vegetable Plot<br>Riverside Village | E 29 50 11.4<br>S 24 47 37.2 | Groundwater & Earth Dam (used separately) | Three Commercial Broilers | Soil, Plant, Fecal |
| T5<br>Ikukeng PPH & Vegetable Plot<br>Schoonoord Village | E 29 56 33.6<br>S 24 39 14.6 | Groundwater | Three Commercial Broilers | none |
| TSAC<br>Main PPH | E 29 27 12.8<br>S 24 47 23.7 | Tap – Mainly inflow from Arabie Dam | Three Commercial Broilers | none |
| BV<br>Bellview Farm<br>Immerpan Resettlement District | E 29 15 10.4<br>S 24 35 57.3 | BV1 – Earth dam<br>BV2 – Drinking trough<br>BV3 – Rain water | Three adult indigenous chickens.<br>Blood (v. jugularis) from mixed cattle breeds.<br>Indigenous goat – thyroid, liver & kidney. | Soil, Plant, Fecal (cattle) |
| SC<br>Voleysrus<br>Immerpan Resettlement District | E 29 20 45.6<br>S 24 37 54.4 | SC1 – Tap from Borehole<br>SC2 – drinking trough | Three adult indigenous chickens.<br>Blood (v. jugularis) from mixed cattle breeds.<br>Indigenous goat – thyroid, liver & kidney. | Soil, Plant, Fecal (cattle) |

Poultry thigh, breast and liver and femur samples were pooled with two samples extracted per sample site listed in Table 2.5.2. Samples were pooled in this manner to obtain sufficient mass for analytical purposes. Pooled samples were dried at 60 degrees Celsius for 48 hours prior to delivery to the ISCW. The same analytical procedures as described for the Jericho District were used.

Following the results of the water quality analyses from these production houses, additional water samples were collected from other poultry production houses (some including layer production houses) that the TSAC was involved in. Three of these villages had been sampled prior during the Polokwane District investigation referred to earlier in this chapter. Additional water samples were also collected and provided from the village poultry production units assisted by the TSAC. These sites were:

Jabulani Mmotongwa Pevekisi
Makgofe Botlokwa
Makgofe Botlokwa
Moletsi Matlala
Mangata Botlokwa
TSAC Layer house input raw water from Arabie dam

### 2.3.3 Results

The water quality assessments are provided in Tables 2.6.1 to 2.6.27, following which the results for the poultry and environmental samples are presented whilst the combined bovine blood samples from the Immerpan and Jericho District are presented Chapter 5 of this report.

#### 2.3.3.1 Water Quality: Communities in the Polokwane District

Table 2.6.1 Sample ID: P1

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Pb | 0.13 | 0.01 – TWQR | Se | 0.01 | 0.02 – TWQR |

Table 2.6.2 Sample ID: P2

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.414 | 0.01 – MCL | Ca | 73 | 75 – TWQR |
| Pb | 0.01 | 0.01 - TWQR | Sr | 0.839 | 0.1 – AV |
| Cl | 201 | 200 – TWQR | Mg | 45 | 50 – TWQR |
| Hg | 0.001 | 0.001 - TWQR | Zn | 0.315 | 0.1 – AV |
| I | 0.759 | 0.1 - TWQR | As | 0.006 | 0.01 – TWQR |
| $NO_3$ | 298 | 25 - TWQR | Se | 0.016 | 0.02 – TWQR |
| Na | 138 | 50 – TWQR | | | |
| TDS | 958 | 500 – TWQR | | | |
| Ti | 0.333 | 0.2 – CL | | | |

Table 2.6.3 Sample ID: P3

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.408 | 0.01 – MCL | Sr | 0.476 | 0.1 - AV |
| F | 1.98 | 1 – TWQR | Zn | 0.143 | 0.1 - AV |
| Pb | 0.019 | 0.01 - TWQR | As | 0.006 | 0.01 – TWQR |
| Hg | 0.091 | 0.001 - TWQR | V | 0.059 | 0.1 - TWQR |
| I | 0.411 | 0.1 - TWQR | Cr | 0.031 | 0.05 - TWQR |
| Na | 210 | 50 – TWQR | | | |
| TDS | 754 | 500 – TWQR | | | |
| Ti | 0.611 | 0.2 – CL | | | |
| Ni | 0.021 | 0.02 - TWQR | | | |
| Mn | 0.337 | 0.1 - TWQR | | | |

Table 2.6.4 Sample ID: P4

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.636 | 0.01 – MCL | Sr | 0.792 | 0.1 - AV |
| F | 4.73 | 1 – TWQR | Zn | 1.667 | 0.1 - AV |
| Pb | 0.016 | 0.01 - TWQR | As | 0.007 | 0.01 – TWQR |
| Hg | 0.005 | 0.001 - TWQR | V | 0.063 | 0.1 - TWQR |
| I | 0.909 | 0.1 - TWQR | Se | 0.01 | 0.02 - TWQR |
| Na | 304 | 50 – TWQR | Ca | 65 | 75 - TWQR |
| TDS | 1517 | 500 – TWQR | | | |
| Ti | 0.327 | 0.2 – CL | | | |
| Cl | 259 | 200 – TWQR | | | |
| $NO_3$ | 377 | 25 - TWQR | | | |
| Mg | 70 | 50 – TWQR | | | |
| $SO_4$ | 181 | 125 - TWQR | | | |

Table 2.6.5 Sample ID: P5

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.980 | 0.01 – MCL | Sr | 0.925 | 0.1 - AV |
| F | 1.95 | 1 – TWQR | Pb | 0.005 | 0.01 - TWQR |
| As | 0.017 | 0.01 – TWQR | V | 0.038 | 0.1 - TWQR |
| Hg | 0.003 | 0.001 - TWQR | | | |
| I | 0.839 | 0.1 - TWQR | | | |
| Na | 357 | 50 – TWQR | | | |
| TDS | 1673 | 500 – TWQR | | | |
| Se | 0.031 | 0.02 - TWQR | | | |
| Ti | 0.417 | 0.2 – CL | | | |
| Cl | 654 | 200 – TWQR | | | |
| $SO_4$ | 174 | 125 - TWQR | | | |
| $NO_3$ | 76 | 25 - TWQR | | | |
| Ca | 92 | 75 - TWQR | | | |
| Mg | 60 | 50 – TWQR | | | |

Table 2.6.6 Sample ID: P6

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.677 | 0.01 – MCL | Sr | 1.136 | 0.1 - AV |
| Pb | 0.016 | 0.01 - TWQR | V | 0.015 | 0.1 - TWQR |
| As | 0.011 | 0.01 – TWQR | Zn | 7.418 | 0.1 - AV |
| Hg | 0.018 | 0.001 - TWQR | Se | 0.011 | 0.02 - TWQR |
| I | 0.489 | 0.1 - TWQR | | | |
| Na | 239 | 50 – TWQR | | | |
| TDS | 1629 | 500 – TWQR | | | |
| Ti | 0.576 | 0.2 – CL | | | |

| | | | | | |
|---|---|---|---|---|---|
| Cl | 388 | 200 – TWQR | | | |
| $SO_4$ | 138 | 125 - TWQR | | | |
| $NO_3$ | 469 | 25 - TWQR | | | |
| Ca | 124 | 75 - TWQR | | | |
| Mg | 91 | 50 – TWQR | | | |

Table 2.6.7 Sample ID: P7

| **PHCC** | | | **COC** | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 1.528 | 0.01 – MCL | Sr | 1.257 | 0.1 - AV |
| Se | 0.032 | 0.02 - TWQR | V | 0.021 | 0.1 - TWQR |
| As | 0.018 | 0.01 – TWQR | Zn | 0.337 | 0.1 - AV |
| Hg | 0.020 | 0.001 - TWQR | Pb | 0.005 | 0.01 - TWQR |
| I | 0.373 | 0.1 - TWQR | | | |
| Na | 466 | 50 – TWQR | | | |
| TDS | 2628 | 500 – TWQR | | | |
| Ti | 0.483 | 0.2 – CL | | | |
| Cl | 546 | 200 – TWQR | | | |
| $SO_4$ | 267 | 125 - TWQR | | | |
| $NO_3$ | 850 | 25 - TWQR | | | |
| Ca | 104 | 75 - TWQR | | | |
| Mg | 114 | 50 – TWQR | | | |

Table 2.6.8 Sample ID: P8

| **PHCC** | | | **COC** | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 1.265 | 0.01 – MCL | Sr | 0.890 | 0.1 - AV |
| Mg | 86 | 50 – TWQR | V | 0.089 | 0.1 - TWQR |
| As | 0.014 | 0.01 – TWQR | Cr | 0.015 | 0.05 - TWQR |
| F | 4.58 | 1 – TWQR | Se | 0.015 | 0.02 - TWQR |
| Hg | 0.003 | 0.001 - TWQR | Pb | 0.004 | 0.01 - TWQR |
| I | 4.248 | 0.1 - TWQR | | | |
| Na | 384 | 50 – TWQR | | | |
| TDS | 1567 | 500 – TWQR | | | |
| Ti | 0.168 | 0.2 – CL | | | |
| Cl | 415 | 200 – TWQR | | | |
| $SO_4$ | 147 | 125 - TWQR | | | |
| $NO_3$ | 30 | 25 - TWQR | | | |

Table 2.6.9 Sample ID: P9

| **PHCC** | | | **COC** | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.357 | 0.01 – MCL | Sr | 0.513 | 0.1 - AV |
| F | 2.25 | 1 – TWQR | V | 0.037 | 0.1 - TWQR |
| Hg | 0.016 | 0.001 - TWQR | As | 0.007 | 0.01 – TWQR |
| I | 1.639 | 0.1 - TWQR | Pb | 0.005 | 0.01 - TWQR |

| | | | | | |
|---|---|---|---|---|---|
| Na | 193 | 50 – TWQR | | | |
| TDS | 741 | 500 – TWQR | | | |
| Ti | 0.120 | 0.2 – CL | | | |
| $NO_3$ | 93 | 25 - TWQR | | | |

Table 2.6.10 Sample ID: P10

| **PHCC** | | | **COC** | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.435 | 0.01 – MCL | Sr | 0.546 | 0.1 - AV |
| F | 2.62 | 1 – TWQR | V | 0.073 | 0.1 - TWQR |
| Hg | 0.114 | 0.001 - TWQR | As | 0.008 | 0.01 – TWQR |
| I | 0.301 | 0.1 - TWQR | Pb | 0.005 | 0.01 - TWQR |
| Na | 229 | 50 – TWQR | Zn | 0.372 | 0.1 - AV |
| TDS | 837 | 500 – TWQR | Se | 0.013 | 0.02 - TWQR |
| Ti | 0.233 | 0.2 – CL | | | |
| $NO_3$ | 88 | 25 - TWQR | | | |

### 2.3.3.2 Water Quality: Immerpan District and TSAC Poultry Projects

Table 2.6.11 Sample ID: T1

| **PHCC** | | | **COC** | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.630 | 0.01 – MCL | Sr | 0.186 | 0.1 - AV |
| Pb | 0.058 | 0.01 - TWQR | Cr | 0.005 | 0.05 – TWQR |
| Na | 53 | 50 – TWQR | F | 0.34 | 1 - TWQR |
| Ti | 0.123 | 0.1 – MPL | TDS | 332 | 500 – TWQR |

Table 2.6.12 Sample ID: T2

| **PHCC** | | | **COC** | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.835 | 0.01 – MCL | Cr | 0.003 | 0.05 – TWQR |
| F | 1.19 | 1 - TWQR | Ca | 58 | 75 - TWQR |
| $NO_3$ | 38 | 25 – TWQR | Sr | 0.267 | 0.1 - AV |
| Pb | 0.01 | 0.01 - TWQR | Se | 0.01 | 0.02 - TWQR |
| Na | 74 | 50 – TWQR | | | |
| TDS | 453 | 500 - TWQR | | | |
| Ti | 0.180 | 0.1 - MPL | | | |

Table 2.6.13 Sample ID: T3

| **PHCC** | | | **COC** | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.125 | 0.01 – MCL | Cr | 0.003 | 0.05 – TWQR |
| Pb | 0.034 | 0.01 - TWQR | Zn | 3.351 | 0.1 - AV |

Table 2.6.14 Sample ID: T4

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.182 | 0.01 – MCL | Cr | 0.004 | 0.05 – TWQR |
| F | 2.51 | 1 - TWQR | Sr | 0.148 | 0.1 - AV |
| Pb | 0.023 | 0.01 - TWQR | TDS | 193 | 500 - TWQR |

Table 2.6.15 Sample ID: T4B

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.121 | 0.01 – MCL | Cr | 0.003 | 0.05 – TWQR |
| Pb | 0.018 | 0.01 - TWQR | Sr | 0.097 | 0.1 - AV |
| | | | TDS | 143 | 500 - TWQR |
| | | | F | 0.65 | 1 - TWQR |

Table 2.6.16 Sample ID: T5

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.749 | 0.01 – MCL | Cr | 0.004 | 0.05 – TWQR |
| $NO_3$ | 135 | 25 – TWQR | Ca | 58 | 75 - TWQR |
| Pb | 0.013 | 0.01 - TWQR | Sr | 0.293 | 0.1 - AV |
| Na | 90 | 50 – TWQR | Zn | 0.552 | 0.1 - AV |
| TDS | 724 | 500 – TWQR | | | |
| Ti | 0.201 | 0.2 – CL | | | |
| Mg | 69 | 50 – TWQR | | | |

Table 2.6.17 Main Poultry House - TSAC

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| As | 0.452 | 0.01 – TWQR | Sr | 0.216 | 0.1 – AV |
| Br | 0.376 | 0.01 – MCL | Zn | 0.146 | 0.1 - AV |
| Cu | 0.024 | 0.002 – TWQR | | | |
| Hg | 0.003 | 0.001 – TWQR | | | |
| Se | 0.02 | 0.01 – TWQR | | | |
| Na | 176 | 50 – TWQR | | | |
| TDS | 842 | 500 – TWQR | | | |
| Ti | 0.201 | 0.2 – CL | | | |
| I | 0.109 | 0.1 – TWQR | | | |
| $NO_3$ | 38 | 25 – TWQR | | | |

Table 2.6.18 Sample ID: BV1

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.019 | 0.01 – MCL | | | |

Table 2.6.19 Sample ID: BV2

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.011 | 0.01 – MCL | Sr | 0.133 | 0.1 - AV |
| Mn | 0.154 | 0.1 - TWQR | | | |

Table 2.6.20 Sample ID: BV3

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| | | | Pb | 0.005 | 0.01 - TWQR |
| | | | Zn | 4.222 | 0.1 – AV |

Table 2.6.21 Sample ID: SC 1

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 6.006 | 0.01 – MCL | Cr | 0.012 | 0.05 – TWQR |
| As | 0.028 | 0.01 – TWQR | Sr | 2.581 | 0.1 - AV |
| Pb | 0.01 | 0.01 - TWQR | V | 0.033 | 0.1 – TWQR |
| Se | 0.107 | 0.02 - TWQR | | | |
| Hg | 0.004 | 0.001 - TWQR | | | |
| I | 1.668 | 0.1 - TWQR | | | |
| U | 0.04 | 0.02 - TWQR | | | |
| Na | 521 | 50 – TWQR | | | |
| TDS | 1014 | 500 – TWQR | | | |
| Ti | 0.927 | 0.2 – CL | | | |
| Mn | 0.136 | 0.1 – TWQR | | | |
| Ni | 0.032 | 0.02 - TWQR | | | |
| Cl | 1635 | 200 – TWQR | | | |
| Mg | 171 | 50 – TWQR | | | |
| Ca | 302 | 75 – TWQR | | | |

Table 2.6.22 Sample ID: SC 2

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.649 | 0.01 – MCL | Cr | 0.012 | 0.05 – TWQR |
| I | 0.339 | 0.1 – TWQR | Ca | 59 | 75 - TWQR |
| $NO_3$ | 144 | 25 – TWQR | Sr | 1.063 | 0.1 - AV |
| Na | 104 | 50 – TWQR | V | 0.043 | 0.1 – TWQR |
| TDS | 924 | 500 – TWQR | As | 0.005 | 0.01 – TWQR |
| Ti | 0.281 | 0.2 – CL | Pb | 0.002 | 0.01 - TWQR |
| Mg | 88 | 50 – TWQR | Se | 0.008 | 0.02 - TWQR |

## 2.3.3.3 Water Quality: Additional samples TSAC

Table 2.6.23 Jabulani Mmotongwa Pevekisi Poultry Production Project

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Br | 0.284 | 0.01 – MCL | Sr | 0.702 | 0.1 - AV |
| $NO_3$ | 53 | 25 – TWQR | I | 0.315 | 0.1 – AV |
| Na | 100 | 50 – TWQR | As | 0.007 | 0.01 - TWQR |
| TDS | 566 | 500 – TWQR | | | |
| Ti | 0.234 | 0.2 – CL | | | |

Table 2.6.24 Makgofe Botlokwa Poultry Production Project

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| As | 0.029 | 0.01 - TWQR | Ca | 70 | 75 – TWQR |
| Br | 1.349 | 0.01 – MCL | Sr | 1.285 | 0.1 – AV |
| Hg | 0.001 | 0.001 – TWQR | Mg | 105 | 125 – TWQR |
| Cl | 506 | 200 – TWQR | | | |
| Cu | 0.029 | 0.002 – TWQR | | | |
| $NO_3$ | 35 | 25 – TWQR | | | |
| Na | 213 | 50 – TWQR | | | |
| Se | 0.01 | 0.01 – TWQR | | | |
| TDS | 1295 | 500 – TWQR | | | |
| I | 0.194 | 0.1 – TWQR | | | |
| Ti | 0.327 | 0.2 – CL | | | |
| U | 0.044 | 0.02 – TWQR | | | |

Table 2.6.25 Moletsi Matlala Poultry Production Project

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| As | 0.013 | 0.01 – TWQR | I | 0.166 | 0.1 – AV |
| Br | 0.522 | 0.01 – MCL | Sr | 0.618 | 0.1 – AV |
| Hg | 0.05 | 0.001 – TWQR | Zn | 0.197 | 0.1 - AV |
| Cl | 194 | 200 – TWQR | | | |
| Na | 127 | 50 – TWQR | | | |
| TDS | 704 | 500 – TWQR | | | |
| Ti | 0.189 | 0.2 – CL | | | |
| $NO_3$ | 48 | 25 – TWQR | | | |

Table 2.6.26 Mangata Botlokwa Poultry Production Project

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| As | 0.015 | 0.01 – TWQR | Ca | 62 | 75 – TWQR |
| Br | 0.417 | 0.01 – MCL | Sr | 0.671 | 0.1 - AV |
| Hg | 0.004 | 0.001 – TWQR | Zn | 0.345 | 0.1 - AV |
| I | 0.168 | 0.1 – TWQR | | | |
| F | 1.42 | 1 – TWQR | | | |
| $NO_3$ | 88 | 25 – TWQR | | | |
| TDS | 872 | 500 – TWQR | | | |

Table 2.6.27 Layer house Input raw water Arabie dam – TSAC*

| PHCC | | | COC | | |
|---|---|---|---|---|---|
| Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) | Constituent | Observed Value (mg/ℓ) | Relevant Guideline (mg/ℓ) |
| Hg | 0.007 | 0.001 – TWQR | Pb | 0.008 | 0.01 – TWQR |
| | | | Zn | 0.718 | 0.1 - AV |

*Se, Br, Sr, Cd not available due to technical laboratory error.

### 2.3.3.4 Biological and Environmental Samples

The results for the biological and environmental samples collected are presented in Tables 2.7.1 and 2.7.2.

**Table 2.7.1**. Biological tissue results in poultry specimens collected in the Immerpan District and from Tompi Seleka Agricultural College Poultry Production House Projects.

| Element* | Means & S.D. (mg/kg DM basis) | | | |
|---|---|---|---|---|
| | Liver | Thigh | Breast | Femur |
| **As** | | | | |
| TSK | $1.5_{a}$ (0.141) | $0.55_{a}$ (0.212) | $1.0_{ab}$ (0.282) | $1.6_{b}$ (0.424) |
| T1 | $0.4_{b}$ (0.001) | $0.7_{a}$ (0.282) | $1.45_{b}$ (1.060) | $1.05_{ab}$ (0.353) |
| T2 | $0.6_{b}$ (0.282) | $0.4_{a}$ (0.001) | $0.4_{a}$ (0.001) | $0.8_{a}$ (0.565) |
| T3 | $1.9_{a}$ (0.565) | $1.3_{b}$ (0.424) | $0.4_{a}$ (0.001) | $0.4_{a}$ (0.001) |

| | | | | |
|---|---|---|---|---|
| T4 | 0.75 $_{b}$ (0.070) | 0.4 $_{a}$ (0.001) | 0.4 $_{a}$ (0.001) | 0.45 $_{a}$ (0.070) |
| T5 | 0.6 $_{b}$ (0.141) | 0.7 $_{a}$ (0.141) | 0.4 $_{a}$ (0.001) | 0.45 $_{a}$ (0.070) |
| SC | 1.4 $_{a}$ (0.707) | 0.7 $_{a}$ (0.424) | 0.5 $_{a}$ (0.141) | 0.5 $_{a}$ (0.001) |
| BV | 1.65 $_{a}$ (0.636) | 0.65 $_{a}$ (0.070) | 0.4 $_{a}$ (0.001) | 0.5 $_{a}$ (0.141) |
| **Pb** | | | | |
| TSK | 0.7 $_{a}$ (0.001) | 2.05 $_{a}$ (0.777) | 2.4 $_{a}$ (1.555) | 16.5 $_{ac}$ (4.949) |
| T1 | 3.75 $_{ac}$ (2.192) | 10.4 $_{a}$ (11.73) | 17.0 $_{a}$ (19.79) | 28.0 $_{c}$ (1.414) |
| T2 | 2.2 $_{a}$ (1.979) | 4.6 $_{a}$ (4.38) | 1.1 $_{a}$ (0.282) | 13.65 $_{a}$ (6.576) |
| T3 | 7.0 $_{c}$ (1.141) | 5.5 $_{a}$ (0.707) | 18.0 $_{a}$ (7.071) | 9.1 $_{a}$ (2.687) |
| T4 | 1.15 $_{a}$ (0.212) | 2.15 $_{a}$ (0.001) | 24.6 $_{a}$ (16.970) | 13.35 $_{ac}$ (12.65) |
| T5 | 0.7 $_{a}$ (0.001) | 2.35 $_{a}$ (0.070) | 7.65 $_{a}$ (8.838) | 12.85 $_{ac}$ (3.040) |
| SC | 17.0 $_{b}$ (2.282) | 6.0 $_{a}$ (2.828) | 10.0 $_{a}$ (5.656) | 32.5 $_{bc}$ (10.606) |
| BV | 0.6 $_{a}$ (0.001) | 2.1 $_{a}$ (0.001) | 21.5 $_{a}$ (14.849) | 7.45 $_{a}$ (0.777) |
| **Se** | | | | |
| TSK | 9.05 $_{cd}$ (0.636) | 4.55 $_{ac}$ (1.343) | 5.5 $_{c}$ (0.282) | 6.1 $_{b}$ (1.272) |
| T1 | 6.65 $_{abcd}$ (1.626) | 3.45 $_{a}$ (0.070) | 6.5 $_{bc}$ (4.384) | 3.65 $_{a}$ (2.757) |
| T2 | 4.05 $_{a}$ (1.767) | 3.9 $_{a}$ (0.424) | 0.85 $_{a}$ (0.636) | 3.0 $_{a}$ (1.838) |
| T3 | 11.15 $_{bcd}$ (3.464) | 7.8 $_{b}$ (0.424) | 5.1 $_{abc}$ (0.848) | 1.6 $_{ab}$ (0.001) |
| T4 | 5.85 $_{ac}$ (0.212) | 3.8 $_{a}$ (0.141) | 0.1 $_{a}$ (0.001) | 2.55 $_{abc}$ (1.343) |
| T5 | 5.05 $_{ac}$ (0.353) | 5.9 $_{c}$ (0.989) | 0.35 $_{a}$ (0.353) | 1.5 $_{a}$ (1.979) |
| SC | 4.8 $_{ac}$ (0.141) | 5.05 $_{ac}$ (1.484) | 3.0 $_{abc}$ (2.828) | 4.8 $_{ab}$ (1.838) |
| BV | 10.5 $_{d}$ (3.39) | 5.3 $_{ac}$ (0.141) | 1.7 $_{ac}$ (0.565) | 1.65 $_{a}$ (1.626) |
| **Br** | | | | |
| TSK | 81.0 $_{a}$ (5.656) | 54.5 $_{a}$ (4.949) | 39.0 $_{cd}$ (1.414) | 72.5 $_{ab}$ (31.819) |
| T1 | 68.5 $_{a}$ (17.677) | 50.5 $_{a}$ (0.707) | 153.5 $_{ab}$ (92.63) | 114.0 $_{b}$ (2.828) |
| T2 | 164.5 $_{c}$ (28.991) | 193.0 $_{b}$ (48.083) | 161.5 $_{b}$ (14.84) | 61.5 $_{a}$ (9.192) |
| T3 | 47.0 $_{a}$ (22.627) | 43.5 $_{a}$ (6.363) | 64.0 $_{abcd}$ (43.84) | 50.5 $_{a}$ (31.819) |
| T4 | 49.0 $_{a}$ (1.414) | 49.5 $_{a}$ (6.363) | 59.5 $_{acd}$ (45.961) | 81.0 $_{ab}$ (7.071) |
| T5 | 49.0 $_{a}$ (7.071) | 56.7 $_{a}$ (7.071) | 35.0 $_{d}$ (14.142) | 43.5 $_{a}$ (12.020) |
| SC | 180.5 $_{bc}$ (20.506) | 228.0 $_{b}$ (125.865) | 148.0 $_{ab}$ (5.656) | 93.0 $_{ab}$ (12.727) |
| BV | 70.5 $_{a}$ (7.778) | 41.0 $_{a}$ (1.414) | 68.0 $_{abcd}$ (35.355) | 40.0 $_{a}$ (39.597) |
| **Cd** | | | | |
| TSK | 0.1 $_{a}$ (0.001) | 0.1 $_{a}$ (0.001) | 0.2 $_{a}$ (0.141) | 0.25 $_{a}$ (0.212) |
| T1 | 0.1 $_{a}$ (0.001) | 0.1 $_{a}$ (0.001) | 0.6 $_{a}$ (0.424) | 0.85 $_{a}$ (0.353) |
| T2 | 0.3 $_{ab}$ (0.282) | 0.35 $_{abc}$ (0.070) | 0.45 $_{a}$ (0.070) | 0.6 $_{a}$ (0.282) |
| T3 | 0.15 $_{a}$ (0.070) | 0.45 $_{abc}$ (0.494) | 0.15 $_{a}$ (0.070) | 0.7 $_{a}$ (0.565) |
| T4 | 0.1 $_{a}$ (0.001) | 0.55 $_{abc}$ (0.212) | 0.35 $_{a}$ (0.070) | 1.25 $_{a}$ (0.353) |
| T5 | 0.1 $_{a}$ (0.001) | 0.65 $_{c}$ (0.070) | 0.3 $_{a}$ (0.282) | 0.95 $_{a}$ (0.777) |
| SC | 0.45 $_{b}$ (0.070) | 0.750 $_{bc}$ (0.070) | 0.6 $_{a}$ (0.001) | 0.35 $_{a}$ (0.070) |
| BV | 0.35 $_{ab}$ (0.070) | 0.25 $_{ac}$ (0.212) | 0.4 $_{a}$ (0.141) | 0.3 $_{a}$ (0.282) |
| **Cr** | | | | |
| TSK | 3.3 $_{a}$ (0.282) | 3.95 $_{a}$ (0.636) | 24.1 $_{b}$ (10.040) | 25.45 (7.84) |
| T1 | 3.35 $_{a}$ (0.212) | 3.6 $_{a}$ (0.424) | 5.55 $_{a}$ (2.192) | 5.6 $_{a}$ (0.989) |
| T2 | 2.7 $_{a}$ (0.565) | 5.1 $_{a}$ (2.121) | 7.15 $_{a}$ (4.313) | 8.35 $_{a}$ (6.151) |
| T3 | 3.65 $_{a}$ (0.212) | 4.65 $_{a}$ (0.070) | 3.85 $_{a}$ (0.353) | 4.8 $_{a}$ (0.848) |
| T4 | 7.15 $_{b}$ (3.464) | 3.5 $_{a}$ (0.001) | 3.65 $_{a}$ (0.212) | 6.25 $_{a}$ (1.060) |
| T5 | 3.25 $_{a}$ (0.636) | 4.1 $_{a}$ (0.141) | 4.7 $_{a}$ (0.989) | 9.9 $_{a}$ (3.676) |
| SC | 2.95 $_{a}$ (0.353) | 5.05 $_{a}$ (0.494) | 3.35 $_{a}$ (0.212) | 3.25 $_{a}$ (0.636) |
| BV | 4.0 $_{a}$ (0.141) | 4.25 $_{a}$ (0.070) | 4.85 $_{a}$ (0.353) | 6.4 $_{a}$ (3.252) |
| **V** | | | | |
| TSK | 0.15 $_{ab}$ (0.070) | 1.35 $_{ac}$ (0.070) | 2.1 $_{a}$ (2.404) | 3.0 b (2.12) |
| T1 | 1.0 $_{ab}$ (0.282) | 1.1 $_{c}$ (0.141) | 0.4 $_{a}$ (0.001) | 0.4 $_{a}$ (0.001) |
| T2 | 0.95 $_{ab}$ (0.353) | 1.65 $_{a}$ (0.636) | 0.4 $_{a}$ (0.001) | 0.4 $_{a}$ (0.001) |

| | | | | |
|---|---|---|---|---|
| T3 | 0.4 $_{a}$ (0.001) | 0.4 $_{b}$ (0.001) | 0.4 $_{a}$ (0.001) | 0.4 $_{a}$ (0.001) |
| T4 | 2.05 $_{c}$ (0.777) | 1.2 $_{ac}$ (0.001) | 0.4 $_{a}$ (0.001) | 0.4 $_{a}$ (0.001) |
| T5 | 1.2 $_{ab}$ (0.141) | 1.5 $_{ac}$ (0.001) | 0.4 $_{a}$ (0.001) | 0.4 $_{a}$ (0.001) |
| SC | 0.4 $_{a}$ (0.001) | 0.4 $_{b}$ (0.001) | 0.4 $_{a}$ (0.001) | 0.4 $_{a}$ (0.001) |
| BV | 1.4 $_{bc}$ (0.001) | 1.3 $_{ac}$ (0.001) | 0.4 $_{a}$ (0.001) | 0.4 $_{a}$ (0.001) |
| **Cu** | | | | |
| TSK | 31.95 $_{a}$ (6.010) | 9.3 $_{ac}$ (2.687) | 11.5 $_{a}$ (2.121) | 36.0 $_{abd}$ (8.485) |
| T1 | 33.9 $_{ac}$ (5.656) | 6.3 $_{c}$ (0.424) | 32.5 $_{a}$ (26.162) | 45.0 $_{bd}$ (5.656) |
| T2 | 32.1 $_{a}$ (12.445) | 13.6 $_{ad}$ (5.939) | 13.0 $_{a}$ (1.414) | 30.0 $_{ac}$ (5.656) |
| T3 | 63.0 $_{bc}$ (1.414) | 31.0 $_{b}$ (1.414) | 15.5 $_{a}$ (3.535) | 19.5 $_{c}$ (0.707) |
| T4 | 22.8 $_{a}$ (3.535) | 11.0 $_{ad}$ (1.838) | 11.0 $_{a}$ (2.828) | 44.5 $_{d}$ (2.121) |
| T5 | 23.85 $_{a}$ (2.474) | 16.3 $_{d}$ (1.979) | 12.0 $_{a}$ (1.414) | 33.0 $_{abcd}$ (2.828) |
| SC | 65.5 $_{bc}$ (23.334) | 29.5 $_{b}$ (21.121) | 15.5 $_{a}$ (4.949) | 36.5 $_{abd}$ (2.121) |
| BV | 59.5 $_{c}$ (15.839) | 13.5 $_{ad}$ (2.121) | 15.5 $_{a}$ (2.121) | 29.0 $_{ac}$ (11.313) |

* Means within a coloumn (tissue type) for each element bearing the same subscripts do not differ significantly at the P< 0.05 level.

** Where: TSK = Tompi Seleka Main Poultry House; T1 = Rehlakile ; T2 = Eenkantaan; T3 = Batlabatale; T4 = Mamodi; T5 = Ikukeng; SC = Foleysrus Immerpan; BV = Bellview Immerpan.

**Table 2.7.2**. Environmental sample results from rural communities in the Immerpan District.

| **Element*** | **Means & S.D. (mg/kg DM basis)** | | |
|---|---|---|---|
| | **Soil** | **Faecal** | **Plant** |
| **As** | | | |
| SC | 0.85 $_{a}$ (0.707) | 1.0 $_{a}$ (0.707) | 0.95 $_{a}$ (0.494) |
| BV | 0.245 $_{a}$ (0.346) | 0.55 $_{a}$ (0.070) | 0.55 $_{a}$ (0.070) |
| T3 | 0.73 $_{a}$ (0.530) | 0.55 $_{a}$ (0.070) | 0.5 $_{a}$ (0.001) |
| T4 | 3.775 $_{b}$ (1.435) | 1.05 $_{a}$ (0.636) | 0.65 $_{a}$ (0.212) |
| **Pb** | | | |
| SC | 8.05 $_{ab}$ (7.335) | 5.0 $_{a}$ (2.828) | 2.4 $_{a}$ (0.141) |
| BV | 3.55 $_{a}$ (1.194) | 3.0 $_{a}$ (0.001) | 2.4 $_{a}$ (0.141) |
| T3 | 5.195 $_{ab}$ (2.199) | 4.5 $_{a}$ (4.949) | 2.45 $_{a}$ (0.353) |
| T4 | 14.88 $_{b}$ (2.199) | 4.5 $_{a}$ (2.121) | 2.35 $_{a}$ (0.353) |
| **Se** | | | |
| SC | 1.62 $_{a}$ (0.820) | 2.35 $_{b}$ (0.353) | 2.45 $_{a}$ (0.636) |
| BV | 0.675 $_{a}$ (0.445) | 1.05 $_{ab}$ (0.626) | 1.45 $_{a}$ (0.494) |
| T3 | 1.515 $_{a}$ (0.148) | 0.75 $_{a}$ (0.777) | 1.350 $_{a}$ (0.070) |
| T4 | 1.63 $_{a}$ (0.311) | 0.75 $_{a}$ (0.353) | 1.85 $_{a}$ (1.060) |
| **Br** | | | |
| SC | 1.52 $_{a}$ (2.149) | 40.5 $_{a}$ (23.334) | 54.0 $_{a}$ (7.071) |
| BV | 0 $_{a}$ () | 16.5 $_{a}$ (6.363) | 41.5 $_{a}$ (20.506) |
| T3 | 0 $_{a}$ () | 93.5 $_{a}$ (94.045) | 40.0 $_{a}$ (9.899) |
| T4 | 0.495 $_{a}$ (0.700) | 29.0 $_{a}$ (8.485) | 40.22 $_{a}$ (22.627) |
| **Cd** | | | |
| SC | 1.135 $_{a}$ (1.209) | 0.2 $_{a}$ (0.001) | 0.25 $_{a}$ (0.070) |
| BV | 0.135 $_{a}$ (0.071) | 0.2 $_{a}$ (0.001) | 0.2 $_{a}$ (0.001) |
| T3 | 0.36 $_{a}$ (0.183) | 0.2 $_{a}$ (0.001) | 0.25 $_{a}$ (0.070) |
| T4 | 0.2 $_{a}$ (0.042) | 0.2 $_{a}$ (0.001) | 0.2 $_{a}$ (0.001) |
| **Cr** | | | |
| SC | 26.96 $_{a}$ (3.804) | 19.2 $_{a}$ (6.929) | 3.4 $_{a}$ (3.111) |
| BV | 19.55 $_{a}$ (15.669) | 13.35 $_{a}$ (2.474) | 1.7 $_{a}$ (2.121) |
| T3 | 31.95 $_{a}$ (12.367) | 7.3 $_{a}$ (1.697) | 0.2 $_{a}$ (0.001) |
| T4 | 46.18 $_{a}$ (25.010) | 16.55 $_{a}$ (3.889) | 1.25 $_{a}$ (1.484) |

| | | | |
|---|---|---|---|
| **V** | | | |
| SC | 20.34 $_a$ (5.833) | 14.75 $_a$ (7.283) | 3.5 $_a$ (2.828) |
| BV | 13.47 $_a$ (9.560) | 8.0 $_a$ (1.555) | 1.40 $_a$ (1.272) |
| T3 | 21.03 $_a$ (9.234) | 5.10 $_a$ (0.141) | 0.7 $_a$ (0.282) |
| T4 | 36.47 $_a$ (25.144) | 10.5 $_a$ (3.394) | 1.4 $_a$ (1.272) |
| **Cu** | | | |
| SC | 8.76 $_a$ (5.359) | 28.0 $_a$ (7.071) | 0.35 $_a$ (0.212) |
| BV | 7.15 $_a$ (3.224) | 20.0 $_a$ (1.414) | 0.2 $_a$ (0.001) |
| T3 | 9.05 $_a$ (7.417) | 19.0 $_a$ (14.142) | 0.45 $_a$ (0.070) |
| T4 | 3.405 $_a$ (1.096) | 26.5 $_a$ (4.949) | 0.2 $_a$ (0.001) |

* Means within a coloumn (tissue type) for each element bearing the same subscripts do not differ significantly at the P< 0.05 level.

** Where: TSK = Tompi Seleka Main Poultry House; T1 = Rehlakile ; T2 = Eenkantaan; T3 = Batlabatale; T4 = Mamodi; T5 = Ikukeng; SC = Foleysrus Immerpan; BV = Bellview Immerpan.

### 2.3.4 Discussion

#### 2.3.4.1 Water quality

The most significant observation remains the presence of PHCC in point of use samples at concentrations that exceed the local and international guideline limits, posing hazards to health, production and product quality norms. As noted for the vast majority of samples collected, multiple user groups apply. This extends to multiple user categories within user types, for example, drinking, food preparation and bathing for domestic use, and use for household layers, broilers and crops. Specific comments regarding possible types of effects from the WQC involved are presented elsewhere in this report. The rural communities in the Polokwane District present with high risk for human and animal health, with four samples returning $NO_3$ values exceeding 200 mg/$\ell$ and seven collections unfit for human use, Br values exceeding 1 mg/$\ell$, and As and Pb concentrations approaching 1 mg/$\ell$. High F values were also noted (> 4 mg/$\ell$). The vast majority of household and village drinking water was classified as completely unfit for domestic purposes. The potentially fatal consequences of the excessive $NO_3$ values warrant intervention, and a report detailing the hazards was submitted to the Limpopo Provincial authorities at Polokwane. The contribution of fertilizer applications and housing small stock on the household premises where hand pumps were located, in addition to natural occurrence in the aquatic environment, is well documented in the scientific literature, and management strategies concerning water sources and commuity agricultural practices need to be implemented. This extends to the village poultry and vegetable projects as they may serve as a significant source of potentially hazardous element intake. Many farmers and household owners interviewed claimed to have experienced livestock fatalities and observed spontaneous abortions in the stock following access to drinking water that had not been utilized for a period of a few weeks. This is inline with $NO_3$ toxicology and the loss of rumen microbe adaptation to elevated rumen $NO_3$ and $NO_2$ levels, but appropriate management can reduce the risk to allow production to continue. However, failure to measure and monitor water quality prevents any successful management programme from being implemented. Clinical symptoms for $NO_3$ and other trace element toxicity problems were confirmed by the Extension Officers.

As noted for the Jericho District, significant differences between villages were noted for elements reflected in different tissue types that accorded with the water chemistry observed. As was observed for the Jericho biological samples, liver predicted the variability between elements the best. The environmental samples did not describe element variance significantly, most probably as a result of the limited observation sites following the lack of appropriate samples as the project sites were fenced off and generally located some distance away from grazing areas and large stock.

However, aside from possible adverse effects on health or production parameters resulting from the excessive ingestion of elements with a high inherent toxicity, the presence of constituents in the drinking water may contribute significantly to the intake of elements, ranging from essential to occasionally beneficial. This should be corrected for in the formulation of any mineral supplements as overfeeding of one element can result in an induced deficiency of another. Furthermore, the effects of elevated osmotically active electrolyte ingestion on water intake and thermoregulation homeostasis should be investigated within the constraints inherent in minimal climate control production systems, as these are typical of rural poultry production projects. These factors should be considered in the planning and management of rural poultry production systems.

Estimates for daily ad-lib water consumption values for broilers yield the following intakes from the drinking water alone:

Estimated water intake/d at 6 weeks:

20 deg C = 0. 28 ℓ/bird

32 deg C = 0.6 ℓ/bird

Layer production systems may pose more hazards in terms of both health and product quality due to the longer exposure period and possibility for EDC effects to occur. As some layer projects are implemented in rural communities and training therefore occurs at TSAC, consideration thereof is required. Estimates for daily ad-lib water consumption values for laying hens yield the following intakes from the drinking water alone:

Estimated water intake/d:

20 deg C = 0.18 ℓ/bird

32 deg C = 0.3 ℓ/bird

Table 2.8 presents the contributions from the water samples collected from the selected villages for some key essential elements in order to illustrate the importance of assessing drinking water contributions to dietary requirements. The estimated water intakes should be interpreted as the minimum intakes given that the poultry production houses sampled do not have sophisticated environmental management systems, as is the case in commercial houses. The areas in which these production houses are situated presents a temperature regulation challenge resulting in elevated water intakes as demonstrated later

in this report in extensive region trials conducted at the Delftzyl Agricultural Research Station.

Table 2.8 Estimated daily intakes of selected constituents from drinking water at two temperatures in broilers and layers in rural poultry production houses.

| **Sample Site and PHCC** | **Estimated Intake Broilers 6 weeks (mg/d/bird)** | | **Estimated Intake Layers mature (mg/d/bird)** | |
|---|---|---|---|---|
| | 20 degrees C | 32 degrees C | 20 degrees C | 32 degrees C |
| **P4 – Zn** | 0.4667 | 1.002 | 0.300 | 0.500 |
| **P6 – Zn** | 2.009 | 4.498 | 1.349 | 2.249 |
| **P8 –I** | 1.189 | 2.548 | 0.764 | 1.274 |
| **P9 – I** | 0.458 | 0.983 | 0.295 | 0.491 |
| **T1 – Pb** | 0.016 | 0.034 | 0.010 | 0.0174 |
| **SC –Br** | 1.68 | 3.6 | 1.08 | 1.80 |
| **SC- Se** | 0.029 | 0.064 | 0.019 | 0.032 |
| **SC –Ca** | 84.56 | 181.2 | 54.3 | 90.6 |

The contribution of the SC drinking water to the daily Ca intake of broilers at 32 degrees C is ca. 70% of that normally obtained from an average ration supplying adequate calcium. These contributions should not been seen in isolation however, as for some areas the requirements may be significantly increased by the presence of other WQC, for example, the Polokwane area yielded many high F and Sr concentrations that could significantly increase Ca requirements. Short-term exposure to high F can be tolerated in broiler production systems (Casey *et al*., 1996), but not only tolerance to direct toxicity is required for successful and efficient production. Apart from the contribution to requirements, excessive supplies not only lead to potential induced deficiencies of associated elements, but may also compromise product quality, as is described later in this report in the poultry experiments conducted. The complex supply of essential and essentially toxic elements through the drinking water should be assessed in deciding on the most appropriate poultry production system to implement.

The high estimated Br intakes are cause for concern as the main adverse effects may include weight loss and goitrogenic complications and ration formulation may need to be adapted due to direct competition with iodine. However, for the sample P8 the water may result in an iodine intake of 1.189 mg/d/bird at the lower temperature for broilers. This represents an intake of between 66 to 23 times the adequate intake required for starting to finishing poultry (Underwood and Suttle, 1999). Since the inclusion rates of minerals in commercial diets tend to be at the upper bands of the requirements, this water contribution represents an excess in addition to a ration that is already supplying all the iodine required. Poultry appear to be tolerant of excess iodine, with this intake still below 30% of the toxic limit. This is in part due to the ability of the hen to increase yolk iodine concentrations with increased iodine intake. However, it has been documented that bovine milk can contain iodine levels sufficient to induce iodine toxicosis in humans without any apparent clinical effects in the cow (Underwood and Suttle, 1999) and it would thus be recommended that under relevant conditions the contribution of eggs to total iodine intake to sensitive users within the community be assessed, particularly when

domestic use of water with high iodine also occurs. This would therefore include an assessment of vegetable crops grown and harvested both at household and community project levels. The decision as to whether to implement broiler or layer systems may thus be influenced by the type of PHCC detected and access within the community to alternative water sources. Due to the incidence of paradoxic hypothyroidism with exposure to excess iodine, the contribution via water to variable total iodine intake with concurrent variable Br intake, suggests that a more detailed site-specific approach is required to accurately formulate rations, diagnose production problem causes, and investigate iodine deficiency disorders in community health investigations.

For $NO_3$ the poultry guideline limit of 25 mg/ℓ should be seen as conservative, however, the value of 88 mg/ℓ observed for Mangata should be treated with caution as it is near the general guideline of 90 – 100 mg/ℓ for cattle and sheep. As mitigation, at least 8000 IU of Vitamin A should be provided. The excessive nitrate concentrations observed for other villages in the Polokwane District effectively result in the water posing significant risk to both domestic and animal users, with the majority being classified as completely unfit for use. Critical to this risk is the lack of a differential diagnosis for "cot-deaths" and nitrate-induced infant methemoglobinaemia as post-mortem evidence is not persistent. Elevated nitrate values in the water is of concern as many of the production houses are located next to or in close proximity to the borehole supplying the drinking water. Animal waste disposal sites were observed to be within the immediate area of the production house on several occasions, but the incidence of high values in household hand-pumps sampled may be due to pit-latrine contamination. An important difference between rural households and poultry production houses with regard to $NO_3$ is the faecal contamination of drinking troughs that can occur, as observed with Foleysrus (SC) in the Immerpan Resettlement District. The differences between the borehole and drinking trough for this farm are largely due to an inflow pipe from roof-collected rainwater, but notably the $NO_3$ value is significantly elevated in the drinking trough due to the utilisation thereof by the cattle. Water is apparently collected from the trough by bucket and provided to the household poultry. This may explain the tissue results for this farm presented later.

Some of the potential adverse effects predicted from the water analyses were reported to be occurring in the production houses. An example was the 105 mg Mg/ℓ observed for Makgofe that may lead to intestinal irritation, resulting in a laxative effect that could lead to watery droppings and wet litter, a continuous problem listed by the community members managing the production house. The accompanying $SO_4$ value was 78 mg/ℓ with adverse effects expected to increase in severity should this reach 250 mg/ℓ, but may already be occurring at the lower value due to higher water intakes following heat stress. Evidence of chronic fluorosis was observed in household poultry in the Polokwane District investigations, and several other trace element related symptoms were observed in all the poultry production houses.

Further adverse effects of excessive exposure to some of these elements may be a reduction in the efficacy of vaccines administered via the drinking water, as is the case with calcium. Given that poultry produced under typical rural systems may be under more stress, either nutritional and/or heat, failure for adequate health care to be maintained could have severe financial implications.

Apart from the hazards of excessive exposure to potential chronic toxicity, the added burden this may place on environmental loading from animal production system waste is also of concern. This issue was widely published in the USA with respect to animal feed regulations preventing the formulation and manufacturing of animal feeds containing an excessive amount of Se due to concerns about environmental Se burdening. Selenium from drinking water alone for the sample SC could contribute to six times in excess of the limit for intake according to maximum allowable dietary inclusion levels for starting broilers at the lower temperature.

### 2.3.4.2 Biological and Environmental Samples

The major concern regarding the observed tissue values is the incidence of tissue types that presented concentrations of constituents (Pb, As, Cr & V) that exceeded the maximum acceptable concentrations (MAC) for animal products used for human consumption. This risk is increased for the villages sampled as many represent the dual risk factors of low dietary dilution and multiple exposure routes to the same potentially hazardous water. Risk management factors that could be considered include careful planning of the most appropriate short-duration exposure production system and the sale of produce to the general market as opposed to the local community. Incidents have been reported to the TSAC of unacceptable product quality following failure to adhere to EU MAC export criteria. Specially formulating rations to enhance excretion and lower absorption would also assist in reducing risk. The ability to provide more intensively controlled housing climates, although costly, may prove a worthwhile investment from both health and product quality norms.

Although many PHCC were observed in all the tissue collection sample sites, significant differences were observed between poultry production houses, and between poultry production houses and household sites, within tissue types. Between poultry production houses sites T3 and T1 yielded the highest liver Pb values, and both these sites were also found to have the highest water Pb values. Site T1 also returned the highest thigh Pb value, with T3 and SC having the second highest means. Similarly, sites with low Pb water concentrations were found to have lower tissue Pb values, such as observed for BV and T5. The elevated tissue Pb values for SC, notably for liver, compared to the highest poultry production houses (T1 & T3) are most probably due to a number of risk factors inherent in the sites and production systems. These would predominantly be a longer exposure period, a poorer nutritional status, exposure to higher daily temperature fluctuations with consequent increased water turnover rates, and the ingestion of other sources of Pb in addition to water, notably soil as was detected for SC (second highest value). Interestingly, the highest faecal Pb value was also from site SC. The high Pb values observed for BV for some tissues suggest that the ingestion from soil and

contamination of rainwater collected from the roof may be the main routes, as the earth dam and drinking trough did not reveal Pb as a PHCC. The occupants of BV provide the collected rainwater to poultry and pigs, but apparently prefer the earth dam water, as the aesthetic properties are better. The earth dam is supplied by a borehole, but also has a natural spring that contributes to the inflow. Differences observed in femur values are again most probably related to different exposure periods and water turnover rates.

The Se values obtained seem to reflect a similar pattern as observed in cattle exposed to inorganic Se as a PHCC in that hepatic stores appear deficient, as does general Se status, whilst renal values increase dramatically. The site SC, with the highest observed water Se, did not return the highest liver value, although it did return the second highest femur value, with breast and thigh values also elevated. Site T3 returned the highest liver value, despite not having Se observed as a PHCC, but did have high environmental samples.

Tissue values for liver and breast appeared to reflect the observed water Br concentrations, as sites SC and T2 with the two highest water values returned the highest values for these tissue types. Bromide in T2 thigh was the highest observed and Br for SC femur was the second highest observed. The observed values for T1 for thigh and femur could reflect the high water Br also observed. Differences between production houses T2 and T1 for the tissues may be due to collection at different stages in the production (week 3 to week 6) cycle. The lowest water Br concentrations were observed for T3, T4 and BV, and these sites all returned the lowest Se values for all tissue types. Liver Br and liver Cu were positively correlated for most sites, with low values observed for T4 and T5, and high values for SC and BV. The significance of this in increasing Cu requirements is worthy of investigation given the experiences with high Br in game case studies and induced Cu deficiency noted elsewhere in this report.

Arsenic observed in the water at sites TSK and SC appeared to be reflected in the high liver values for these sites, and high breast, thigh and femur for TSK. Low water As also appeared to be reflected in tissue values for T1, T2, T4 and T5. The high values observed for T3 are not explained by the water or environmental samples, but as As was detected in samples collected in nearby sites, additional sampling may well detect elevated values at certain times of year. It must be noted in this regard that the rainfall experienced during site collections was very isolated and scattered over the entire district.

High Cr in water appeared to be reflected in faecal, plant and breast tissue for site SC. Other high tissue values may be influenced by environmental Cr, as although within guideline limits, was detected as a COC for most sites. Other constituent values in production house sites may be more influenced by ration inclusion levels than by water chemistry.

#### 2.3.4.3 Village household interviews

Informal discussions were held in all the villages with household members with the assistance of the Animal Technicians from the Jericho Office. Structured interviews were held in Fafung, Rooiwal and Wilgerkuil villages with similar key issues apparent in

all villages. Although presented elsewhere in more detail (Braker, 2001; Reuver, 2002) key aspects noted were the use of groundwater for domestic and agricultural purposes, reliance on animal products in sensitive user groups and difficulties in managing available water sources. Most of the residents were from three user groups, namely, over 50 years of age, pregnant women and mothers with children, and infants and children at school. Due to the close proximity to Pretoria most economically active males returned to households in the Jericho District over the weekends, but in the Immerpan and related districts tended to visit less frequently. This relates to the increased impact of localized geochemical anomalies within sensitive user groups that do not have a high percentage of dietary dilution through multiple acquisition routes.

Many households collected rainwater but preferred to mix it with subterranean water. In some villages a major concern related to the theft of borehole pumps and fuel, with many communities having a designated person responsible for both. Most residents paid a fixed levy for fuel in return for unlimited access to water, but some individuals still made money by collecting river water and selling it in the villages. In the Rooiwal village some residents dug in the dry riverbed for water in the belief that it was healthier, but only small amounts were collected as it was very time consuming. Most respondents indicated a daily water intake of more than 2$\ell$, whilst many school children apparently drank water at home, from animal drinking troughs and from the school on a daily basis. The use of water classified as unfit for domestic drinking purposes occurred in all schools in these villages. Most respondents used water for household purposes (drinking, food preparation and bathing) and for agricultural purposes - mostly livestock and the irrigation of household crops. Whilst large and small stock were often kept, indigenous poultry provided the main source of meat intake. Most households collected an average of five eggs per week, and most slaughtered a minimum of one chicken per week, with all but the beak and feathers being consumed after cooking in water. All mothers claimed to prefer breastfeeding of infants to the purchase of baby formula products, a critical aspect in the etiology of many trace element related disorders. All communities supported the local poultry and vegetable projects well.

## 2.4 Conclusion

A generic level water quality risk assessment (Casey *et al*., 2001a) is recommended as the first step in determining baseline exposures required for the identification of constituents in the geochemical environment that may contribute to adverse effects on health, productivity, and product quality in animal users, and for health-related norms for domestic users. Any potential hazards identified then require further investigation regarding the water, user, environment and nutrition in order to ascertain the hazard posed by the presence of toxic constituents at concentrations that exceed the various forms of recommended guidelines, and in so-doing acquire relevant site-specific risk factor information required for risk management strategies to be formulated. This approach is addressed in further detail when the proposed software system is presented.

With regard to PHCC two aspects must be noted. Firstly, elevated water intakes due to osmo-sodium responses, high ambient temperatures, and palatability responses, significantly increase the risk for toxicity at any given guideline value (most are based on

an average temp of 16 deg C). Further inadequacies associated with mg/ℓ concentration-based guidelines are presented in previous WRC reports (Casey *et al*., 1998 & 2001a & 2001b). Secondly, combinations of hazardous constituents in the same water source can be synergistic, or antagonistic, and as such, end effects may mitigate, or exacerbate, toxicity. Few water quality guidelines comment on recommended levels of water and diet/feed/forage levels simultaneously. Dual incorporation of these factors are at times impractical, for example, within the rural communal production system context high variability between breeds and species make the incorporation thereof into guidelines difficult. In addition, the presence of different production system types (communal grazing and poultry production houses) and sensitive user group categories also necessitate a site-specific approach. Biological sampling benefits in validating these potential hazards and constituents detected as COCs but tending to predominate as PHCCs.

The results from the household collections indicate that PHCC in the drinking water do significantly influence the tissue results of poultry specimens collected. Two main benefits can be obtained from this information. Firstly, it assists in providing insight into the outcome of many mineral x mineral and mineral x diet interactions that are too complex to predict accurately. This ranges from identifying the main elements in induced deficiencies to the possible compromising of organ function with tissue accumulation. The second benefit is that the fitness for use of a significant contribution to the dietary intake of household occupants is obtained. The information obtained from poultry production houses is also valuable as it assists in determining where the most suitable market for the product may be. In many of the villages collected from in the Immerpan District and TSCA projects the community were offered a discount incentive to purchase from the poultry production houses, however, as the results indicate consumption of these products within a localized community that has additional multiple exposure routes of the same geochemical anomalies may pose a significant community health risk as the MACs for many elements were exceeded. Similar concerns would exist for vegetable garden produce. Under these conditions, as EU standards for import would not be met, the general commercial market would be a viable alternative. It is crucial to sustainable agriculture and development projects that the impact of water quality on production norms and product quality norms be addressed during the planning and management phases. There also exists an ethical responsibility to provide food that is fit for use by consumers. This is particularly relevant as the constituents observed in these investigations primarily result in developmental insults, with neurological and cognitive impairment, growth, carcinogenic, immuno-suppression and endocrine disruption effects all documented. The use of the animal tissues to guide focused community epidemiological investigations is seen as one of the primary benefits of following the procedure of biological sampling after water quality investigations. Biological sampling would also assist in interpreting the high variability that may be obtained with insufficient water quality monitoring. Often single samples are provided for a large number of different village agricultural projects and requests for more frequent sampling are seldom met.

Similarly, the environmental samples provided acceptable correlations for many of the PHCC observed. The soil and faecal samples would appear to be most suited, as plant variation between growth phases, species and pasture management practices introduce a high degree of variability. In addition to providing information on site-specific interactions, faecal collection also assists in investigating contamination of earth dams and drinking troughs. A common observation in the communities was that the fecal contamination of earth dams becomes increasingly apparent at the critical time when rains are expected, as typically environmental temperatures are high and water levels low. Cattle also tend to wade several meters into the dams with low water levels, increasing turbidity and contributing to geophagia. Avian excrement contamination appears to be more problematic with cement reservoirs. It is recommended that earth dams be fenced off to prevent excessive erosion and more manageable stock watering, but the fenced area should preferably be large enough to prevent the formation of a severe sacrifice zone on its border. Those dams that were protected in this manner tended to have more established aquatic vegetation and were also more biologically active. Additional information on nutritionally important macro-elements and trace elements was also obtained from the faecal and soil samples, but the presentation thereof in this report would have digressed from the set objectives. Nonetheless, it should be noted that the analytical techniques employed were beneficial in nutritional investigations as well as health-based studies.

Comparisons of biological values between the districts presented in this report indicate similar concentrations at low ranges but the Jericho District presented with greater upper range values for all tissues and elements. The environmental samples also indicated higher values for this district, but more sample collections from the Immerpan District may have revealed similar anomalies. The water chemistry alone does not explain these elevated tissue sample values obtained and a significant contribution may be explained by the different production systems, namely predominantly scavenging with indigenous breeds for the Jericho District, and semi-intensive commercial poultry production houses in the Immerpan and TSAC associated districts. Although the production houses in these rural communities do not approach the same degree of environmental control as occurs in the commercial sector, the benefit of the housing facilities and commercial feeding programme followed may not only reduce water turnover rates but also place the poultry on a better nutritional plane allowing them more tolerance to PHCC. More importantly, significant reductions in geophagia and a shorter duration exposure period may be primarily responsible for the lower values obtained in the production houses. Another non-tissue related benefit is a decrease in loss of poultry to predators. This was cited as a major problem in all villages in the Jericho District. However, despite the conclusion being a preference of poultry production houses in rural communities towards reducing risk to human health from ingesting hazardous animal products, in many instances the values in these production houses still do not comply with product quality requirements for human consumption and therefore require intervention and monitoring. Whilst preference may be given to these village projects, household production will inevitably still continue, accordingly mechanisms for the reduction of risk factors need to be investigated. Offering drinking water in suitable containers, feeding of food scraps on

non-soil surfaces, and not using the same water source for food preparation are a few possible steps.

The site-specific approach followed for these investigations demonstrate the importance of water quality and environmental geochemistry in animal production, health and community health. Although the focus has been on animal product quality the approach also indicates many animal health problems that could be addressed by formulating specific supplements and managing water sources, storage, presentation and allocation on an informed basis. An additional option for mitigation involves the addition of alleviator chemical treatments to the drinking water to either reduce absorption of PHCC and/or increase renal clearance rates. Investigations in this regard are presented in the next chapter.

The benefits of biological and environmental sampling in acquiring site-specific data are further illustrated in the results presented later from the NDA Groundwater Project where the majority of the PHCC reported were within 50% of the guideline thresholds. Risk for incurring both false negatives and false positives may be reduced by the acquisition of site-specific data.

The planning and implementation of community agricultural projects, typically poultry and food gardens, must take into account the role these projects may play in contributing to ingestion routes and total exposure of communities to PHCC in order to prevent a positive intention from having a potentially irreversible negative health impact.

# 3. EFFECTS OF HAZARDOUS CONSTITUENTS AND POTENTIAL ALLEVIATORS IN POULTRY UNDER DIFFERENT RURAL COMMUNAL PRODUCTION SYSTEMS

## 3.1 Introduction

Following observations of specific potentially hazardous chemical constituents (PHCC) in the subterranean drinking water, poultry specimens collected from households in several rural communal villages in the North West and Limpopo Provinces, and in current and intended USDA-funded Community Poultry Projects (in conjunction with the Tompi Seleka Agricultural College Community Upliftment Short Courses), concerns regarding the norm of fitness for use of poultry products within localized communities arose. Based on the occurrence of PHCC in subterranean water and the divergent potential for bioaccumulation in different production systems, it was necessary to investigate the final concentrations of selected PHCC in various poultry tissues under both rural extensive and commercial intensive conditions. The main concerns for the commercial system were elevated tissue concentrations due to higher feed and water intakes, and the concerns regarding high exposure rates to localized communities with low dietary dilution. Furthermore, increased efforts to provide rural communities with viable broiler production units to feed the community were also a consideration. Additional concerns were the fitness for use according to EU standards, as the intention in many of the Community Poultry Projects was to export to the EU. Concerns for the extensive system were largely attributed to increased risk factors due to higher geophagia related ingestion of PHCC and longer exposure times prior to consumption. The variable mix of PHCC observed between communities, geochemistry and tissue residue differences, prompted the need to investigate the effects of some of the major WQC differences on product quality. Three separate experiments were designed and executed in order to accomplish these goals. They are presented separately in this section in the order in which they were conducted, with the conclusion placing perspective on the implications of the results attained.

## 3.2 Commercial Production System

### 3.2.1 Methods

Twenty eight 10-day old Ross broiler chicks were randomly allocated to four separate standard production cages in an intensive environmentally controlled broiler housing system at the Hatfield Experimental Farm at the University of Pretoria and reared until 46 days of age, resulting in a 36 day trial exposure period with seven broilers per cage. Commercially obtained feed was provided *ad libitum* to all birds using standard feeding practices, entailing a starter feed (day old to 16 days old) and a finisher feed (17 days old to 46 days old) with feed tube lids connected on day 36 of the trial. Two water types, one control and one chemical water treatment, were allocated randomly to the four cages to yield two replicates for control and chemical treatment cages respectively, as follows:

Replicate C1 = control – municipal water (n = 7)
Replicate T1 = chemical water treatment with reconstituted water (n = 7)
Replicate T2 = chemical water treatment with reconstituted water (n = 7)
Replicate C2 = control – municipal water (n = 7)

The watering system of the production house was specifically altered to enable the recording of water intake and the administering of separate water treatments for each cage separately. The reconstituted water delivered a final concentration of 0.9 mg As/ℓ as arsenic-trioxide ($As_2O_3$) and 0.1 mg Pb/ℓ as lead nitrate ($Pb(NO_3)_2$) in accordance with naturally occurring concentrations of these two potentially hazardous chemical constituents (PHCC) observed in Community Poultry Project houses in the rural communities in the Jericho District. AR-grade chemicals were used to produce the water treatments at the NutriLab premises at the Department of Animal and Wildlife Sciences, UP. Final concentrations were confirmed by testing samples of point of use at the ISCW. Access to water was via nipple drinkers with height-correction applied on a weekly basis. Standard immunization schedules and health related programs were followed.

Parameters measured were daily feed and water intakes, daily minimum and maximum air temperatures, and weekly individual body weights, except for weeks 1 and 2, during which group weights were measured in order to reduce handling stress. The broilers were slaughtered on day 36 of the trial (at age 46 days) at the Meat Science Abattoir located on the Hatfield Experimental Farm. Thigh, breast, liver, heart and thyroid samples were collected on the day of slaughter from each broiler. Broiler thigh, breast and liver samples were pooled in pairs yielding three observation sets per group for each of these tissues. Heart samples were pooled using three broilers to yield two observation sets per water treatment type, whilst all thyroid samples from each group were pooled to obtain one observation set per water treatment type. Samples were pooled in this manner to obtain sufficient mass for analytical purposes. Pooled samples were dried at 60 degrees Centigrade for 48 hours prior to delivery to the ISCW where each observation set was ground and analyzed using standard ICP-MS techniques to determine trace element concentrations.

### 3.2.2 Results

Tissue results are presented separately for replicates and pooled samples in Tables 3.1 and 3.2. Results for liver samples within replicates (Table 3.1) did not differ significantly for all elements assessed, with the exception of TI that was significantly greater than T2 for Mo. The elements As and Pb both delivered significantly higher liver concentrations for the treatment replicates compared to the control replicates, as did the treatment replicates for Mo for both control replicates. Treatment replicates were also significantly greater than control replicate 1 for Br, as was treatment replicate 1 compared to control replicate 1 for liver Cr. The elements Se, Cd, Cu, Mn and I did not return any significant differences between any of the replicates for liver tissue. Similar observations were made for thigh and breast samples, with thigh samples from treatment replicates tending to return higher values for Pb, whereas breast replicate samples returned higher As values. Pooled results for As and Pb (Table 3.2) supported these findings. The pooled treatment replicates tended to deliver higher values for some elements compared to the pooled control replicates, in some cases significantly so (Table 3.2), namely for Se, Mo, Cd, Br and Cr, mostly for liver and heart samples. Accordingly, the main significant correlations ($P<0.05$) were observed for liver and breast tissues, with some chemical

water treatments returning positive correlations, whilst the control yielded negative correlations between these two tissue types (chemical treatments = 0.73 for As, 0.86 for I, 0.7 for Mo, control = -0.82 for Mn). Liver and thigh correlations were predominantly negative, although not significantly so, for both water treatment types. Heart and liver correlations were mostly positive for the chemical treatments and negative for the control (Pb, Cd, Se and Cr) but with the exception for Cd (0.82), were non significant. These elements also returned a trend of heart and thigh concentrations being negative for both treatment types. Cadmium also returned a significant positive correlation between heart and breast samples for the chemical treatments, as did Br (0.82) and Cr (0.89) for heart and thigh samples.

Although some differences were noted between the replicates with regard to live weight in the first two recordings, these were non-significant for the remainder of the trial, and most probably due to the group average recordings used for the first two observations (Table 3.3). Replicate C2 consistently returned the highest group average from day 22 until the remainder of the trial, but this was not significant at any stage. This live weight observation for replicate C2 was supported by the replicate returning the highest water and feed intakes over the last half of the exposure period (Tables 3.4 & 3.5), although as with the live weight values, these differences were non-significant.

Resultant average intakes were 0.307 mg As/d/bird and 0.034 mg Pb/d/bird over the trial period, with a total ingestion of 45.47 mg As and 5.052 mg Pb per bird over the trial period. It was also observed that as ambient temperature increased, water and feed intake tended to decrease, although this correlation was not significant. A significant correlation of 0.83 was obtained for water and feed intake.

**Table 3.1**. Tissue results in commercial broilers exposed to arsenic and lead in the drinking water.

| Element* | Means & S.D. (mg/kg DM basis) | | |
|---|---|---|---|
| | **Liver** | **Thigh** | **Breast** |
| **As** | | | |
| Replicate T1 | $1.866_{a}$ (0.416) | $1.366_{a}$ (0.461) | $1.3_{a}$ (0.458) |
| Replicate T2 | $1.6_{a}$ (0.1) | $0.966_{a\,b}$ (0.513) | $1.1_{a}$ (0.2) |
| Replicate C1 | $0.833_{b}$ (0.11) | $0.466_{b}$ (0.06) | $0.393_{b}$ (0.005) |
| Replicate C2 | $0.666_{b}$ (0.115) | $0.3966_{b}$ (0.005) | $0.596_{a\,b}$ (0.268) |
| **Pb** | | | |
| Replicate T1 | $32.667_{a}$ (11.372) | $10.33_{a}$ (2.516) | $5_{a\,b}$ (1.732) |
| Replicate T2 | $24.666_{a}$ (3.785) | $11.333_{a}$ (3.511) | $4.33_{a}$ (0.577) |
| Replicate C1 | $2.666_{b}$ (0.577) | $2.666_{b}$ (0.577) | $3_{b}$ (0) |
| Replicate C2 | $2.666_{b}$ (0.577) | $3_{b}$ (0) | $2.667_{b}$ (0.577) |
| **Se** | | | |
| Replicate T1 | $4.833_{a}$ (0.45) | $1.966_{a}$ (0.321) | $2.133_{a}$ (0.472) |
| Replicate T2 | $4.733_{a}$ (0.305) | $2.833_{a}$ (1.285) | $1.9_{a}$ (0.888) |
| Replicate C1 | $5.4_{a}$ (2.211) | $1.633_{a}$ (0.45) | $1.733_{a}$ (0.115) |
| Replicate C2 | $3.9_{a}$ (0.9) | $1.6_{a}$ (0.519) | $1.733_{a}$ (0.057) |
| **Mo** | | | |
| Replicate T1 | $6.7_{a}$ (0.346) | $3.133_{a}$ (2.702) | $1.233_{a}$ (0.585) |
| Replicate T2 | $5.4_{b}$ (0.173) | $1.5_{a}$ (0.519) | $1.1_{a}$ (0.346) |
| Replicate C1 | $4.533_{c}$ (0.251) | $1_{a}$ (0.3) | $0.933_{a}$ (0.416) |
| Replicate C2 | $4.3_{c}$ (0.346) | $0.933_{a}$ (0.230) | $0.732_{a}$ (0.057) |

| | | | |
|---|---|---|---|
| **Cd** | | | |
| Replicate T1 | 0.667 $_{a}$ (0.472) | 0.7 $_{a}$ (0.001) | 1.033 $_{a}$ (0.115) |
| Replicate T2 | 0.5 $_{a}$ (0.1) | 1 $_{a b}$ (0.36) | 0.633 $_{b}$ (0.152) |
| Replicate C1 | 0.4 $_{a}$ (0) | 0.566 $_{b}$ (0.057) | 0.566 $_{b}$ (0.057) |
| Replicate C2 | 0.333 $_{a}$ (0.057) | 0.733 $_{a}$ (0.057) | 0.533 $_{b}$ (0.152) |
| **Br** | | | |
| Replicate T1 | 40.667 $_{a}$ (4.509) | 19 $_{a}$ (7) | 30.667 $_{a}$ (17.616) |
| Replicate T2 | 45 $_{a}$ (4.582) | 21.333 $_{a}$ (3.511) | 21.666 $_{a}$ (14.365) |
| Replicate C1 | 25.333 $_{b}$ (3.511) | 23.667 $_{a}$ (9.237) | 17.333 $_{a}$ (5.686) |
| Replicate C2 | 31.666 $_{a b}$ (3.785) | 19.333 $_{a}$ (4.932) | 20 $_{a}$ (2.645) |
| **Cu** | | | |
| Replicate T1 | 20.666 $_{a}$ (4.163) | 4.666 $_{a}$ (0.577) | 6 $_{a}$ (3) |
| Replicate T2 | 25 $_{a}$ (3) | 5.666 $_{a}$ (1.732) | 4 $_{a}$ (1) |
| Replicate C1 | 21 $_{a}$ (3.05) | 6 $_{a}$ (1) | 4.66 $_{a}$ (1.154) |
| Replicate C2 | 21.333 $_{a}$ (2.081) | 4 $_{a}$ (3) | 5 $_{a}$ (1.732) |
| **Mn** | | | |
| Replicate T1 | 36.667 $_{a}$ (3.785) | 3.333 $_{a}$ (0.577) | 4.666 $_{a}$ (2.081) |
| Replicate T2 | 33.333 $_{a}$ (6.658) | 2.666 $_{a}$ (0.577) | 3 $_{a}$ (1.732) |
| Replicate C1 | 32.333 $_{a}$ (3.511) | 2.666 $_{a}$ (0.577) | 2.333 $_{a}$ (0.577) |
| Replicate C2 | 32.333 $_{a}$ (3.511) | 3.666 $_{a}$ (1.527) | 2.333 $_{a}$ (0.577) |
| **Cr** | | | |
| Replicate T1 | 1.4 $_{a}$ (0.2) | 1.133 $_{a}$ (0.351) | 1.366 $_{a}$ (0.251) |
| Replicate T2 | 1.333 $_{a b}$ (0.416) | 1.233 $_{a}$ (0.152) | 1.133 $_{a}$ (0.513) |
| Replicate C1 | 0.766 $_{b}$ (0.057) | 0.933 $_{a}$ (0.251) | 1.133 $_{a}$ (0.68) |
| Replicate C2 | 0.966 $_{ab}$ (0.208) | 1.166 $_{a}$ (0.251) | 1.1 $_{a}$ (0) |
| **I** | | | |
| Replicate T1 | 0.166 $_{a}$ (0.057) | 0.133 $_{a}$ (0.057) | 0.2 $_{a}$ (0) |
| Replicate T2 | 0.566 $_{a}$ (0.042) | 0.1 $_{a}$ (0) | 0.2 $_{a b}$ (0.73) |
| Replicate C1 | 0.2 $_{a}$ (0.173) | 0.1 $_{a}$ (0) | 0.266 $_{a b}$ (0.288) |
| Replicate C2 | 0.233 $_{a}$ (0.115) | 0.1 $_{a}$ (0) | 0.1 (0) |

* Means within a coloumn (tissue type) for each element bearing the same subscripts do not differ significantly at the P< 0.05 level.

**Table 3.2.** Pooled tissue results in commercial broilers exposed to arsenic and lead in the drinking water.

| **Element*** | **Means & S.D. (mg/kg DM basis)** | | | | |
|---|---|---|---|---|---|
| | **Heart** | **Thyroid** | **Liver** | **Thigh** | **Breast** |
| **As** | | | | | |
| Treatment | 1.15 $_{a}$ (0.435) | 0.9 $_{a}$ (0.142) | 1.733 $_{a}$ (0.307) | 1.166 $_{a}$ (0.488) | 1.2 $_{a}$ (0.334) |
| Control | 0.47 $_{a}$ (0.10) | 0.445 $_{a}$ (0.077) | 0.75 $_{b}$ (0.137) | 0.428 $_{b}$ (0.051) | 0.495 $_{b}$ (0.2) |
| **Pb** | | | | | |
| Treatment | 44 $_{a}$ (53.304) | 65 $_{a}$ (86.26) | 28.555 $_{a}$ (0.875) | 10.833 $_{a}$ (2.786) | 4.666 $_{a}$ (1.211) |
| Control | 2.25 $_{a}$ (0.5) | 3 $_{a}$ (0) | 2.666 $_{b}$ (0.516) | 2.833 $_{b}$ (0.408) | 2.833 $_{b}$ (0.408) |
| **Se** | | | | | |
| Treatment | 3 $_{a}$ (0.294) | 2.2 $_{a}$ (1.131) | 4.783 $_{a}$ (0.348) | 2.4 $_{a}$ (0.963) | 2.016 $_{a}$ (0.649) |
| Control | 1.85 $_{b}$ (0.506) | 2.2 $_{a}$ (0) | 4.65 $_{a}$ (1.719) | 1.616 $_{a}$ (0.435) | 1.733 $_{a}$ (0.081) |
| **Mo** | | | | | |
| Treatment | 1.85 $_{a}$ (0.732) | 1.21 $_{a}$ (0.212) | 6.05 $_{a}$ (0.752) | 2.316 $_{a}$ (1.956) | 1.667 $_{a}$ (0.436) |
| Control | 1.525 $_{a}$ (0.320) | 0.85 $_{a}$ (0.212) | 4.416 $_{b}$ (0.299) | 0.966 $_{a}$ (0.242) | 0.833 $_{a}$ (0.287) |
| **Cd** | | | | | |
| Treatment | 0.85 $_{a}$ (0.264) | 0.6 $_{a}$ (0) | 0.583 $_{a}$ (0.318) | 0.85 $_{a}$ (0.281) | 0.833 $_{a}$ (0.25) |
| Control | 0.475 $_{b}$ (0.25) | 0.5 $_{a}$ (0) | 0.366 $_{a}$ (0.051) | 0.65 $_{a}$ (0.104) | 0.55 $_{b}$ (0.104) |

| | | | | | |
|---|---|---|---|---|---|
| **Br** | | | | | |
| Treatment | 29.25 $_a$ (13.0) | 18.5 $_a$ (9.192) | 42.833 $_a$ (4.708) | 20.166 $_a$ (5.115) | 26.166 $_a$ (15.19) |
| Control | 28.5 $_a$ (6.557) | 24.5 $_a$ (4.949) | 28.5 $_b$ (4.764) | 21.5 $_a$ (7.035) | 18.666 $_a$ (4.226) |
| **Cu** | | | | | |
| Treatment | 20.5 $_a$ (10.847) | 7.5 $_a$ (0.707) | 22.833 $_a$ (4.020) | 5.166 $_a$ (0.752) | 5 $_a$ (2.280) |
| Control | 16.75 $_a$ (7.228) | 6.5 $_a$ (2.121) | 21.166 $_a$ (2.639) | 5 $_a$ (1.673) | 4.833 $_a$ (1.329) |
| **Mn** | | | | | |
| Treatment | 18.75 $_a$ (7.410) | 7.5 $_a$ (2.121) | 35 $_a$ (5.176) | 3 $_a$ (0.632) | 3.822 $_a$ (1.940) |
| Control | 11.25 $_a$ (0.957) | 8.5 $_a$ (0.707) | 32.22 $_a$ (3.141) | 3.166 $_a$ (1.169) | 2.333 $_a$ (0.516) |
| **Cr** | | | | | |
| Treatment | 1.85 $_a$ (0.655) | 2.85 $_a$ (1.767) | 1.366 $_a$ (0.294) | 1.183 $_a$ (0.248) | 1.24 $_a$ (0.383) |
| Control | 1.2 $_a$ (0.216) | 1.5 $_a$ (0.282) | 0.866 $_b$ (0.175) | 1.05 $_a$ (0.258) | 1.11 $_a$ (0.43) |
| **I** | | | | | |
| Treatment | 0.15 $_a$ (0.1) | 0.1 $_a$ (0) | 0.366 $_a$ (0.463) | 0.116 $_a$ (0.04) | 0.2 $_a$ (0.109) |
| Control | 0.3 $_a$ (0.18) | 0.2 $_a$ (0.141) | 0.216 $_a$ (0.132) | 0.1 $_a$ (0.001) | 0.183 $_a$ (0.204) |

* Means within a coloumn (tissue type) for each element bearing the same subscripts do not differ significantly at the P< 0.05 level.

**Table 3.3.** Live weight (kg) results in broilers exposed to arsenic and lead in the drinking water over the production cycle.

| **Observation** | **Means & S.D. (kg)** | | | | **Pooled T & C[4]** |
|---|---|---|---|---|---|
| | **Replicate T1[3]** | **Replicate T2[3]** | **Replicate C1[3]** | **Replicate C2[3]** | |
| **LW 1 (day 7)[1]** | 0.236 $_a$ (0) | 0.216 $_b$ (0) | 0.245 $_c$ (0) | 0.203 $_d$ (0) | Ns |
| **LW 2 (day 15)[1]** | 0.54 $_a$ (0) | 0.522 $_b$ (0) | 0.521 $_c$ (0) | 0.527 $_d$ (0) | S |
| **LW 3 (day 22)[2]** | 1.565 $_a$ (0.101) | 1.537 $_a$ (0.141) | 1.525 $_a$ (0.119) | 1.587 $_a$ (0.085) | Ns |
| **LW 4 (day 29)[2]** | 2.208 $_a$ (0.173) | 2.166 $_a$ (0.241) | 2.153 $_a$ (0.199) | 2.288 $_a$ (0.156) | Ns |
| **LW 5 (day 36)[2]** | 2.778 $_a$ (0.228) | 2.710 $_a$ (0.328) | 2.762 $_a$ (0.291) | 2.872 $_a$ (0.200) | Ns |

[1]Observations for live weight based on group recordings.
[2]Observations for live weight based on individual recordings.
[3]Means within a row for replicates bearing the same subscript do not differ significantly (P < 0.05 level).
[4]ns = means not significantly different for pooled observations at the P < 0.05 level.
[4]s = means significantly different for pooled observations at the P < 0.05 level.

**Table 3.4.** Water intake (mℓ/bird/d) results in broilers exposed to arsenic and lead in the drinking water over the production cycle.

| **Observation[1]** | **Means & S.D. (mℓ/bird/day)[2]** | | | | **Pooled T & C[4]** |
|---|---|---|---|---|---|
| | **Replicate T1[3]** | **Replicate T2[3]** | **Replicate C1[3]** | **Replicate C2[3]** | |
| **WI 1 (week 1)** | 148.5 $_a$ (16.511) | 165.1 $_a$ (20.041) | 156.8 $_a$ (23.068) | 162.2 $_a$ (17.544) | Ns |
| **WI 2 (week 2)** | 245.8 $_a$ (42.861) | 251.5 $_a$ (44.858) | 253.8 $_a$ (42.88) | 236.7 $_a$ (40.941) | Ns |
| **WI 3 (week 3)** | 286.2 $_a$ (40.640) | 305 $_a$ (13.686) | 288.4 $_a$ (58.787) | 301.7 $_a$ (35.41) | Ns |
| **WI 4 (week 4)** | 362.4 $_a$ (48.476) | 369.7 $_a$ (41.084) | 362.5 $_a$ (34.379) | 363 $_a$ (48.96) | Ns |
| **WI 5 (week 5)** | 383.3 $_a$ (83.711) | 380.2 $_a$ (48.360) | 362.5 $_a$ (58.189) | 393.8 $_a$ (56.132) | Ns |

[1]Observations for water intake based on average for week from daily group recordings.
[2]Means for water intake based on average group recordings.

[3]Means within a row for replicates bearing the same subscript do not differ significantly (P < 0.05 level).
[4]ns = means not significantly different for pooled observations at the P < 0.05 level.
[4]s = means significantly different for pooled observations at the P < 0.05 level.

**Table 3.5.** Feed intake (mg/bird/d) results in broilers exposed to arsenic and lead in the drinking water over the production cycle.

| Observation[1] | Means & S.D. (mg/bird/day)[2] | | | | Pooled T & C[4] |
|---|---|---|---|---|---|
| | Replicate T1[3] | Replicate T2[3] | Replicate C1[3] | Replicate C2[3] | |
| **FI 1 (week 1)** | 62.3 $_a$ (16.441) | 65.97 $_a$ (20.119) | 60.6 $_a$ (17.724) | 63.4 $_a$ (19.661) | Ns |
| **FI 2 (week 2)** | 124.3 $_a$ (29.433) | 128.5 $_a$ (28.253) | 112.2 $_{ab}$ (14.716) | 95.5 $_b$ (27.980) | S |
| **FI 3 (week 3)** | 136.2 $_a$ (33.80) | 130.8 $_a$ (22.349) | 133 $_a$ (18.533) | 135.8 $_a$ (22.971) | Ns |
| **FI 4 (week 4)** | 169.7 $_a$ (21.79) | 165.4 $_a$ (15.39) | 160.1 $_a$ (11.085) | 190.5 $_a$ (44.576) | Ns |
| **FI 5 (week 5)** | 167.6 $_a$ (28.214) | 164.45 $_a$ (26.678) | 168.8 $_a$ (17.891) | 169.4 $_a$ (20.06) | ns |

[1]Observations for feed intake based on average for week from daily group recordings.
[2]Means for feed intake based on average group recordings.
[3]Means within a row for replicates bearing the same subscript do not differ significantly (P < 0.05 level).
[4]ns = means not significantly different for pooled observations at the P < 0.05 level.
[4]s = means significantly different for pooled observations at the P < 0.05 level.

### 3.2.3 Discussion

The most significant observation of the commercial trial was not that the broilers receiving As and Pb in the drinking water accumulated these elements at significantly higher concentrations than the control counterparts, as this was too be expected, but that the concentrations attained within a short production cycle exceeded the maximum allowable concentrations (EU – MAC) for these elements in poultry products destined for human consumption. Although the liver concentrations were the highest for both of these elements compared to breast and thigh tissue, the significant observations were for breast and thigh tissues that both exceeded the MAC limits and contribute a significant portion of the edible carcass that would be consumed, most notably for Pb-thigh and As-breast. The distribution of different elements to different tissue types prohibits one tissue type from being classified as more fit for use, although with the cultural cooking practices typically followed, the presence of the elements in all types of soft and hard tissues may be considered to be significant to dietary intake. When the same drinking water containing the PHCC is also utilized for cooking practices, the risk is increased further. This is more so for some elements, such as Cd, that are sufficiently heat-stabile to survive the cooking process and present with nephrotoxicity in the human (Underwood and Suttle, 1999).

The implications are that even in a commercially orientated short exposure production cycle, these tissues may present a health hazard to geographically localized communities that routinely consume these products. Concerns would be greater for rural production systems in that the production exposure period is usually longer due to the limitations on controlling the production environment. That the chemical treatments did not adversely affect growth or water and feed intake is typical of the chronic sub-clinical route followed by these elements, and could be expected to be similar for other PHCC reported in the

rural community groundwater supplies reported earlier in this report. The concern with this attribute is that the lack of aesthetic deterrents can create the impression to the observer, be it consumer or producer, is that the water is without potential adverse effects. The same concerns apply to milk and eggs for many of the PHCC reported.

Despite no obvious problems observed regarding meat production in the commercially orientated trial conducted here, the tissue results do suggest that the chemical treatment interfered with Mo, Br and Cr, but not Se, Cu, Mn or I with regard to liver values, and with Mn, Cr, I, Br and Cu with regard to heart and breast values. The effects of this nature will be of concern primarily to long-exposure periods and to production systems where affected trace elements are marginal in supply, a situation that may arise within rural communal production systems.

### 3.3 Extensive Rural Production System

#### 3.3.1 Methods

Eighty 10 - 30 day old indigenous poultry specimens were obtained from several rural villages in the Immerpan District (Van der Merwes Kraal, Elands Kraal, Grass Valley, Rooiwal, and Weltevreden) in the Limpopo Province within a three-day period. The species were mixes of predominantly naked-necked indigenous breeds and Rhode Island Red crosses. The chicks were randomly allocated to four groups of 20 each, and placed in separate side-by-side open air cages (8 x 4 m) located on the southern section of Delftzyl Agricultural Research Station, which bordered the western section of the Immerpan Resettlement Area. The one boundary for all cages was walled (2m high) with an overhang metal sheet (2 x 4m) for protection from the elements and to provide shade. It must be noted that the structure had also served as overnight pens for goats, and was typical of the structures used for both goats and chickens in the rural villages in the district. The housing system thus represented an open-air natural floor (sand and grass) non-environmentally controlled extensive system.

A watering system was installed that allowed for treatments to be administered to a 50$\ell$ container for each group *in situ*. Suspended water and feeder troughs were installed. The entire cage was covered in wire mesh to discourage natural predators. A commercial chicken feed mix consisting primarily of maize kernels that was used by the local communities for their poultry was obtained from the local cooperative and offered *ad libitum* to all groups. The same water treatment types that were used for the commercial trial conducted on the Hatfield Experimental Farm were again applied, denoted as T1, T2, C1 and C2 replicates. The water supply differed in that the primary groundwater source used at Delftzyl was significantly different than the municipal supply utilized in the commercial trial (see results for the Immerpan District for chemical composition). A 1000 $\ell$ tank was installed from the nearest water trough pipeline next to the experimental site in order to deliver a constant water pressure for the duration of the experiment. Observations included twice daily temperatures of shade, sun and water, daily water intakes, weekly feed intakes, and live weight recordings every two weeks. Similar tissue collections and processing for analytical procedures at slaughter were employed as for the commercial tril. The longer observation intervals were due to labour constraints on the

research station. The duration of the exposure period was 25 weeks, and was conducted through the winter season in order to obtain a best-case scenario regarding lower dose intakes that would be expected compared to summer heat regulation related water intake increases. Observation periods of 5-weeks each were used for statistical comparisons for some of the parameters measured.

### 3.3.2 Results

Tissue results are presented separately for replicates and pooled samples in Tables 3.6 and 3.7 respectively. For all tissue types tested As and Pb was found to exceed the MAC by a factor of 10 or more. Some control replicates were observed to have higher element concentrations that the treatment replicates, notably for Se (thigh), Cu (all tissues), Mn (liver and thigh) and Br (thigh). Pooled results indicate that heart samples for the controls yielded significantly higher Se concentrations than the treatments (Table 3.7), the opposite of what was observed in the commercial trial (Table 3.2) whilst no significant differences were observed for liver, thigh or breast tissue, the same as for the commercial trial results. Thigh Cu was also significantly higher in the control replicate compared to the treatment replicate, with a similar trend evident for Mn and Br, but not significant at the $P<0.05$ level (but significant at the $P< 0.1$ level).

Significant increases for most of the tissues were observed in all extensive region trial replicates compared to the commercial trial replicates for Mo, Cu, and Cr (Tables 3.1, 3.2, 3.6 and 3.7). For Se and Br the extensive region trial replicates presented with elevated concentrations for mainly liver and thigh tissues, whilst I, Cd and Mn were largely similar between the two trials. The variability of element concentrations was greater in the extensive region replicates.

The replicates adjusted water intakes in accordance with the changing seasonal temperature, with the expected increase in intake due to growth largely negated by decreased water requirements with the onset of cold winter conditions. Within replicates some significant period differences were observed. These were for weeks 6 – 10 to weeks 11 – 15, and weeks 16 – 20 and weeks 21 – 25, for T1, both yielding significant increases, and weeks 10 – 15 and weeks 16 – 20 for C2, also yielding a significant increase ($P<0.05$). As Table 9 illustrates, significant differences were observed between replicates for the same period, mostly attributed to replicates T1 and C1. Notably, replicates T1 and T2 did not differ significantly throughout period comparisons, whereas replicates C1 and C2 differed significantly on each of the three last periods. Average means for water intake for each replicate over the entire exposure period did not differ significantly ($P<0.05$).

The effects of temperature in general, and specifically water temperature, on water intake indicated an early initial adaptation to the experimental conditions, followed by several responses to changing temperatures. With the observation variables of shade, sun and water being monitored in the morning (08h:00) and afternoon (15h:00), the highest correlation coefficient between air temperatures and replicate water intakes was found for replicates C2 and T2 and the afternoon temperature monitored in the sun (0.75 and 0.66 respectively), whilst the morning shade reading yielded the highest correlation coefficient

for the same replicates (0.67 and 0.59 respectively). However, the water temperature readings for both the morning and afternoon returned the most significant correlation coefficients with water intakes for all replicates (0.68 – morning and 0.75 – afternoon). Between the methods of temperature monitoring throughout the exposure period, mean water temperature returned the highest correlation with water intake (0.75), compared to mean shade temperature (0.74) and mean sun temperature (0.70). The challenges placed on the poultry and consequent effects in dose ingestion under the extensive conditions are highly variable in comparison with the commercial trial. Over the exposure period the highest daily temperature recordings for shade, sun and water were 34, 35, and 37 degrees Centigrade respectively, with the lowest being 1, 3 and 0 degrees Centigrade respectively. The highest weekly average recorded was 33, 34 and 34 degrees Centigrade respectively, and the lowest 5.7, 7.1 and 4.1 degrees Centigrade respectively.

Feed intakes were not recorded reliably, as strong winds and consumption of feed by wild birds and small mammals, all contributed to variations between observations. Comparisons between groups also differed as individual behavior differed. Generally, the treatment replicate birds demonstrated more foraging (wild seeds and insects) and scratching patterns, with much of the feed being extracted from the feeder prior to its consumption. The consumption did however indicate that an average of 1.6 to 1.9 kg of feed per replicate per day was consumed equally by the replicates. This would accord with the observations regarding water intake with respect to the correlation between water and feed intake. The live weights also support this observation. Despite several significant differences between replicates during the trial period, no significant differences were apparent for pooled replicates at the final three 5-week period live weight recordings (Table 3.8). Noteworthy are the lower live weights obtained for the extensive trial compared to the commercial trial. External and internal parasite loads can be expected to play a significant part in this difference, in addition to the different diets and harsher production conditions (Tables 3.3 and 3.8). Accordingly, less variation in live weight observations through the growth phases were apparent in the commercial trial, whilst decreases and subsequent significant recoveries ($P<0.05$) were evident in the extensive trial, notably within replicate T1 (weeks 6 –10 compared to 11 –15, and 16 – 20 compared to 21 – 25), and within replicate C2 (weeks 11 – 15 compared to 16 – 20).

Mortalities were experienced for all replicates, totaling 8, 11, 3 and 7 birds for replicates T1, T2, C1 and C2 respectively. This cannot be solely attributed to the treatments, as natural predators and individual variation played significant roles. The treatment replicates did present with a greater degree of cannibalism and neurological disorders though, and also suffered earlier losses than the control replicates. The majority of the fatalities occurred during the period of 16 – 25 weeks.

**Table 3.6**. Tissue results in broilers exposed to arsenic and lead in the drinking water under extensive production conditions.

| **Element*** | **Means & S.D. (mg/kg DM basis)** | | |
|---|---|---|---|
| | **Liver** | **Thigh** | **Breast** |
| **As** | | | |
| Replicate T1 | $13.5_{a}$ (1.979) | $16.08_{a}$ (6.67) | $10.78_{a}$ (7.86) |
| Replicate T2 | $35.75_{a}$ (12.51) | $14.04_{a}$ (5.35) | $14.46_{a}$ (7.38) |
| Replicate C1 | $1.65_{b}$ (1.06) | $1.54_{b}$ (2.43) | $0.98_{b}$ (1.296) |

| | | | |
|---|---|---|---|
| Replicate C2 | 0.55 $_{b}$ (0.2.12) | 0.8 $_{b}$ (0.738) | 0.88 $_{b}$ (0.822) |
| **Pb** | | | |
| Replicate T1 | 17 $_{ac}$ (2.82) | 7.6 $_{ac}$ (4.66) | 13 $_{a}$ (10.17) |
| Replicate T2 | 19.5 $_{a}$ (0.707) | 21.4 $_{a}$ (14.55) | 15.4 $_{a}$ (12.21) |
| Replicate C1 | 10 $_{bc}$ (4.24) | 5.8 $_{bc}$ (3.63) | 1.4 $_{b}$ (0.547) |
| Replicate C2 | 8.5 $_{b}$ (2.121) | 4.8 $_{bc}$ (3.11) | 4.2 $_{ab}$ (2.774) |
| **Se** | | | |
| Replicate T1 | 6.55 $_{a}$ (0.35) | 2.46 $_{a}$ (1.937) | 1.38 $_{a}$ (1.296) |
| Replicate T2 | 7 $_{ab}$ (1.31) | 2.54 $_{a}$ (1.031) | 4.66 $_{b}$ (1.66) |
| Replicate C1 | 7.95 $_{ab}$ (6.01) | 3.54 $_{a}$ (2.24) | 0.68 $_{a}$ (0.7) |
| Replicate C2 | 4.2 $_{b}$ (0) | 3.96 $_{a}$ (2.86) | 2.7 $_{ab}$ (3.37) |
| **Mo** | | | |
| Replicate T1 | 11.1 $_{a}$ (1.27) | 2.82 $_{a}$ (0.443) | 2.24 $_{ab}$ (1.08) |
| Replicate T2 | 35.5 $_{a}$ (31.32) | 3.92 $_{a}$ (2.1) | 2.78 $_{a}$ (0.719) |
| Replicate C1 | 17.5 $_{a}$ (5.091) | 2.88 $_{a}$ (1.333) | 2.4 $_{ab}$ (0.331) |
| Replicate C2 | 10.8 $_{a}$ (1.979) | 2.66 $_{a}$ (0.784) | 1.92 $_{b}$ (0.402) |
| **Cd** | | | |
| Replicate T1 | 0.45 $_{a}$ (0.353) | 0.14 $_{a}$ (0.089) | 0.12 $_{a}$ (0.044) |
| Replicate T2 | 0.7 $_{a}$ (0.141) | 0.22 $_{a b}$ (0.164) | 0.8 $_{b}$ (0.13) |
| Replicate C1 | 1.05 $_{a}$ (0.777) | 0.2 $_{b}$ (0.141) | 0.1 $_{b}$ (0.001) |
| Replicate C2 | 0.45 $_{a}$ (0.212) | 0.3 $_{b}$ (0.122) | 0.4 $_{b}$ (0.282) |
| **Br** | | | |
| Replicate T1 | 46.35 $_{a}$ (63.14) | 66.8 $_{ab}$ (28.45) | 57.4 $_{a}$ (27.627) |
| Replicate T2 | 75 $_{a}$ (5.65) | 58 $_{a}$ (18.761) | 93.6 $_{b}$ (24.19) |
| Replicate C1 | 101.5 $_{a}$ (53.03) | 93 $_{b}$ (17.392) | 59 $_{a}$ (19.65) |
| Replicate C2 | 73 $_{a}$ (1.414) | 94.8 $_{ab}$ (64.596) | 55.2 $_{ab}$ (40.14) |
| **Cu** | | | |
| Replicate T1 | 61.5 $_{a}$ (9.192) | 24.8 $_{a}$ (4.711) | 8.24 $_{a}$ (5.67) |
| Replicate T2 | 6.3 $_{a}$ (7.07) | 16.6 $_{b}$ (2.88) | 29.4 $_{b}$ (12.95) |
| Replicate C1 | 88 $_{a}$ (25.45) | 39.6 $_{c}$ (9.581) | 14.8 $_{c}$ (2.387) |
| Replicate C2 | 55.5 $_{a}$ (0.701) | 35.6 $_{ab}$ (20.94) | 35.4 $_{ac}$ (43.57) |
| **Mn** | | | |
| Replicate T1 | 24.1 $_{a}$ (25.31) | 3.66 $_{ab}$ (0.512) | 1.38 $_{a}$ (0.81) |
| Replicate T2 | 69.5 $_{a}$ (23.32) | 2.88 $_{a}$ (1.091) | 5.06 $_{b}$ (1.847) |
| Replicate C1 | 82 $_{a}$ (22.62) | 4.82 $_{b}$ (1.329) | 2.22 $_{a}$ (0.37) |
| Replicate C2 | 55 $_{a}$ (7.071) | 5.2 $_{ab}$ (3.87) | 2.72 $_{ab}$ (1.92) |
| **Cr** | | | |
| Replicate T1 | 3.75 $_{a}$ (0.353) | 4.62 $_{a}$ (0.941) | 3.04 $_{a}$ (1.687) |
| Replicate T2 | 5 $_{a}$ (0.989) | 5.08 $_{a}$ (1.08) | 5.6 $_{b}$ (1.18) |
| Replicate C1 | 6.75 $_{a}$ (1.909) | 5.56 $_{a}$ (0.912) | 4.92 $_{ab}$ (0.433) |
| Replicate C2 | 3.7 $_{a}$ (0.565) | 5.5 $_{a}$ (1.29) | 5.34 $_{b}$ (1.41) |
| **I** | | | |
| Replicate T1 | 0.1 $_{a}$ (0) | 1.28 $_{a}$ (2.63) | 1.62 $_{a}$ (3.233) |
| Replicate T2 | 0.1 $_{a}$ (0) | 0.172 $_{a}$ (1.38) | 0.14 $_{a}$ (0.089) |
| Replicate C1 | 0.1 $_{a}$ (0) | 0.54 $_{a}$ (0.98) | 0.1 $_{a}$ (0.001 |
| Replicate C2 | 0.1 $_{a}$ (0) | 0.1 $_{a}$ (0.001) | 0.1 $_{a}$ (0.001) |

* Means within a coloumn (tissue type) for each element bearing the same subscripts do not differ significantly at the P< 0.05 level.

**Table 3.7.** Pooled tissue results in broilers exposed to arsenic and lead in the drinking water under extensive production conditions.

| Element* | Means & S.D. (mg/kg DM basis) | | | |
|---|---|---|---|---|
| | **Heart** | **Liver** | **Thigh** | **Breast** |
| **As** | | | | |
| Treatment | 15.55 $_a$ (3.88) | 24.62 $_a$ (14.78) | 15.06 $_a$ (5.8) | 12.62 $_a$ (7.44) |
| Control | 0.7 $_a$ (0.42) | 1.1 $_b$ (0.89) | 1.17 $_b$ (1.74) | 0.93 $_b$ (1.025) |
| **Pb** | | | | |
| Treatment | 20.5 $_a$ (17.67) | 18.25 $_a$ (2.27) | 14.5 $_a$ (12.51) | 14.2 $_a$ (10.67) |
| Control | 4.5 $_a$ (2.12) | 9.25 $_b$ (2.87) | 5.3 $_b$ (3.23) | 2.8 $_b$ (2.34) |
| **Se** | | | | |
| Treatment | 2.5 $_a$ (0) | 6.775 $_a$ (0.732) | 2.5 $_a$ (1.463) | 3.02 $_a$ (2.23) |
| Control | 3.55 $_b$ (2.757) | 6.075 $_a$ (4.09) | 3.75 $_a$ (2.435) | 1.69 $_a$ (2.53) |
| **Mo** | | | | |
| Treatment | 3.35 $_a$ (0.35) | 23.32 $_a$ (22.95) | 3.37 $_a$ (1.544) | 2.51 $_a$ (0.91) |
| Control | 3.45 $_a$ (0.49) | 14.4 $_a$ (4.99) | 2.77 $_a$ (1.03) | 2.16 $_a$ (0.429) |
| **Cd** | | | | |
| Treatment | 0.1 $_a$ (0) | 0.575 $_a$ (0.262) | 0.18 $_a$ (0.131) | 0.2 $_a$ (0.124) |
| Control | 0.1 $_a$ (0) | 0.75 $_a$ (0.58) | 0.25 $_a$ (0.135) | 0.25 $_a$ (0.246) |
| **Br** | | | | |
| Treatment | 121.5 $_a$ (24.74) | 60.67 $_a$ (40.16) | 62.4 $_a$ (23.19) | 75.5 $_a$ (31.03) |
| Control | 95 $_a$ (2.828) | 87.25 $_a$ (34.76) | 93.9 $_a$ (44.6) | 57.1 $_a$ (29.58) |
| **Cu** | | | | |
| Treatment | 104.5 $_a$ (7.77) | 62.25 $_a$ (6.75) | 20.7 $_a$ (5.67) | 18.82 $_a$ (14.6) |
| Control | 97 $_a$ (9.89) | 71.75 $_a$ (23.83) | 37.6 $_b$ (15.5) | 25.1 $_a$ (31.05) |
| **Mn** | | | | |
| Treatment | 17 $_a$ (9.89) | 46.8 $_a$ (32.89) | 3.27 $_a$ (0.9) | 3.22 $_a$ (2.36) |
| Control | 10.5 $_a$ (0.7) | 68.5 $_a$ (20.7) | 5.01 $_a$ (2.73) | 2.47 $_a$ (1.33) |
| **Cr** | | | | |
| Treatment | 4.45 $_a$ (0.212) | 4.37 $_a$ (0.942) | 4.85 $_a$ (0.986) | 4.32 $_a$ (1.926) |
| Control | 4.3 $_a$ (0.565) | 5.22 $_a$ (2.1) | 5.53 $_a$ (1.05) | 5.13 $_a$ (1.149) |
| **I** | | | | |
| Treatment | 0.01 $_a$ (0) | 0.1 $_a$ (0) | 1 $_a$ (2) | 0.88 $_a$ (2.29) |
| Control | 0.01 $_a$ (0) | 0.1 $_a$ (0) | 0.32 $_a$ (0.069) | 0.1 $_a$ (0.001) |

* Means within a coloumn (tissue type) for each element bearing the same subscripts do not differ significantly at the P< 0.05 level.

**Table 3.8.** Live weight (kg) results in broilers exposed to arsenic and lead in the drinking water under extensive production conditions.

| Observation | Means & S.D. (kg) | | | | Pooled |
|---|---|---|---|---|---|
| | **Replicate T1[2]** | **Replicate T2[2]** | **Replicate C1[2]** | **Replicate C2[2]** | **T & C[3]** |
| **LW weeks 1 -5[1]** | 0.135 $_a$ (0.132) | 0.145 $_a$ (0.134) | 0.092 $_a$ (0.052) | 0.105 $_a$ (0.027) | Ns |
| **LW weeks 6 -10[1]** | 0.077 $_a$ (0.01) | 0.086 $_b$ (0.014) | 0.118 $_b$ (0.017) | 0.09 $_a$ (0.008) | S |
| **LW weeks 11 -15[1]** | 0.111 $_a$ (0.02) | 0.138 $_a$ (0.048) | 0.153 $_a$ (0.043) | 0.107 $_a$ (0.02) | Ns |
| **LW weeks 16 -20[1]** | 0.095 $_a$ (0.029) | 0.157 $_{ab}$ (0.084) | 0.119 $_a$ (0.035) | 0.167 $_b$ (0.023) | Ns |
| **LW weeks 21 -25[1]** | 0.179 $_{ab}$ (0.049) | 0.259 $_a$ (0.085) | 0.12 $_b$ (0.041) | 0.174 $_{ab}$ (0.049) | Ns |

[1]Observations for live weight based on group recordings.
[2]Means within a row for replicates bearing the same subscript do not differ significantly (P < 0.05 level).
[3]ns = means not significantly different for pooled observations at the P < 0.05 level.
[3]s = means significantly different for pooled observations at the P < 0.05 level.

**Table 3.9.** Water intake (mℓ/bird/d) results in broilers exposed to arsenic and lead in the drinking water under extensive production conditions.

| Observation[1] | Means & S.D. (mℓ/bird/day)[2] | | | | Pooled T & C[4] |
|---|---|---|---|---|---|
| | Replicate T1[3] | Replicate T2[3] | Replicate C1[3] | Replicate C2[3] | |
| **WI 1 (weeks 1 –5)** | 135 $_{a}$ (132) | 145 $_{a}$ (134) | 92 $_{a}$ (52) | 105 $_{a}$ (27) | Ns |
| **WI 2 (weeks 6 - 10)** | 77 $_{a}$ (10) | 86 $_{a}$ (14) | 118 $_{b}$ (17) | 90 $_{a}$ (8) | s |
| **WI 3 (weeks 11 – 15)** | 111 $_{a}$ (27) | 138 $_{a}$ (48) | 153 $_{a}$ (43) | 107 $_{a}$ (24) | Ns |
| **WI 4 (weeks 16 – 20)** | 95 $_{a}$ (29) | 157 $_{ab}$ (84) | 119 $_{a}$ (35) | 167 $_{b}$ (23) | Ns |
| **WI 5 (weeks 21 - 25)** | 179 $_{ab}$ (49) | 259 $_{a}$ (80) | 124 $_{b}$ (41) | 174 $_{ab}$ (49) | Ns |

[1]Observations for water intake based on average for 5-week intervals from daily group recordings.
[2]Means for water intake based on average group recordings.
[3]Means within a row for replicates bearing the same subscript do not differ significantly ($P < 0.05$ level).
[4]ns = means not significantly different for pooled observations at the $P < 0.05$ level.
[4]s = means significantly different for pooled observations at the $P < 0.05$ level.

### 3.3.3 Discussion

The most significant finding from this extensive region trial was the significantly elevated concentrations for As and Pb in all the tissues examined for not only the treatment replicates, but also in comparison with the commercial trial treatment replicates. This highlights the significant effects of temperature and exposure period on increasing the tissue concentrations derived from constituents in the drinking water. This emphasizes the important role that Village Poultry Production units can play in providing the community with better product quality in terms of carcass PHCC concentrations, but as the commercial trial results indicated, the presence of these elements in the drinking water at concentrations observed in rural drinking supplies can still deliver unacceptable product quality even if an intensive production environment applies. The Village Poultry Production units do not deliver the same level of performance and management as the commercial trial achieved, and are thus probably midway between what was achieved in the commercial trial and the extensive region trial. The conclusion is thus that even though Village Poultry Production units do contribute to a safer product, the concentrations of PHCC in the drinking water must be kept within the recommended guideline ranges to prevent exposure of the community to harmful food. Consideration must also be given to the prevalence of household scavenging poultry production systems as despite general support for the village agricultural projects, household production still continues. As a result, management of PHCC in rural water sources must include household product quality considerations.

As for the ingestion of these products in the household context, two considerations are applicable. Firstly, the tissue values realistically achieved can be expected to be closer to the extensive region trial due to poor diets, longer exposure periods, and significant geophagia contributions. Secondly, the cultural cooking practices may increase the probability for the ingestion of unacceptable concentrations of PHCC as the same water may be used for cooking and food preparation, and many soft tissues known to have a

high concentration of heavy elements are routinely consumed. It must also be kept in perspective that the concentrations of the water treatments provided were formulated to be an average of observations of PHCC that exceeded the recommended guidelines in rural water supplies in several communities. Under realistic village conditions it can be expected that these concentrations will fluctuate more significantly, a factor that increases bioaccumulation for many elements as intermittent exposure is considered worse than continuous high exposure.

The observation of non-treatment related elements that exceeded the MAC (Se, Br and Cr) for both treatment and control replicates would be attributed to the presence of these elements at elevated concentrations in the geochemical environment, as presented in the subterranean water results for the Immerpan District and Delftzyl Research Station in this report and previous reports (Casey *et al*., 2001a). This again emphasizes the importance of establishing geochemical anomalies and investigating the hazards thereof to the various forms of exposure for localized communities, from drinking water and food crops to livestock products.

As with the commercial trial, the tissue results also suggest that the chemical treatment interfered with some nutritionally important elements, specifically Cu and Mn. As stated in the discussion for the commercial trial, these effects are of concern primarily to long-exposure periods and to production systems where affected trace elements are marginal in supply, a situation that may arise within rural communal production systems, and was apparently demonstrated in this extensive region trial. The feasibility of risk management strategies at the household level is highly variable, but would be more appropriate within the Village Poultry Production unit context.

The results from the temperature reading methods indicate the importance of using the most appropriate method in terms of accuracy desired and practical feasibility within extensive conditions, as usually only a single reading per day will be collected. Based on the results obtained, afternoon water temperature would appear to be the most reliable indicator for single daily monitoring.

The non-significant differences in average water intakes between replicates over the exposure period not only supports the finding in the commercial experiment of the lack of aesthetic protection from the As and Pb treatments, but also highlights the dominance of temperature related water requirements, and consequent dose-ingestion increases with temperature-related thermoregulation mechanisms. This, coupled to the shorter duration of exposure in commercial production units supports the need for assessments on fitness for use to be applied with the production system specifics taken into account. This also holds true for Village Poultry Production projects as the housing facilities and degree of control over housing environment differs significantly between communities.

The higher mortality rate experienced for the treatment replicates may certainly have an economic impact for rural households, but the lower live weights achieved were not significantly different from the controls, a similar finding to the commercial trial indicating the cumulative, chronic nature of the constituents involved enabling an unfit

product for human consumption being produced in the absence of obvious performance deficits. The purpose of the trial was not to achieve similar carcass weights as achieved in the commercial trial, but to maintain the same production conditions as observed in the households in the rural villages in the Immerpan District. This impacts negatively on parasite control and feed requirements.

As stated in the introduction, the concerns regarding achieving EU product quality standards are valid, as the chemical treatment for both commercial and extensive region demonstrates. This is a key issue for USDA-funded Poultry Projects initiated in the Limpopo Province in partnership with the TSAC. For those communities that have subterranean water that negatively affects poultry product quality, diluting the water source with an alternative source to arrive at an acceptable dose-ingestion is an option. However, many communities investigated for this project did not have alternative sources, nor was rainwater collection significant enough to use for livestock watering (clinics and household use taking preference). For these communities alternative strategies are needed to prevent hazardous or non-compliant poultry products from being produced. The next experiment was designed to test an inexpensive alleviator treatment for this purpose, and to also investigate the potential protective effects of some naturally occurring PHCC.

## 3.4 Potential alleviators under commercial production conditions

### 3.4.1 Methods

The same production house facility used in the commercial production system experiment presented at the start of this chapter was used for this investigation. The same health and overall management programs were also applied. The experiment used Ross broilers, with twelve broilers per group, four different treatment groups, and seven replicates per group. The following four water types were allocated randomly to the four groups and replicates:

C1 = control – municipal water (12 birds x 7 replicates)
T1 = chemical water treatment with reconstituted water (12 birds x 7 replicates)
T2 = chemical water treatment + saline alleviator (n = 12 birds x 7 replicates)
T3 = municipal water + saline alleviator (n = 12 birds x 7 replicates)

The chemical water delivered a final concentration of 0.1 mg As/ℓ as arsenic-trioxide ($As_2O_3$), 0.1 mg Pb/ℓ as lead nitrate ($Pb(NO_3)_2$), and 1 mg Br/ℓ as sodium bromate(*). The lowered As concentration compared to the first experiment was selected in an attempt to identify an acceptable hazardous margin in excess of the recommended guideline limit (0.01 mg/ℓ). The inclusion of Br was due to the repeated observations thereof in rural groundwater at elevated concentrations and possible protective effects on PHCC exposure. Sodium chloride (NaCl – AR Grade) was chosen as a potential alleviator at 1500 mg/ℓ based on the positive results obtained in cattle and sheep (Casey *et al*, 2001a) and the observations of high TDS concentrations in some communities. The

same preparation and administration of the treatments as applied in the first experiment was employed. The same parameters, tissue collection and processing procedures were also followed, except that heart and kidney samples were also collected. Due to the higher group sizes used it was possible to test for replicate differences in breast and thigh tissues, with replicates 1 and 2 being used for breast and thigh collections, whilst pooled comparisons for these replicates were used for liver, heart and kidney comparisons.

### 3.4.2 Results

Tissue results are presented separately for replicates and pooled samples in Tables 3.10 and 3.11 respectively. As expected, the treatment group (T1R1) yielded the highest observed liver values for As, Br and Pb. For Br, Mn and Mo these were significantly so compared with the control group CR1, whilst for Se and Pb significantly so compared to the alleviator group (T2R1). Group T2R1 liver values were reduced compared to group T1R1 for Cr, Mn, As, Br, Cd, Mo and Pb. Group T3R1 livers returned the lowest means for Cr, As, Cd (significant at $P<0.05$) and I. A similar trend was observed for the breast values for replicate 1, but only Cr and Pb yielded significant differences between groups. Despite reductions in the T2R1 from the T1R1 values, these were not significant, the only significant differences being between T1R1 and CR1, and T1R1 and T3R1 due to the elevated values for T1R1. A pattern seen for many of the elements, though not always significantly so, was for the non-As-Br-Pb recipient groups C1 and T3 to present with similar means, whilst groups T1 and T2 that did receive As-Br-Pb tended to be dissimilar, with T1 tending to present with higher means than T2. Within the similarities between C1 and T3, T3 still tended to present with lower means, therefore, groups receiving the NaCl treatments tended to return lower means than their direct comparisons (C1 - T3, and T1-T2). For the pooled results, thigh As, Br, Pb and Se all returned significant results for the treatment (T1) and the alleviator treatment (T2), whereas for breast samples, for these elements only Pb returned a significant effect between the treatment and the saline group (T1 v T3). The trends were the same for breast, but for As, Br and Se, although not significant at the $P< 0.05$ level (most with $P = 0.05$ to 0.08). Chromium also followed the same trend between these pooled tissues, with T1 differing significantly from C1 and T3 from both C1 and T1.

As with the first commercial trial, the broilers attained similar live weights and presented with no abnormal health related problems. A decrease in feed intake was noted for all groups in week 6, due to a change to a finisher ration (standard production practice). Although no significant differences were found for feed or live weight between groups or within replicates within groups, water intakes did differ significantly ($P<0.05$). Similar aspects as observed for the first commercial regarding aesthetic attributes and consumer norms apply. The water intake observations indicated that the TDS treatments (T2 & T3) significantly increased water intake from the second week throughout the course of the exposure period. No significant differences were observed between the TDS treatment groups (T2 & T3) or between the non-TDS treatment groups (C & T1). Average increases in water intake between the TDS and non-TDS groups rose from an initial 7% in week 1 to 13% in week 5, followed by a reduction in the last two weeks to ca. 9%.

Resultant average intakes for As and Pb were 0.0236 mg/d/bird for T1, 0.0262 mg/d/bird for T2, and for Br 0.236 mg/d/bird for T1 and 0.262 mg/d/bird for T2 over the trial period. The total ingestion of As and Pb over the duration of the trial was 1.325 mg for T1 and 1.469 mg for TW respectively for each element, with 13.257 and 14.697 mg of Br being ingested for T1 and T2 respectively over the trial period. Correlations between feed and water intakes were most significant for group T3 (0.90 for week 2 and 0.95 for week 6), but generally weak or negative (although non-significant) for the other groups, with an exception being observed for group C on week 5 (0.92).

**Table 3.10**. Tissue results in broilers exposed to arsenic, lead, bromide and sodium chloride in the drinking water under commercial production conditions.

| **Element*** | **Means & S.D. (mg/kg DM basis)** | | | | |
|---|---|---|---|---|---|
| | **Liver**** | **Thigh Replicate R2** | **Thigh Replicate R1** | **Breast Replicate R2** | **Breast Replicate R1** |
| **As** | | | | | |
| C1 | 0.3710 $_{a}$ (0.052) | 0.2440 $_{a}$ (0.048) | 0.2360 $_{ab}$ (0.063) | 0.1930 $_{a}$ (0.045) | 0.1080 $_{a}$ (0.030) |
| T1 | 0.3980 $_{a}$ (0.088) | 0.2933 $_{a}$ (0.059) | 0.2560 $_{a}$ (0.072) | 0.2020 $_{a}$ (0.084) | 0.1320 a (0.036) |
| T2 | 0.3860 $_{a}$ (0.056) | 0.2860 $_{a}$ (0.057) | 0.2110 $_{ab}$ (0.049) | 0.2060 $_{a}$ (0.074) | 0.1240 $_{a}$ (0.032) |
| T3 | 0.3560 $_{a}$ (0.048) | 0.2670 $_{a}$ (0.039) | 0.1970 $_{b}$ (0.042) | 0.1830 $_{a}$ (0.067) | 0.110 $_{a}$ (0.047) |
| **Pb** | | | | | |
| C1 | 0.2450 $_{ab}$ (0.104) | 0.1020 $_{a}$ (0.040) | 0.1620 $_{a}$ (0.080) | 0.0860 $_{a}$ (0.075) | 0.1590 $_{a}$ (0.033) |
| T1 | 0.3120 $_{a}$ (0.035) | 0.2270 $_{a}$ (0.132) | 0.2460 $_{b}$ (0.154) | 0.090 $_{a}$ (0.096) | 0.2960 $_{b}$ (0.175) |
| T2 | 0.2720 $_{b}$ (0.022) | 0.1200 $_{a}$ (0.050) | 0.1110 $_{a}$ (0.035) | 0.0440 $_{a}$ (0.030) | 0.2170 $_{ab}$ (0.210) |
| T3 | 0.2620 $_{ab}$ (0.077) | 0.1620 $_{a}$ (0.076) | 0.1710 $_{ab}$ (0.158) | 0.0470 $_{a}$ (0.042) | 0.1620 $_{a}$ (0.083) |
| **Se** | | | | | |
| C1 | 0.9930 $_{ab}$ (0.211) | 0.553 $_{a}$ (0.127) | 0.3930 $_{a}$ (0.102) | 0.4620 $_{a}$ (0.304) | 0.4080 $_{a}$ (0.097) |
| T1 | 1.1270 $_{a}$ (0.147) | 0.496 $_{ab}$ (0.121) | 0.5010 $_{a}$ (0.177) | 0.5800 $_{a}$ (0.325) | 0.5060 $_{a}$ (0.144) |
| T2 | 0.9870 $_{b}$ (0.096) | 0.4750 $_{ab}$ (0.091) | 0.3160 $_{b}$ (0.047) | 0.5910 $_{a}$ (0.384) | 0.4520 $_{a}$ (0.145) |
| T3 | 1.110 $_{a}$ (0.160) | 0.4324 $_{b}$ (0.087) | 0.3810 $_{a}$ (0.083) | 0.4290 $_{a}$ (0.239) | 0.3930 $_{a}$ (0.184) |
| **Mo** | | | | | |
| C1 | 0.6390 $_{a}$ (0.176) | 0.0390 $_{a}$ (0.011) | 0.0380 $_{a}$ (0.011) | 0.0110 $_{a}$ (0.007) | 0.0460 $_{a}$ (0.007) |
| T1 | 0.8550 $_{b}$ (0.169) | 0.0470 $_{a}$ (0.008) | 0.0840 $_{a}$ (0.123) | 0.0190 $_{b}$ (0.010) | 0.0530 $_{a}$ (0.009) |
| T2 | 0.790 $_{b}$ (0.100) | 0.0440 $_{a}$ (0.011) | 0.0340 $_{a}$ (0.006) | 0.0160 $_{ab}$ (0.007) | 0.0480 $_{a}$ (0.010) |
| T3 | 0.8220 $_{b}$ (0.156) | 0.0460 $_{a}$ (0.014) | 0.0370 $_{a}$ (0.004) | 0.0170 $_{b}$ (0.003) | 0.0470 $_{a}$ (0.017) |
| **Cd** | | | | | |
| C1 | 0.0950 $_{a}$ (0.010) | 0.0310 $_{a}$ (0.016) | 0.0130 $_{a}$ (0.021) | nd | 0.0080 $_{a}$ (0.016) |

| | | | | | |
|---|---|---|---|---|---|
| T1 | 0.1090 $_{ab}$ (0.046) | 0.030 $_{a}$ (0.016) | 0.0160 $_{a}$ (0.026) | nd | 0.0070 $_{a}$ (0.008) |
| T2 | 0.090 $_{ab}$ (0.011) | 0.0340 $_{a}$ (0.020) | 0.0570 $_{a}$ (0.174) | nd | 0.0020 $_{a}$ (0.004) |
| T3 | 0.0840 $_{b}$ (0.006) | 0.0310 $_{a}$ (0.029) | 0.0080 $_{a}$ (0.013) | nd | 0.0020 $_{a}$ (0.003) |
| **Br** | | | | | |
| C1 | 10.610 $_{a}$ (3.449) | 9.4230 $_{a}$ (3.260) | 6.050 $_{a}$ (3.424) | 5.0340 $_{a}$ (4.891) | 5.0980 $_{a}$ (4.193) |
| T1 | 14.890 $_{b}$ (4.542) | 14.530 $_{a}$ (6.618) | 13.3940 $_{b}$ (5.106) | 7.5410 $_{a}$ (5.605) | 7.8650 $_{a}$ (4.555) |
| T2 | 11.920 $_{ab}$ (3.890) | 9.850 $_{a}$ (4.251) | 4.6750 $_{a}$ (2.806) | 7.270 $_{a}$ (4.748) | 7.1380 $_{a}$ (4.829) |
| T3 | 12.030 $_{ab}$ (4.120) | 8.890 $_{a}$ (4.485) | 6.7640 $_{a}$ (2.499) | 4.9790 $_{a}$ (4.107) | 5.5290 $_{a}$ (4.403) |
| **Cu** | | | | | |
| C1 | 3.890 $_{a}$ (1.122) | 0.702 $_{a}$ (0.202) | 0.680 $_{a}$ (0.220) | 0.6330 $_{ab}$ (0.103) | 0.4070 $_{a}$ (0.059) |
| T1 | 4.4980 $_{a}$ (0.775) | 0.6960 $_{a}$ (0.162) | 0.6610 $_{a}$ (0.155) | 0.6180 $_{a}$ (0.079) | 0.4350 $_{a}$ (0.041) |
| T2 | 5.4340 $_{b}$ (3.174) | 0.650 $_{a}$ (0.146) | 0.7130 $_{a}$ (0.221) | 0.6540 $_{ab}$ (0.068) | 0.4390 $_{a}$ (0.057) |
| T3 | 4.1590 $_{b}$ (0.571) | 0.7530 $_{a}$ (0.198) | 0.7460 $_{a}$ (0.170) | 0.6890 $_{b}$ (0.057) | 0.3830 $_{a}$ (0.128) |
| **Mn** | | | | | |
| C1 | 3.5730 $_{a}$ (0.580) | 0.1539 $_{a}$ (0.042) | 0.0320 $_{ab}$ (0.051) | nd | 0.0190 $_{a}$ (0.039) |
| T1 | 4.2140 $_{a}$ (0.616) | 0.1599 $_{a}$ (0.055) | 0.0610 $_{a}$ (0.053) | nd | 0.0290 $_{a}$ (0.032) |
| T2 | 3.8010 $_{a}$ (0.444) | 0.1338 $_{a}$ (0.037) | 0.0840 $_{ab}$ (0.129) | nd | 0.0130 $_{a}$ (0.030) |
| T3 | 4.1560 $_{a}$ (0.571) | 0.1388 $_{a}$ (0.198) | 0.0160 $_{ab}$ (0.170) | nd | 0.0010 $_{a}$ (0.128) |
| **Cr** | | | | | |
| C1 | 1.2180 $_{a}$ (0.146) | 0.8021 $_{a}$ (0.169) | 0.590 $_{a}$ (0.081) | 0.8420 $_{a}$ (0.114) | 0.7940 $_{a}$ (0.087) |
| T1 | 1.160 $_{a}$ (0.285) | 0.8517 $_{a}$ (0.187) | 0.7860 $_{b}$ (0.243) | 0.8630 $_{a}$ (0.084) | 0.8880 $_{b}$ (0.119) |
| T2 | 1.0540 $_{a}$ (0.232) | 0.8573 $_{a}$ (0.173) | 0.5610 $_{a}$ (0.125) | 0.830 $_{a}$ (0.119) | 0.810 $_{ab}$ (0.117) |
| T3 | 1.1170 $_{a}$ (0.255) | 0.7915 $_{a}$ (0.100) | 0.5450 $_{a}$ (0.104) | 0.8410 $_{a}$ (0.070) | 0.7110 $_{a}$ (0.266) |
| **I** | | | | | |
| C1 | 0.2480 $_{a}$ (0.015) | 0.1021 $_{a}$ (0.007) | 0.0010 $_{a}$ (0.005) | nd | 0.0050 $_{a}$ (0.004) |
| T1 | 0.2520 $_{a}$ (0.273) | 0.0144 $_{a}$ (0.008) | 0.0250 $_{a}$ (0.062) | nd | 0.0120 $_{a}$ (0.015) |
| T2 | 0.2520 $_{a}$ (0.022) | 0.0123 $_{a}$ (0.008) | 0.0010 $_{a}$ (0.001) | nd | 0.0030 $_{a}$ (0.004) |
| T3 | 0.2340 $_{a}$ (0.042) | 0.0088 $_{a}$ (0.006) | Nd | nd | 0.0030 $_{a}$ (0.005) |

* Means within a coloumn (tissue type) for each element bearing the same subscripts do not differ significantly at the P< 0.05 level.

** Liver replicates pooled.

Nd = not detected below 0.001 mg/kg

**Table 3.11.** Pooled tissue results in broilers exposed to arsenic, lead, bromide and sodium chloride in the drinking water under commercial production conditions.

| Element | Means & S.D. (mg/kg DM basis)* | |
|---|---|---|
| | **Thigh** | **Breast** |
| **As** | | |
| C1 | 0.2400 $_{ab}$ (0.055) | 0.1510 $_{a}$ (0.057) |
| T1 | 0.2740 $_{a}$ (0.067) | 0.1670 $_{a}$ (0.072) |
| T2 | 0.2490 $_{ab}$ (0.064) | 0.1650 $_{a}$ (0.069) |
| T3 | 0.2320 $_{a}$ (0.053) | 0.1460 $_{a}$ (0.067) |
| **Pb** | | |
| C1 | 0.1320 $_{a}$ (0.069) | 0.1230 $_{ab}$ (0.068) |
| T1 | 0.2370 $_{b}$ (0.140) | 0.1930 $_{a}$ (0.174) |
| T2 | 0.1160 $_{a}$ (0.042) | 0.1300 $_{ab}$ (0.171) |
| T3 | 0.1380 $_{a}$ (0.127) | 0.1040 $_{ab}$ (0.087) |
| **Se** | | |
| C1 | 0.4360 $_{a}$ (0.096) | 0.4350 $_{a}$ (0.222) |
| T1 | 0.5350 $_{b}$ (0.165) | 0.5430 $_{a}$ (0.249) |
| T2 | 0.3950 $_{a}$ (0.107) | 0.5220 $_{a}$ (0.292) |
| T3 | 0.410 $_{a}$ (0.086) | 0.4110 $_{a}$ (0.209) |
| **Mo** | | |
| C1 | 0.0390 $_{a}$ (0.011) | 0.0280 $_{a}$ (0.019) |
| T1 | 0.0650 $_{a}$ (0.087) | 0.0360 $_{a}$ (0.019) |
| T2 | 0.0390 $_{a}$ (0.010) | 0.0320 $_{a}$ (0.018) |
| T3 | 0.0420 $_{a}$ (0.011) | 0.0320 $_{a}$ (0.019) |
| **Cd** | | |
| C1 | 0.0220 $_{a}$ (0.020) | 0.0040 $_{a}$ (0.012) |
| T1 | 0.0230 $_{a}$ (0.022) | 0.0030 $_{a}$ (0.006) |
| T2 | 0.0460 $_{a}$ (0.121) | 0.0010 $_{a}$ (0.003) |
| T3 | 0.020 $_{a}$ (0.025) | 0.0010 $_{a}$ (0.002) |
| **Br** | | |
| C1 | 7.7370 $_{a}$ (3.695) | 5.0660 $_{a}$ (4.455) |
| T1 | 13.9640 $_{b}$ (5.810) | 7.7030 $_{a}$ (4.998) |
| T2 | 7.2630 $_{a}$ (4.387) | 7.2040 $_{a}$ (4.684) |
| T3 | 7.8270 $_{a}$ (3.713) | 5.2540 $_{a}$ (4.173) |
| **Cu** | | |
| C1 | 0.6910 $_{a}$ (0.207) | 0.5200 $_{a}$ (0.141) |
| T1 | 0.6780 $_{a}$ (0.156) | 0.5260 $_{a}$ (0.112) |
| T2 | 0.6820 $_{a}$ (0.186) | 0.5460 $_{a}$ (0.125) |
| T3 | 0.7500 $_{a}$ (0.180) | 0.5350 $_{a}$ (0.184) |
| **Mn** | | |
| C1 | 0.0930 $_{a}$ (0.077) | 0.0090 $_{a}$ (0.029) |
| T1 | 0.110 $_{a}$ (0.073) | 0.0140 $_{a}$ (0.027) |
| T2 | 1.7770 $_{a}$ (0.096) | 0.0060 $_{a}$ (0.022) |
| T3 | 0.0770 $_{a}$ (0.068) | 0.0005 $_{a}$ (0.002) |
| **Cr** | | |
| C1 | 0.6960 $_{a}$ (0.169) | 0.8180 $_{ab}$ (0.102) |
| T1 | 0.8190 $_{b}$ (0.215) | 0.8750 $_{a}$ (0.101) |
| T2 | 0.7090 $_{ab}$ (0.211) | 0.8200 $_{ab}$ (0.116) |
| T3 | 0.6680 $_{a}$ (0.161) | 0.7760 $_{ab}$ (0.202) |
| **I** | | |
| C1 | 0.0070 $_{a}$ (0.008) | 0.0020 $_{a}$ (0.004) |
| T1 | 0.0190 $_{a}$ (0.043) | 0.0060 $_{a}$ (0.012) |
| T2 | 0.0060 $_{a}$ (0.008) | 0.0010 $_{a}$ (0.003) |
| T3 | 0.0040 $_{a}$ (0.006) | 0.0010 $_{a}$ (0.004) |

* Means within a coloumn (tissue type) for each element bearing the same subscripts do not differ significantly at the P< 0.05 level.

**Table 3.12.** Live weight (kg) results in broilers exposed to arsenic, bromide and lead in the drinking water over the production cycle.

| Observation[1] | Means & S.D. (kg/bird) [2] | | | |
|---|---|---|---|---|
| | Control C[3] | Treatment T1[3] | Treatment T2[3] | Treatment T3[3] |
| **LW 1 (week 1)** | $0.30_a$ (0.006) | $0.298_a$ (0.013) | $0.302_a$ (0.012) | $0.306_a$ (0.010) |
| **LW 2 (week 2)** | $0.636_a$ (0.019) | $0.633_a$ (0.011) | $0.62_a$ (0.016) | $0.638_a$ (0.020) |
| **LW 3 (week 3)** | $1.110_a$ (0.037) | $1.119_a$ (0.021) | $1.11_a$ (0.023) | $1.117_a$ (0.045) |
| **LW 4 (week 4)** | $1.694_a$ (0.072) | $1.727_a$ (0.041) | $1.70_a$ (0.044) | $1.702_a$ (0.062) |
| **LW 5 (week 5)** | $2.230_a$ (0.082) | $2.334_a$ (0.087) | $2.323_a$ (0.036) | $2.310_a$ (0.077) |
| **LW 6 (week 6)** | $2.90_a$ (0.107) | $2.901_a$ (0.128) | $2.887_a$ (0.080) | $2.891_a$ (0.137) |
| **LW 7 (week 7)** | $2.50_a$ (1.716) | $2.499_a$ (1.711) | $2.483_a$ (1.700) | $2.465_a$ (1.690) |

[1]Observations for live weight based on weekly individual recordings for bird in each replicate.
[2]Means for live weight calculated from observations of 7 replicates per group with 12 birds per replicate.
[3]Means within a row for replicates bearing the same subscript do not differ significantly (P < 0.05 level).

**Table 3.13.** Feed intake (mg/bird/d) results in broilers exposed to arsenic, bromide and lead in the drinking water over the production cycle.

| Observation[1] | Means & S.D. (mg/bird/day) [2] | | | |
|---|---|---|---|---|
| | Control C[3] | Treatment T1[3] | Treatment T2[3] | Treatment T3[3] |
| **FI 1 (week 1)** | $32.8_a$ (0.804) | $31.2_a$ (4.617) | $32.7_a$ (0.938) | $32.8_a$ (0.810) |
| **FI 2 (week 2)** | $39.4_a$ (4.184) | $37.2_a$ (2.529) | $38.2_a$ (2.480) | $39.3_a$ (3.151) |
| **FI 3 (week 3)** | $105.4_a$ (11.947) | $114.2_a$ (6.664) | $113.8_a$ (3.802) | $115.3_a$ (8.876) |
| **FI 4 (week 4)** | $157.5_a$ (6.249) | $159.1_a$ (4.598) | $152.6_a$ (4.055) | $156.6_a$ (10.222) |
| **FI 5 (week 5)** | $178.6_a$ (10.989) | $186.9_a$ (28.235) | $176.6_a$ (10.614) | $177.5_a$ (6.674) |
| **FI 6 (week 6)** | $162.5_a$ (12.658) | $163.8_a$ (12.452) | $159.5_a$ (13.557) | $163.3_a$ (10.190) |
| **FI 7 (week 7)** | $186.8_a$ (18.775) | $181.0_a$ (9.709) | $181.5_a$ (14.178) | $183.0_a$ (10.192) |
| **FI 8 (week 8)** | $212.5_a$ (18.248) | $211.7_a$ (15.960) | $197.2_a$ (21.049) | $201.6_a$ (14.278) |

[1]Observations for feed intake based on weekly replicate recordings.
[2]Means for feed intake calculated from observations of 7 replicates per group with 12 birds per replicate.
[3]Means within a row for groups bearing the same subscript do not differ significantly (P < 0.05 level).

**Table 3.14.** Water intake (mℓ/bird/d) results in broilers exposed to arsenic, bromide and lead in the drinking water over the production cycle.

| Observation[1] | Means & S.D. (mℓ/bird/day) [2] | | | |
|---|---|---|---|---|
| | Control C[3] | Treatment T1[3] | Treatment T2[3] | Treatment T3[3] |
| **WI 1 (week 1)** | $93_{ab}$ (0.009) | $92_a$ (0.002) | $99_{ab}$ (0.012) | $103_a$ (0.001) |
| **WI 2 (week 2)** | $153_a$ (0.012) | $150_a$ (0.005) | $173_b$ (0.011) | $174_b$ (0.008) |
| **WI 3 (week 3)** | $180_a$ (0.005) | $176_a$ (0.007) | $203_b$ (0.009) | $197_b$ (0.009) |
| **WI 4 (week 4)** | $238_a$ (0.006) | $232_a$ (0.007) | $260_b$ (0.013) | $272_b$ (0.013) |
| **WI 5 (week 5)** | $298_a$ (0.013) | $288_a$ (0.012) | $326_b$ (0.013) | $320_b$ (0.016) |
| **WI 6 (week 6)** | $310_a$ (0.012) | $301_a$ (0.012) | $340_b$ (0.035) | $338_b$ (0.021) |
| **WI 7 (week 7)** | $323_a$ (0.015) | $321_a$ (0.021) | $355_b$ (0.029) | $358_b$ (0.026) |
| **WI 8 (week 8)** | $332_a$ (0.014) | $329_a$ (0.020) | $334_b$ (0.019) | $358_b$ (0.015) |

[1]Observations for water intake based on weekly replicate recordings.
[2]Means for water intake calculated from observations of 7 replicates per group with 12 birds per replicate.
[3]Means within a row for replicates bearing the same subscript do not differ significantly (P < 0.05 level).

### 3.4.3 Discussion

The liver values indicated that although the treatment elevated the concentrations of most of the elements observed, the TDS alleviator treatment trend was a reduction of the concentrations, with the presence of Br in the treatment arguably responsible for the reduced residue concentrations attained in comparison with the first commercial experiment observations. The reduced As concentration in the treatment (0.1 compared to 0.9 mg/ℓ in the first experiment) appeared to be a safe exposure in the context of commercial broiler production, returning values below the MAC of 1 mg/kg DM. In this context, this last experiment indicates the threshold range for tissue accumulation for this type of experimental model and production system (commercial intensive broiler production) for the constituents As and Pb to be 0.1 mg/ℓ to 0.9 mg/ℓ, in the presence of 1 mg Br/ℓ. As similar live weights and feed intakes were observed for comparable groups (non-TDS treatments) as observed in the first commercial trial, health effects linked to potential EDC effects and induced trace element toxicities and imbalances appear to be acceptable within the short exposure period applied to intensive production.

It is thus relevant to not only assess more than single WQC ranges with regard to water quality norms, but also production systems. Based on the results obtained it would appear that the treatment levels applied for this third trial would be acceptable if observed in the rural communal environment in terms of health, production and product quality norms, with the notable prerequisite being similar environmentally controlled housing facilities and quality rations. These findings support the need for rural communities to be provided with adequate facilities with which to implement poultry production, specifically under circumstances that see them reliant on groundwater to provide water for livestock watering.

Tissue comparisons yielded more sensitive results for thigh samples than for breast samples. The trends in both tissue types were the same, however, indicating a positive accumulation as could be expected of the treatment for As, Pb and Br, and however, also for Se and Cr. The alleviator treatment returned promising results for both tissue types, with significantly lower tissue concentrations compared to the treatment observed for thigh tissues, with breast results again following a similar trend. The observation of some significantly lower values for T3 (saline treatment) compared to T1 suggest that the alleviator potential of a volume loaded hypertensive chemical may be significant, but must not be applied in the absence of these key PHCC, as the dynamics of the alleviator treatment may precipitate a marginal deficiency of specifically those elements with a narrow range between essentiality and toxicity, as evidenced by the Se results. An additional perspective, by implication, is that TDS must be considered in the site-specific formulation of water quality guidelines for poultry when present at concentrations exceeding 100 mg/ℓ in terms of potential increases in tolerable ranges of other trace elements.

That the alleviator effect observed for ruminant species extends to poultry is most likely due to the renal portal system of poultry not significantly reducing increased filtration dynamics at the site of glomerular filtration, and filtration speed not being significantly altered with accordingly increased plasma clearance rates of PHCC, despite the lower TDS used (1500 mg/ℓ compared to > 3000 mg/ℓ for ruminants). As discussed with reference to the first two trials in this section, the addition of Br to the treatment in this trial, and naturally occurring Br in the second trial, suggest it contributed to the elevated As levels observed in groups T1 and T2. What is relevant is that further work is needed to assess which of these constituents is the least desirable following cultural food preparation and consumption practices, within exposure scenarios of slaughter based production, as opposed to reproduction based where adverse effects of Br may outweigh any potential benefit.

### 3.5 Summary

An initial experiment confirmed that concentrations of PHCC observed in the subterranean drinking water of rural communities, and utilized for poultry production purposes in Village Poultry Projects, can accumulate to concentrations that exceed the maximum acceptable concentration (MAC) for animal tissues used for human consumption, despite a short exposure period. A second experiment sought to assess these potential hazards within a harsher, less environmentally controlled production system, similar to conditions found in rural community household production systems. This experiment revealed the importance of temperature on elevated intakes, geophagia contributions, a longer exposure period and reduced level of nutrition, on elevated tissue concentrations of PHCC. This experiment also highlighted the need for adequate trace element nutrition to be applied within the context of exposure to PHCC with poorer diets provided, as adverse effects extended not only to product quality, but also essential trace element nutrition. A third experiment demonstrated that an alleviator treatment that had been successful in ruminant species also significantly reduced the concentrations of some PHCC in broiler tissues. This experiment also indicated that a reduced arsenic exposure concentration from 0.9 to 0,1 mg/ℓ may result in acceptable product quality in the presence of high bromide, a frequently observed geochemical anomaly in the rural subterranean groundwater investigated. The experiments demonstrated that prior to commencing with agricultural initiatives that improve food security within rural communities, due consideration to the potential accumulation of PHCC in animal tissues must be given. Furthermore, safe dosages, limiting essential trace elements and safe alleviator treatments can be formulated on a site-specific basis. Applications to a household level and to potential EU export markets also require a site-specific approach.

The central departure point remains a comprehensive water quality investigation in which the relevant norms for the proposed use of the water are investigated, followed by which site-specific risk factors should be assessed in order to most appropriately utilize and manage the available water.

# 4. The testing of an alleviator treatment for potentially hazardous concentrations of selenium in the sheep

## 4.1 Introduction and Motivation

Water quality guidelines have been shown to be inadequate in predicting and preventing problems of chronic selenosis due to their inability to be applicable to different site-specific scenario's (Casey *et al.,* 1998). Factors that may play a role on the Se requirements of animals may include breed, age, physiological status, soil Se content, diet and production system, to name but a few. Previous research conducted for the WRC highlighted several concerns for Se concentrations in groundwater investigated in commercial, rural and wildlife systems due to excessively high concentrations being observed in both drinking water and blood (Casey *et al*., 1998; 2005a; 2005b). An additional concern arose in rural communities as sharing of the same water source between agricultural and domestic uses was frequently observed, and the ingestion of livestock products containing high Se concentrations. Selenium may accumulate in body tissues of humans and livestock, but it is predominantly complex interactions on thyroid function and other elements that appear to pose the greatest threat.

Selenium has many valence states (Miller, 1979) and is involved in different biochemical reactions in different forms, thus its inherent complexity of involvement in metabolic reactions (McNeal and Balistrieri, 1989). It shows variable responses in the presence of nutrients such as Cu, As, S, Mo and Vitamin E (Rosenfeld and Beath, 1964; Diplock, 1970; Georgievskii *et al.,* 1982). Concentrations that are above 0.075 mg/ℓ may be associated with chronic selenosis and if Se intake occurs only from water, then the concentration at which chronic selenosis may occur in beef cattle is 0.7 mg/ℓ (Underwood and Suttle, 1999). As observed in the communities investigated, Se is documented to fluctuate dramatically during wet and dry cycles, and monitoring thereof is usually justified (Plant *et al*., 1996).

Although itself a valuable source of Se, drinking water may contribute to excessive Se exposure when dietary levels are high, as Se is commonly included at high levels in rations and supplements. Selenium in the natural aquatic environment is usually of the selenite (4+) or selenate (6+) forms, depending on oxidation and reducing conditions. Usually, under oxidising or alkaline conditions the more soluble selenate form predominates, as opposed to the more toxic selenite (Plant et al., 1996). Inorganic Se is regarded as being a pro-oxidant, whereas organic forms are noted for their anti-oxidant properties. However, from a toxicological perspective, strong practical evidence of a significant advantage of organic forms over inorganic sources remain unconvincing.

Adverse chronic effects that may be noted include: induced Cu deficiency; disruption of thyroid function; teratogenic effects (reported in pigs, sheep and cattle); cardiac atrophy; erosions of joints of long bones; hepatic cirrhosis, anemia; alopecia (specifically tail region); epidermal hoof lesions (note laminitis lesions are dermal). The pre-ruminant is more susceptible to Se poisoning. Milk does not store Cu to a significant level, and may

not provide sufficient Cu for the suckling calf. Furthermore, the placenta has a blocking effect with regard to Cu. As a consequence, Se toxicity can be involved at a developmental stage.

Several case studies conducted by the project team have found high groundwater Se to be involved with induced Cu deficiency in cattle, Sable and Roan antelope (ARAD, 2004) with endocrine disrupting affects consequently impacting negatively on reproduction parameters. During several of these case studies the diagnosis was confirmed by a response to Cu supplementation via the drinking water, whole blood Se levels and through macroscopic evaluation of the thyroid glands. Selenium is one of the most common elements added to animal feeds and supplements. It is also regarded as one of the most potentially toxic elements supplemented in animal nutrition having a narrow range between requirement and toxicity. Significant variation in forage Se values and feedstuffs in South Africa have also been reported (Van Ryssen, 1996). Although these differences may be influenced largely by soil Se, the contribution to animal Se status via the drinking water and variable relationships between soil and plant types require that all routes be assessed in order assess actual requirements. Given the high values in drinking water observed in the communities investigated and the high incidence of case studies involving adverse effects associated with exposure to high Se in the drinking water, it was decided to investigate means for increasing systemic clearance of ingested Se. This may also be seen to be relevant given the presence of high Br and highly variable iodine values in many of these water sources and complex interactions affecting predominantly thyroid function.

During extensive region testing of an alleviator chemical treatment for fluorosis (ca. 3000 mg/ℓ TDS) at Delftzyl Agricultural Research Station the clinical symptoms of chronic selenosis were notably lower or entirely absent in the treatment cattle. Exposure to groundwater Se concentrations at the research station were usually in excess of 0.1 mg/ℓ, with similar concentrations noted in groundwater in the adjacent Immerpan District in Chapter 2 and previous reports (Casey *et al*., 1998 & 2001a). The results from testing blood Se in these cattle over two seasons are presented in Table 4.1 and indicate a significant reduction in whole blood Se in treatment animals over two seasons. The primary mechanism by which the treatment operates is a volume-loaded hypertension that increases tubular fluid speed through an elevation of glomerular filtration rate and consequently increased renal clearance rates.

Table 4.1 The effects of a saline treatment on whole blood selenium (ng/g) in beef cattle.

| **Groups** | **Means (ng/g) & (SD)*** | |
|---|---|---|
| | **Summer** | **Winter** |
| Treatment (n = 16) | $49.717_a$ (9.343) | $63.559_a$ (12.784) |
| Control (n = 16) | $105.330_b$ (17.181) | $139.684_b$ (15.339) |

* Means within a coloumn bearing the same subscripts do not differ significantly at the $P<0.05$ level.

The aim of the trial was to quantify the effects of total dissolved solids (TDS) in water on selenium status and the resultant effect that it may have on the growth rate and certain production parameters of recently weaned mutton sheep in order to evaluate the potential for water treatment and category allocation as viable means for using groundwater with high Se in rural communities.

## 4.2 Methods

Twenty four Dohne Merino ram lambs were divided into four groups (T1 to T4) using a complete randomised block design where:

TR1 = 0 mg Se/ℓ & <200 mg TDS/ℓ

TR2 = 0 mg Se/ℓ & >3000 mg TDS/ℓ

TR3 = 0.7mg Se/ℓ & <200 mg TDS/ℓ

TR4 = 0.7mg Se/ℓ & >3000 mg TDS/ℓ

Treatments were formulated and prepared in the NutriLab facilities at the Department of Animal Sciences (UP) from AR-grade chemicals using sodium selenite. A 2-week adaptation period was followed by a 10-week treatment exposure period conducted on the Small Stock Section at the Hatfield Experimental Farm (UP) with animals housed in individual open-air pens of 1,5 X 2m with an overhead steel as shade provision. Feed and water were provided on an ad libitum basis. The feed chosen for the trial was lucerne grown in an area known to have a low soil Se (Van Ryssen, pers. Comm.). Three weeks prior to the start of the adaptation period all the sheep were dosed against internal parasites using 7mℓ of the commercial product Prodose Red® and given access to Rumevite Cattle Block® to cater for their mineral requirements. Replensol® was used in cases of diarrhoea to replenish the animal's electrolytes that may have been lost as a result of this condition. Two severe cases of diarrhoea occurred in which Replensol® was dosed in conjunction with an injection of Sulfatrim 240®. Again a week prior to the adaptation period the animals were dosed as above against internal parasites. At this time they were also vaccinated against pulpy kidney. The sheep, at the initiation of the trial, were weaned about a month before and provided with Eragrostis tef hay ad libitum.

Feed (DMI) water (WI) and ambient temperature (Ta) was monitored twice daily (09:00 and 17:00. Several feed samples were collected during the course of the trial with the moisture percentage determined and Se content tested. A 16hr fasting individual live weight was measured at the beginning of the adaptation period, the end of the adaptation period and every three weeks thereafter. Whole blood samples were collected for Se determination a the start of the exposure period and every three weeks thereafter by jugular venipuncture using lithium-heparinised vacutainers. Faecal samples were collected four weeks prior to the end of the trial and on the last day of the trial using faecal collection bags. According to Van Ryssen *et al*. (1992) the amount of Se retained in the animal's body increases in a non-linear and decreasing rate after the commencement of ingestion. The SAS programme (SAS version 8.2, 2001) was used

for all the statistical analyses analysing variance and general linear regression models. An F-test was used to test significance levels using the programme GLM of SAS.

### 4.3 Results

The effect of Se in the drinking water on DMI was significant ($P<0.05$) and more pronounced for weeks 3 to 6. The Manova test (Statistical Analysis Systems, 2001) revealed that the length of exposure of the sheep to the trial conditions had a significant effect on the DMI at $P<0.0001$. Treatments TR2 and TR4 differed significantly for DMI over the entire trial period ($P<0.05$). Significant differences were noted between TR1 and TR3, TR1 and TR4 and TR2 and TR3 (Figure. 4.1) most probably a function of the benefits of Se supplementation towards fulfilling nutrient requirements.

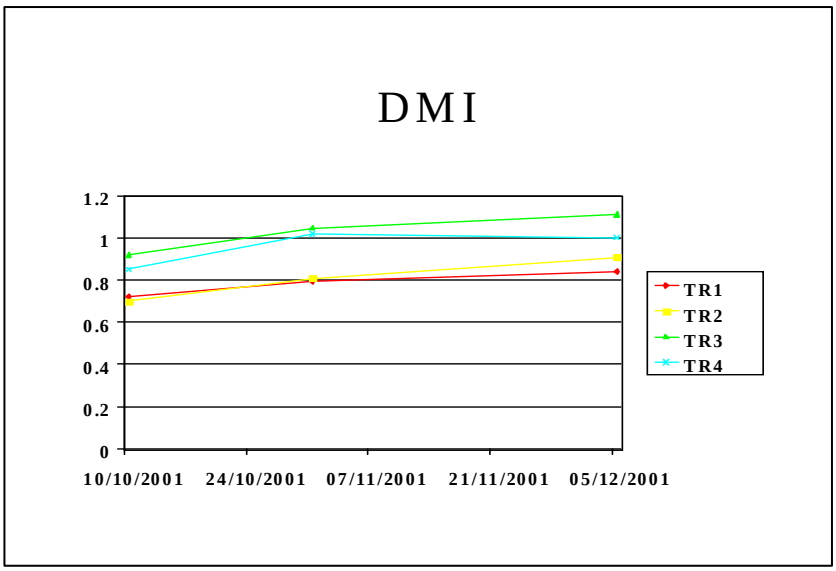


Fig 4.1. Daily dry matter intake (kg) during the exposure period.

Significant differences were noted between groups for water intake (Table 4.2) and these appear correlated to similar DMI increases in accordance with documented positive relationship between these two variables (Ruckenbusch *et al.*, 1991). Elevations in WI for groups receiving high TDS drinking water are a consequence of increased osmotic loading and subsequent osmo-sodium responses. Other Se-related effects on WI increases noted were possibly an indirect consequence of the benefits of Se on nutrient requirements, adequate activation of iodine at the thyroid level, and consequent feed intake responses (Kaneko, 1989). Table 4.2 indicates increasing significant differences between treatments for water intake as the exposure period increases.

Table 4.2 Least squares means and standard errors for weekly water intake (WI) in ℓ between the treatments.

| WEEK | Observations* | | | |
|---|---|---|---|---|
| | TR1 (0 mg/ℓ Se; <200 mg/ℓ TDS) | TR2 (0 mg/ℓ Se; 3000 mg/ℓ TDS) | TR3 (0.7 mg/ℓ Se; <200 mg/ℓ TDS) | TR4 (0.7 mg/ℓ Se; 3000 mg/ℓ TDS) |
| 1 | 12.671 ± 1.622[1] | 16.505 ± 1.622[1] | 16.601 ± 1.622[1] | 14.91 ± 1.776[1] |
| 2 | 14.483 ± 1.923[1] | 19.125 ± 1.923[1a] | 22.425 ± 1.923[a] | 21.39 ± 2.107[3] |
| 3 | 15.79 ± 2.411[1] | 18.056 ± 2.411[1a] | 24.033 ± 2.411[a3] | 26.642 ± 2.641[3] |
| 4 | 16.675 ± 2.134[1] | 16.106 ± 2.134[1] | 23.625 ± 2.134[a] | 26.412 ± 2.337[a] |
| 5 | 17.7016 ± 2.023[1] | 17.838 ± 2.023[1] | 23.68 ± 2.023[1a] | 27.604 ± 2.216[a] |
| 6 | 15.336 ± 1.640[1] | 19.035 ± 1.640[13] | 23.335 ± 1.640[3a] | 26.774 ± 1.797[a] |
| 7 | 15.876 ± 1.682[1] | 19.293 ± 1.682[13] | 24.026 ± 1.682[3a] | 25.716 ± 1.842[a] |
| 8 | 16.811 ± 1.942[1] | 18.06 ± 1.942[1] | 25.286 ± 1.942[a] | 26.216 ± 2.127[a] |
| 9 | 16.4 ± 1.658[1] | 19.901 ± 1.658[13] | 24.258 ± 1.658[3a] | 27.15 ± 1.816[a] |
| 10 | 15.595 ± 2.062[1] | 20.603 ± 2.062[a] | 23.923 ± 2.062[a] | 23.702 ± 2.258[a] |

*Similar superscripts within a row indicate means are not statistically significant at $P < 0.05$.

As noted in Table 4.3 TDS and combined TDS and Se treatments have no significant effect on ADG, whereas time of exposure and the interaction of time of exposure and Se did. Animals receiving Se in the drinking water gained mass more rapidly and with a better feed conversion ratio than those without.

Table 4.3 Least squares means and standard errors for average daily gain (ADG) in grams between the treatments over 3 weekly intervals.

| Interval | TR1 (0 mg/ℓ Se; <200 mg/ℓ TDS) | TR2 (0 mg/ℓ Se; 3000 mg/ℓ TDS) | TR3 (0.7 mg/ℓ Se; <200 mg/ℓ TDS) | TR4 (0.7 mg/ℓ Se; 3000 mg/ℓ TDS) |
|---|---|---|---|---|
| 1 | 65.079 ± 28.838 [a] | 93.651 ± 28.838 [a] | 160.317 ± 28.838 [b] | 192.381 ± 31.591 [b] |
| 2 | 88.889 ± 18.571 [a] | 76.190 ± 18.571 [a] | 73.016 ± 18.571 [a] | 97.143 ± 20.343 [a] |
| 3 | 90.370 ± 19.884 [a] | 123.81 ± 19.884 [a] | 164.762 ± 19.884 [b] | 161.143 ± 21.782 [b] |

*Similar superscripts within a row indicate means are not statistically significant at $P < 0.05$.

Table 4.4 provides the treatment means for the whole blood Se observed, demonstrating the response in blood Se to Se the drinking water and the reduction in association with elevated TDS concentrations. The Repeated Measures analysis revealed a significant period effect ($P < 0.0001$) as well as a combined effect of both the period and treatment. Despite the differences between TR3 and TR4 not being significant, the trend demonstrated suggests a TDS dependant reduction. If the exposure period continued for a similar period as the trial duration, a significant difference between these treatments would be predicted.

Table 4.4 Whole blood selenium results observed between treatments over four sampling points.

| Interval | Observations (ng/g)* | | | |
|---|---|---|---|---|
| | TR1 (0 mg/ℓ Se; <200 mg/ℓ TDS) | TR2 (0 mg/ℓ Se; 3000 mg/ℓ TDS) | TR3 (0.7 mg/ℓ Se; <200 mg/ℓ TDS) | TR4 (0.7 mg/ℓ Se; 3000 mg/ℓ TDS) |
| 1 | 25.97[a] | 28.78[a] | 28.75[a] | 24.17a[a] |
| 2 | 11.9[a] | 18.84[a] | 237.71[b] | 211.28[b] |
| 3 | 12.12[a] | 17.48[a] | 363.7[b] | 337.14[b] |
| 4 | 10.37[a] | 12.24[a] | 441.16[b] | 415.74[b] |

*Similar superscripts within a row indicate means are not statistically significant at $P < 0.05$.

Consistently low faecal Se excretions were observed in the treatments not receiving Se in the drinking water. Between the treatments receiving Se variability in the amount of Se excreted in faecal matter was observed but tended to increase in TR4 as the exposure period lengthened (Table 4.5).

Table 4.5 LS Means and standard deviations of the faecal Se excreted by the SAMM in their respective treatment groups.

| Sampling | Observations (mg/kg DM)* | | | |
|---|---|---|---|---|
| | TR1 (0 mg/ℓ Se; <200 mg/ℓ TDS) | TR2 (0 mg/ℓ Se; 3000 mg/ℓ TDS) | TR3 (0.7 mg/ℓ Se; <200 mg/ℓ TDS) | TR4 (0.7 mg/ℓ Se; 3000 mg/ℓ TDS) |
| 1 | 29,490 ± 284,550[a] | 43,798 ± 284,550[a] | 3014,177 ± 449,914[b] | 1798,705 ± 259,758[c] |
| 2 | 84,262 ± 307,449[a] | 68,296 ± 307,449[a] | 2414,777 ± 486,119[b] | 3939,670 ± 280,661[c] |

*Similar superscripts within a row indicate means are not statistically significant at $P < 0.05$.

## 4.4 Discussion

The treatments demonstrated the significant effects of Se and TDS on several parameters. Predicted elevations in WI occurred between no TDS and TDS supplemented groups, highlighting the important increase in dose ingestion with exposure to high TDS concentrations. This could result in a lower concentration of a WQC being hazardous due to significant long-term increases in intake. However, as the results further indicate should the WQC be the primary source of an essential nutrient then a higher water concentration could be tolerated, and the presence of high TDS may be beneficial with respect to increased intake. The results obtained must be seen in context of the low Se forage provided as Se-deficient areas are known to occur in South Africa. The incorporation of these site-specific factors is necessary to accurately assessing benefits and hazards from water. The results also indicate that inorganic Se administered via the drinking water is absorbed and appears in systemic circulation following hepatic transformations.

Although the effect of TDS on whole blood Se was not as pronounced as observed in beef cattle and most probably attributed to the short exposure period and the relatively low TDS concentration for the experimental model (ovine renal tolerance of high saline diets exceeds that of the bovine), the TDS treatment did indicate the trend of reducing blood values as noted in beef cattle. Greater volume-loading may also occur in non-ovine species due to different locations of osmo-sodium receptors with respect to the blood-brain barrier having a different influence on thirst and renal mechanisms. The location of the experiment also exposed the animals to lower heat-stress conditions compared to those at Delftzyl Agricultural Research Station. The faecal values suggest that late digestive tract osmotic gradients may also play a role with drinking water containing high TDS concentrations. The differences observed demonstrate the need to assess fitness for use of a WQC in conjunction with other constituents present. The lack of clear adverse effects that were Se dependent was expected as the chronic cumulative route typically followed would be unlikely to present to a significant extent within the exposure period used. This emphasizes the benefits and category allocation method that may be applied to enable safe use of potentially hazardous water. The use of short-term exposure, preferably within intensive systems, is a viable option for many rural groundwater sources, with the provisory that the product is fit for use for the target user group. The results obtained should also be seen in perspective of the Se concentration administered, as concentrations greater than the 0.7 mg/ℓ administered have been observed in many rural groundwater sources investigated (Casey *et al*., 1998; 2001a; 2001b).

The use of elevated TDS treatments as an alleviatory mechanism for several PHCC is not necessarily dependent on the addition of chemicals to a reservoir or water sources, but may also be applied in choosing between alternative water sources as many rural villages investigated in this and previous reports were found have naturally occurring TDS concentrations varying between 250 mg/ℓ and 6000 mg/ℓ. Inverse correlations between high TDS concentrations in groundwater and hazardous trace elements have also been reported in previous WRC reports (Casey *et al*., 1998; 2001a; 2001b).

Finally, the presence of other trace PHCC may significantly alter the bioavailability of Se. In several case studies (ARAD, 2004; 2005) induced Cu deficiency was a consequence of high Se in association with other trace PHCC anomalies (notably Br and Pb) and macroscopic thyroid pathology noted in bovine investigations were suggestive of a Se deficiency despite the high blood Se values observed prior to slaughter. The suggestion that the systemic Se was not available was supported by a positive response to both Cu and organic Se supplementation and by excessively high renal cortex values obtained. Table 4.6 provides the observations for tissue values in Bonsmara beef cattle exposed to geochemical anomalies in the drinking water that were linked to gastric hemorrhagic diarrhoea in calves and Se and Cu deficiency in adult animals (Elsenbroek *et al*., 2001). However, the results for the kidney cortex Se concentrations were twice those obtained by Van Ryssen (pers. comm.) in sheep that were supplemented with organic Se at the maximum dietary inclusion rates allowed, and four times that obtained with inorganic Se at the same inclusion rates (6 mg Se/kg DM). Comparison of the

results indicate that, in accordance with the element speciation for Se in groundwater, the high Se exposure via the drinking water may precipitate a complex with Cu that is reflected in the excessively high kidney cortex values, consequently reducing both systemic Se and Cu in terms of physiological availability. The whole blood Se values obtained were suggestive of marginal to deficient status, whilst the kidney Cu values were suggestive of adequate to excessive Cu status. The paradoxic kidney and blood values for Se and positive response in animals to Se and Cu supplementation to several health and production problems highlight the complexity between element speciation and biotransformations that necessitate multiple clinical biochemistry observation points to arrive at a statement for fitness for use of water sources presenting with PHCC and the formulation of appropriate risk management strategies that take into account the differences in route of exposure and element speciation.

Table 4.6 Tissue means and standard deviations for selenium and copper in Bonsmara beef cattle exposed to PHCC anomalies in the drinking water.

| Observations (n = 8) | Kidney Cortex Se (mg/kg DM) | Kidney Cortex Cu (mg/kg DM) | Liver Se (mg/kg DM) | Liver Cu (mg/kg DM) | Whole Blood Se (ng/g) |
|---|---|---|---|---|---|
| Mean | 6466.12 | 23.36 | 686.20 | 166.49 | 56.57 |
| SD | 644.45 | 3.072 | 170.83 | 54.47 | 3.04 |

# 5. AN OVERVIEW OF GROUNDWATER QUALITY FOR DOMESTIC AND AGRICULTURAL USES IN RURAL COMMUNITIES

## 5.1 Introduction

This chapter presents some results from broader comparisons between sample sites presented in Chapter 2 with respect to bovine blood chemistry and results from a collaborative project conducted with the National Department of Agriculture (NDA), Directorate of Water Use and Irrigation Development, Agricultural Risk Assessment Division (Business Enterprises at the University of Pretoria) and the Institute of Soil, Climate and Water of the Agricultural Research Council. The purpose of the NDA project was to investigate rural community groundwater supplies throughout the Republic of South Africa. At the time of writing this report the NDA project was still in progress, consequently not all the data could be included as intended. Comparisons between the NDA and rural communities investigated in Chapter 2 were therefore not feasible, but should appear in a final report to the NDA entitled "Assessing the fitness for use of groundwater for domestic and livestock purposes in rural communities throughout the Republic of South Africa". Those results presented here are provided as a prelude to the related inputs for the model described in Chapter 6.

## 5.2 Methods

The blood collection methods, locations and statistical procedures employed were presented in Chapter 2. The NDA project entailed the collection of new and existing groundwater supplies in rural communities at locations determined by the Directorate of Water Use and Irrigation Development. Plastic sample bottles were prepared using nitric acid as preservative for trace element analysis (separate sample container used for macro elements) at the ISCW and delivered to the relevant project managers at the NDA. Samples were collected using Whatman filter paper (number 42) for trace element determination with GPS coordinates and appropriate borehole numbers recorded. The same analytical procedures were used as described in Chapter 2. The chemistry results and assessment of fitness for use for each sample site for domestic and livestock uses were submitted to the NDA and are available from the Directorate of Water Use and Irrigation Development. For the purposes of this report the results for key selected trace elements were indexed and imported to ArcMap 9.1 and interpolated (inverse distance weighted) using ArcInfo 9.1 to produce the maps presented in this Chapter. In addition to the water quality investigation aspects the purpose for following these methods was to test the feasibility of a standard sampling and analytical procedure used by different working groups for input into the model presented in Chapter 6. A total of 507 sample sites are included in the chemistry results presented but only 472 of these were used in for the indexed figures generated due to outstanding NDA borehole numbers. The chemistry results presented in Table 5.2 below consider only those WQC from the 507 samples that presented as either a COC or a PHCC. An additional 500 samples to be collected by 2007 should form part of the final report to be submitted to the NDA. The maps were generated using the following index values selected to be similar to those employed in the

assessment of domestic water supplies (Quality of Domestic Water Supplies, Volume 1, 1998):

| Index Value | Interpretation |
|---|---|
| 1 | no COC (Ideal) |
| 2 | COC (Good) |
| 3 | PHCC (Marginal) |
| 4 | PHCC (Poor) |
| 5 | PHCC (Unacceptable Risk) |
| 6 | PHCC (Completely Unacceptable) |

The map presenting the total index values consists of the summation of all recorded index values for each sample site (maximum value possible = 114 (6 x 19)).

## 5.3 Results

### 5.3.1 Blood Chemistry

The results for selected trace elements from the following sites are presented in Table 5.1 (refer to Chapter 2 for water chemistry results).

**Table 5.1** Bovine blood chemistry results for samples collected in the Jericho and Immerpan districts.

| **Blood Group Sample** | **Means & S.D. (ug/ℓ)** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Zn** | **As** | **Br** | **Se** | **Sr** | **Cd** | **I** | **Pb** |
| **SC (n = 4)** | $1.891_{abc}$ (0.886) | $0.748_{b}$ (0.637) | $10.366_{b}$ (10.582) | $2.773_{a}$ (3.228) | $0.281_{a}$ (0.150) | $0.876_{a}$ (0.959) | $1.213_{a}$ (0.936) | $0.461_{a}$ (0.622) |
| **BV (n = 6)** | $0.754_{a}$ (0.140) | $5.533_{a}$ (3.066) | $0.135_{c}$ (0.067) | $22.69_{b}$ (18.59) | $0.845_{abg}$ (0.571) | $0.012_{ab}$ (0.012) | $0.004_{b}$ (0.003) | $0.001_{ab}$ (0.001) |
| **RW (n = 24)** | $1.07_{ab}$ (1.181) | $4.854_{a}$ (2.794) | $0.335_{a}$ (0.102) | $60.70_{c}$ (17.87) | $1.465_{c}$ (0.494) | $0.094_{bc}$ (0.127) | $0.007_{b}$ (0.007) | $0.001_{b}$ (0.001) |
| **KBT (n = 24)** | $0.843_{a}$ (0.17) | $5.576_{a}$ (3.487) | $0.188_{d}$ (0.056) | $38.77_{d}$ (15.10) | $0.873_{db}$ (0.318) | $0.150_{bc}$ (0.591) | $0.005_{b}$ (0.005) | $0.001_{b}$ (0.001) |
| **KBP (n = 24)** | $1.043_{ac}$ (0.162) | $6.031_{a}$ (2.238) | $0.226_{e}$ (0.064) | $52.663_{ce}$ (16.973) | $1.171_{eg}$ (0.390) | $0.132_{bc}$ (0.278) | $0.004_{b}$ (0.004) | $0.001_{b}$ (0.001) |
| **FF (n = 24)** | $1.199_{b}$ (0.300) | $5.744_{a}$ (1.507) | $0.378_{af}$ (0.083) | $85.350_{f}$ (18.630) | $2.429_{f}$ (0.462) | $0.060_{c}$ (0.013) | $0.003_{b}$ (0.004) | $0.001_{b}$ (0.002) |

* Means within a coloumn for each element bearing the same subscripts do not differ significantly at the P< 0.05 level.

** Where: SC = Foleysrus Immerpan; BV = Bellview Immerpan; RW = Rooiwal; KBT = Kalkbank Trust; KBP = Kalkbank Private; FF = Fafung 1 & 2.

### 5.3.2 Quality of rural groundwater supplies

A summary of selected inorganic chemistry results obtained from 507 groundwater samples is provided in Table 5.2.

**Table 5.2** Results (mg/ℓ) from water quality constituents recorded as COCs or PHHCs from 507 rural groundwater supplies throughout South Africa.

| Element | Mean (SD) | Minimum - Maximum | Median | 1st Quartile | 2nd Quartile | 3rd Quartile | 4th Quartile |
|---|---|---|---|---|---|---|---|
| **As** | 0.145 (0.239) | 0.008 – 1.056 | 0.020 | 0.010 | 0.020 | 0.181 | 1.056 |
| **Br** | 0.785 (1.928) | 0.009 – 18.426 | 0.216 | 0.118 | 0.216 | 0.595 | 18.426 |
| **F** | 2.963 (2.189) | 0.7 – 16.69 | 1.7 | 1.115 | 1.7 | 3.765 | 16.69 |
| **Fe** | 2.439 (4.950) | 0.023 – 40.44 | 0.715 | 0.036 | 0.715 | 2.135 | 40.44 |
| **I** | 0.711 (1.066) | 0.008 – 6.269 | 0.278 | 0.144 | 0.278 | 0.6 | 6.269 |
| **Pb** | 0.162 (0.531) | 0.003 – 5.411 | 0.035 | 0.022 | 0.035 | 0.074 | 5.411 |
| **Mn** | 0.341 (0.327) | 0.003 – 2.058 | 0.22 | 0.143 | 0.22 | 0.383 | 2.058 |
| **Hg** | 0.245 (0.652) | 0.001 – 2.742 | 0.007 | 0.002 | 0.007 | 0.023 | 2.742 |
| **Mo** | 0.132 (0.306) | 0.008 – 1.673 | 0.036 | 0.015 | 0.036 | 0.115 | 1.673 |
| **Ni** | 0.103 (0.184) | 0.017 – 0.813 | 0.026 | 0.022 | 0.026 | 0.050 | 0.813 |
| **$NO_3$** | 150 (88.14) | 56 – 437 | 115 | 80.5 | 115 | 186 | 437 |
| **Se** | 0.311 (0.670) | 0.016 – 3.069 | 0.036 | 0.023 | 0.036 | 0.070 | 3.069 |
| **Sr** | 0.740 (3.584) | 0.1 – 70.14 | 0.363 | 0.205 | 0.363 | 0.673 | 70.14 |
| **TDS** | 2040 (1267) | 1030 – 6060 | 1589 | 1154 | 1589 | 2637 | 6060 |
| **U** | 0.423 (0.773) | 0.018 – 2.677 | 0.038 | 0.026 | 0.038 | 0.3 | 2.677 |
| **V** | 0.513 (0.252) | 0.108 – 0.86 | 0.545 | 0.342 | 0.545 | 0.727 | 0.86 |
| **Zn** | 1.001 (1.859) | 0.103 – 12.707 | 0.291 | 0.159 | 0.291 | 0.953 | 12.707 |
| **Cd** | 0.415 (0.286) | 0.004 – 0.859 | 0.47 | 0.154 | 0.47 | 0.595 | 0.859 |
| **Cr** | 0.274 (0194) | 0.042 – 0.667 | 0.33 | 0.057 | 0.33 | 0.372 | 0.667 |

The following six figures present the chemistry results obtained from 472 of the 507 samples received in an index format. Figure 5.1 presents the total index for all of these samples, whilst the remaining figures present on a constituent specific basis. Figures 5.3 and 5.5 provide an interpolation for specific sample sites.

## 5.4 Discussion

### 5.4.1 Blood chemistry

The results indicate that significant differences were obtained between blood collected from adult bovines for selected trace elements between the rural communities investigated. These differences must be interpreted in perspective regarding the purposes for risk assessment procedures. The values cannot therefore be taken to indicate trace element status, as aside from varied specific biochemistry required for a clinical approach for different elements, many significant influencing factors are not accounted for (varied nutritional practices, breed differences, physiological stage differences, immune system variation). Within the relevance of water quality investigations pertaining to this report the purpose of collecting a biological sample, such as blood, is to gain an indication of the possible outcome of many site-specific factors with regard to the presence of a potential hazard. As such, the values should be seen as step providing an indication of whether further specific investigations are warranted (e.g. thyroid function tests).

Assessed within this context the results do indicate that the environmental presence at potentially hazardous concentrations in the drinking water of some elements was reflected in the elevated values observed in the blood samples collected (refer to relevant community water chemistry results in Chapter 2). The reverse is also true for some elements, but to a lesser extent, most probably due to the ubiquitous presence of many of the elements in other possible exposure routes (e.g. soil, plant). The elevated values were most noted for the elements Se, Br, I and Sr, and to a lesser extent for Zn. The significance of this is to be found in the central role these elements have in thyroid function with consequent effects on growth, health, reproduction and immune function. Accordingly, these results suggest that obtaining bovine blood samples based on the motivation of groundwater chemistry results is a warranted action. Although additional correlations and interpretations concerning health and mineral nutrition may also be made from the results obtained, the topic is not entirely appropriate for this report and hence not described in further detail here.

### 5.4.2 Quality of rural groundwater supplies

Following the concerns expressed from the results of the rural communities investigated (Chapter 2) and the implications of the experimentation conducted (Chapters 3 and 4) with reference to domestic and livestock norms for water use, the NDA project provided an opportunity to assess the extent of similar potential hazards in other rural communities in South Africa. In this aspect the results indicate that the observations presented in Chapter 2 are not localized anomalies confined to those study areas, but rather appear to be encountered on a widespread basis in rural groundwater supplies across the additional areas investigated for the NDA project. This accords with case study experience in the private and commercial animal sector (ARAD Technical Reports, BEUP) in which animal health investigations have revealed several problems associated with excessive exposure to hazardous trace elements in the subterranean drinking water sources at locations throughout South Africa. The complexities are vast with regards to multiple exposure scenarios with a diagnosis often confirmed by a positive response to supplementation formulated to mitigate these hazards. Within the context of developmental disorders and endocrine disruption, the recognition of trace elements

implicated in epidemiological studies becomes a critical first step in establishing baseline conditions. The results obtained from the NDA project support the findings in previous chapters and indicate a need to apply recognized risk assessment procedures to current and future rural communal groundwater supplies.

As detailed in Chapter 6, a stepwise approach is best followed with water chemistry serving as an initial step to guide additional site-specific sampling. Figure 5.1 demonstrates that many samples present with multiple hazards, as opposed to simply being localized anomalies of a single WQC. Figure 5.2 indicates that certain high priority areas may also be identified from single constituent considerations, in this case for Pb. Having prior knowledge of the occurrence of a geochemical anomaly may assist clinical investigations by providing a better understanding of a possible lack of comparative reference norm. Studies investigating the blood Pb level of school children may provide confusing results if baseline conditions are not accounted for (Matthee, pers. comm.). The Eastern Cape sampling area indicated in Figure 5.2 highlights that groundwater as opposed to petrochemical and/or geophagia may contribute significantly to elevated blood Pb levels in that area.

Although the broad area of concern may be noted, in Figures 5.3 and 5.5 indicate that a more focused approach may be warranted, as spatial variation in groundwater is significant, and key communities within an area need to be identified. The interpolations provided in these two figures may further assist animal-based studies in the assessment of human related epidemiological studies by indicating possible grazing areas also affected – an important consideration within the rural communal grazing systems typically encountered. The additional incorporation of associated elements should also be considered, as demonstrated for Iodine in Figure 5.4, with respect to the Br distribution presented in Figure 5.3. Similarly, the Sr noted in Figure 5.5 would be of assistance in investigating endemic fluorosis and other Ca related problems in the area highlighted. This approach is further supported by the similarity in Se and As anomalies presented in Figure 5.6, and biological sampling from animals in key villages in selected communities from this area may accordingly be identified.

An important component in the application of groundwater chemistry to identify locations (communities and villages) warranting further site-specific investigations is the identification of the environmental and biological sample types required. This is in order to adequately prepare sampling and analytical protocols. To assist this process, groundwater chemistry may indicate significant correlations between constituents that refer to other potential exposure routes requiring investigation not necessarily evident based on groundwater or blood chemistry alone. For the 507 samples evaluated, significant Pearson product moment correlations were obtained for many of the PHCCs obtained. Key correlations observed were between Br and I (0.80), Br and Mn (0.68) and I & Pb (0.82). Further implications would apply to diagnostics and related user norms.

## 5.5 Summary

The use of groundwater chemistry to assist risk assessment procedures is not restricted to those WQC that present as primarily toxic elements. Value is also gained from addressing marginal excesses and induced deficiencies of essential elements. For many trace elements maximum safe levels for chronic exposure are not established. The list of elements regarded as essential is also continuously growing, as is the understanding of the vast complexities between trace elements. For many of trace elements tolerance is less in drinking water to excesses, and furthermore significantly influenced by the concentration of associated elements. Extreme conflicts noted in scientific literature regarding safe exposure levels continue to be appear, often due to the lack of adequately describing baseline conditions and/or applying data correctly (Neathery and Miller, 1977; Vodela *et al.*, 1997; Jacobson *et al.*, 1999).

The results presented in this report for groundwater chemistry further highlight the need to assess risk to human and animal health with appropriate consideration given to the evidence used to estimate exposure routes and dosages relevant to developmental toxicities. In many cases reference material to exposure to the PHCCs and COCs observed in this report is not suited to applications of health relevance in actual exposures, often due to inappropriate experimental exposure scenarios. Difficulties in differentiating between inhibitory, additive and synergistic effects following exposure to multiple hazards also limit the application of laboratory toxicity studies (Komulainen 2004).

Concerns for human exposure to PHCCs have arisen largely due to potential adverse effects on prenatal development and adverse pregnancy and neonatal outcomes. Much of the reference material available for developing guidelines do not account adequately for requirements for developmental toxicity risk assessment procedures. The results presented in this report emphasize the importance of using relevant exposure routes. Key problem areas that remain include the lack of quantitative exposure assessments and failure to account for known risk factors or variables that may affect the outcome of an adverse effect. In this regard the application of the model proposed accounts for the recognition of specialist groups to address these variables, including for example, socioeconomic status and maternal smoking.

In the context of difficulties in selecting appropriate animal models to predict human responses, investigating site-specific variables remains a viable alternative for accounting for species differences. The sampling strategies and risk assessment procedures proposed seek to consider these appropriate aspects when using geochemistry and animal studies to predict risk to humans. Several key aspects may be considered when investigating the application of groundwater chemistry to animal and human uses. These may be summarized briefly as:

- Are background exposures adequately accounted for?
- Do the exposure concentrations and predicted dose magnitudes apply to the risk assessment?

- Is a conservative approach valid with respect to interspecies variation regarding absorption, handling and excretion?
- Can the observations assist in formulating a risk assessment?
- Can the predictions be applied to other similar geochemical anomalies in different areas?

These aspects may accordingly place different emphasis on the focus of specific water user norms, with increasing concern for animal product quality intended for human consumption within rural communities a main observation raised in this report. This aspect is not confined to soft tissues in all livestock species (Alonso *et al*., 2000; Baldini *et al.*, 2000), nor should low sample mass of some tissue types imply low risk. Cultural food preparation techniques, intake frequency, presence of sensitive user groups, and exacerbating risk factors are key considerations for groundwater fitness for use in rural communities.

The targeted sampling in the model proposed accords with the intention of using groundwater quality and PHCC occurrence as a guideline tool for site-specific investigations. This is particularly relevant for animal products in rural communities, not just for consumption is a rural context that is associated with greater risk factors and reduced probability of dietary protection attributed to dilution, but also to meet increasingly stringent export requirements. Concerns of trace elements in agricultural products can be expected to increase, with the ability to apply food safety and food security necessitating an ability to identify relevant areas that may require on-farm investigation when action levels are triggered (Coleman *et al*., 1992). Continued lowering of maximum allowable concentrations due to lower analytical detection limits and increased routine assessments of most trace elements with ICP techniques can also place further pressure to apply more emphasis on the water quality guideline norm of product quality.

In this regard, the model proposed acknowledges the problem area of inter- and intra-laboratory variation (Langlands *et al*., 1988) and hence proposes the use of a single laboratory for reference and detection purposes.

The model proposed has further implications for animal production in rural communities with regard to the management of nutrition (Mohanna and Nys, 1998) and diseases (Yaeger *et al*., 1998). These aspects are of additional relevance with increases in environmental problems associated with intensive animal production systems and the use of a nutritional approach that employs a reduction in trace element supplementation to alleviate risk from groundwater associated excesses, as opposed to the widespread tendency to rather supplement at a level near the upper band of requirements.

The significant contribution of inorganic WQCs to endocrine disruption and carcinogenicity is being increasingly recognized. Accordingly, the PHCCs and COCs noted in this report warrant further investigation due to their role in both these areas. The bromide content of groundwaters observed in this report raises concern regarding the recognized role thereof in the formation of disinfection by-products and endocrine

disruption (Arthur and Beckett, 1989; Chang *et al*., 2000; McDorman *et al*., 2005). Further Br-related implications may be made regarding appropriate water treatment strategies for rural communities and potentially hazardous household water handling practices and may additionally be a source of error when estimating exposures in epidemiological studies (Krasner and Wright 2005). An additional disinfection by-product aspect noteworthy is the application of establishing baseline conditions with regard to Br to the recovery of waters used for potable purposes (Pavelic *et al*., 2005). The anomalous iodine concentrations noted in this report also refer to disinfection by-product formation and to the additional considerations for bicarbonate values with regard to possible strategies to minimize bromate formation (von Gunten 2003).

Within the localized extent of the Br anomalies observed the presence of sensitive user groups (pregnant, breastfeeding and infants) for domestic use and significant developmental insults attributed to excess Br, a conservative approach is warranted to establishing an action level for site-specific investigations. Significant considerations for increases in neonatal iodine requirements are also warranted in light of the adverse thyroid effects and well-documented iodine-deficiency disorders (Pavelka *et al*., 2002; Cozzolino *et al*., 2005). Additional benefits for performing adequate risk assessments may be found in the promotion of greater awareness of key issues affecting the public in water-stressed basins in South Africa (Levite *et al*., 2003).

Case studies conducted (ARAD, BEUP) in livestock and wildlife support the suggestion that induced copper deficiencies and thyroid dysfunction are significantly influenced by groundwater Br concentrations and further investigations to establish safe levels and major trace element relationships are regarded by the researchers as a high priority.

Given the poor understanding of adverse effects following exposure to low concentrations of PHCCs on many of the cellular mechanisms involved, complicated by unpredictable mixture effects, typical of the rural groundwater chemistry presented in this report, the use of biological monitoring and animal studies in a site-specific context provides a feasible method to assess the effects of geochemistry on human and animal health.

# 6. A HAZARD MANAGEMENT MODEL FOR RURAL WATER SOURCES

## 6.1 Introduction

As described in the preceding chapters the observation of PHCC in water used for agricultural and domestic uses was the primary motivation for developing a model that would not only deliver a statement on the fitness for use, but also indicate when site-specific investigations would be appropriate and how to conduct the process. The objective is therefore to address the geochemical anomalies and difficulties in applying primary prevention to community health by using water quality as a departure point, with geochemistry and biological monitoring as indicators for human health hazards. In order to achieve this objective the model must be able to deliver a practical application that enables a cost-effective multidisciplinary approach to identify and propose management options for key water quality hazards in rural communities.

## 6.2 Overview of the proposed model

The primary adverse effects to be dealt with may be considered to originate from constituents that occur as geochemical anomalies that find multiple routes of exposure to human and animal health. These constituents may also be considered to present as anomalies in water, and in so doing be suggestive of similar occurrences in soil and plant material. Although the primary concerns are for naturally occurring anomalies, these exposure routes may also contain anthropogenic contributions and hazardous wastes from numerous sources. In addition, the relationship between the anomalies and water, soil and plant material are complex, and may not be taken to always imply a positive correlation. Changing theories on soil iodine and the occurrence of iodine deficiency disorders (IDD) over the past decade have highlighted the important role of soil characteristics on other environmental expressions of iodine anomalies on human health. The model must therefore not only investigate anomalies that indicate excessive supply following exposure, but also anomalies that suggest deficiencies and/or inadequate supply of essential nutrients may occur. The model proposed must thus function as a management tool, specifically designed for rural communal production systems. The proposed model is a tool for Hazard Management for Rural Water Sources, referred to as HMRWS, and functions as a multidisciplinary effort between groups with specializations and commonalities, within a discreet functioning units that may be linked for various reasons (geographical and technical) referred to as a HUB.

The main components of the HMRWS are:

- A series of parent-child software programs
- A Central Administrator that receives, processes and directs information between five Specialist Groups:
    - Analytical Group
    - Animal Health Group
    - Geochemistry Group

  - Community Health Group
  - Rural Groundwater Implementation and Monitoring Group

The main processes within the HMRWS occur as four phases:

- Hazard Identification Phase (HIP)
- Exposure Assessment Phase (EAP)
- Toxicity and Risk Assessment Phase (TA & RA)
- Risk Management Strategy Phase (RMSP)

The HMRWS objectives are:

- Generic Objectives: For sustained water resource management issues in rural communal agricultural systems.
- Specific Objectives: For community-dependent risk factors that may range from agricultural productivity to safe household food preparation of high-risk agricultural products.

It is suggested that the HMRWS should be implemented on a national scale, but initially commence as a single unit (HUB) that could serve to assess the most appropriate means for future expansion, and may consist of various stakeholders identified on a regional or provincial level. Primary stakeholders are specialist groups, whilst recipients of group outputs vary according to need, and level of application (local or provincial). The stakeholders presented in this chapter should not be seen as prescriptive, but rather as an example of viable working groups. The allocation of various stakeholders to groups is based on the facilitation of processes in the different phases, with flexible involvement in multiple phases suggested. Several protocol specific Research Partnerships may be incorporated where appropriate. A brief description of the major stakeholders in sequence of envisaged phase involvement is provided next:

- HIP; EAP; TA & RA:
- Analytical Group:
  - Laboratory Partners: Institute of Soil, Climate and Water – ARC; Water Chemistry – SABS; NutriLab - UP; Department of Pathology and Department of Chemical Pathology – UP; NHLI; CSIR-Biochemtek.
- Animal Health Group:
  - Community Forums: Joint Education Project / Local and Provincial Extension services / Outreach Programmes
  - Academic and Research Insitutions; / Tompi Seleka Agricultural College; Department of Animal and Wildlife Sciences, Faculty of Natural and Agricultural Sciences & Department of Toxicology, Faculty of Veterinary Sciences, UP; Provincial Departments of Agriculture (Animal Production and Animal Health).
- Geochemistry Group:
  - Research Groups or Consultants: Groundwater Consulting Services; Council for Geosciences.

- Community Health Group:
  - Environmental and Health Office – MRC; Department of Consumer Sciences – UP; International Water Management Institute – Pretoria; Centre for Nutrition – UP; Private consultants.
- Rural Groundwater Implementation and Monitoring Group:
  - Directorate Water Use and Irrigation Development, NDA

- RMSP:
  - The Agricultural Risk Assessment Division at Business Enterprises at UP (Pty) Ltd (ARAD) is proposed as the responsible party for synthesizing the outputs from the preceding phases and should operate as a coordinator between the relevant groups. Linked to ARAD would be the responsible IT-systems administrator and support group. Given the involvement of Incasu (Pty) Ltd in the development of CIRRA it is proposed that this function be allocated to them.

There is a need within these various phases and stakeholders to co-ordinate and manage the overall process including implementation and continuation. A Central Administrator could assume responsibility for these functions. It is proposed that this be performed by ARAD with the collaboration of Incasu (Pty) Ltd. Specifics pertaining to the software programming aspects are largely dealt with in previous WRC reports (Casey *et al.*, 1998; 2001a) and an overview of systems additions required for the proposed model are presented in Figure 6.1. Specific programming required to implement the model will be dependent on institutional IT systems and will need to be performed with each specialist group. Seated at the University of Pretoria, ARAD is well situated to facilitate inter-faculty, inter-departmental and inter-institutional partnership agreements. As such a primary role would be to formalize the model between the responsible groups to facilitate implementation. A key element in the HMRWS model is the identification of individual specialists that function within a specialist group, accordingly, continuance requires the identification of new emerging scientists within the appropriate fields. It follows that the capacity building initiatives provide an input to the continuation strategy of the research team from the Central Administrator implementation function, and that this could be well served by seating this function at an academic institution. Collaborative agreements between UP and other universities could further assist in this role, and could also assist with investigating critical knowledge gaps with reference to low-level, long-term, concurrent multiple hazard exposures in different sensitive user groups. Reasons for this approach are to be found in the multi-disciplinary scientific fields involved. As described earlier in this report the model proposed stems from a need for a multidisciplinary approach to assess and manage groundwater due to the hazards observed in rural water quality investigations, and the HMRWS offers a mechanism for implementing a process that utilizes water quality as a departure point, with geochemistry and biological monitoring as indicators for human health hazards, within a cost-effective multidisciplinary approach, to identify and propose management options for key water quality hazards in rural communities. In order to motivate the design chosen for the model proposed the issue of rural risk assessments pertaining to water quality need to be clarified further. A need exists for measures that not only assess country-specific health

problems correlated primarily to naturally occurring water quality hazards within rural communities, but also acquire sufficient site-specific information to formulate viable actions to reduce risk.

The challenge is thus not to only accurately classify fitness for use within varied user groups under varied conditions, but more specifically to find least risk methods of utilizing the available water resources. Accomplishing this requires the integration of varied specializations within environmental health assessments. Specific challenges relate to trace element specific toxicodynamic and toxicokinetic features with specific risk factors associated with rural communal agricultural production systems and are too specialized for presentation in this report. The specific challenges do however provide insight into the types of critical knowledge gaps with reference to low-level, long-term, concurrent multiple hazard exposures in different sensitive user groups that currently exist with reference to water quality guidelines. The lack of a similar constituent ingestion-based model for domestic uses such as CIRRA, and the multiple domestic uses applicable in the rural context, further complicate the process of addressing these critical knowledge gaps. The process therefore needs to identify geochemical anomalies affecting community health whilst recognizing water quality and rural agricultural risk factors in order to enabling differentiation between necessary and sufficient causation. The proposed process accords with the increasing application of epidemiology to non-infectious diseases, and would be integral to placing health care services in a position where multiple causation aspects can be assessed in order to progress from secondary and tertiary prevention to primary prevention. The specific areas targeted are environmental controls and protection from natural hazards, with the preclinical phase assisted by the quantification of baseline conditions and developmental toxicity.

The model must thus find application to public health issues, specific to rural communities, within the context of water quality related health issues. Although fundamental connections between cause and effect can never be proved, public health ethics demand action to prevent and control adverse health effects even if information is incomplete, or knowledge provisional. The importance of implementing control programmes for public health reasons, correlated to the presence of PHCC in the aquatic environment, follows from the epidemiological definition of community health as “one of the efforts organised by society to protect, promote and restore the health of the population. It is a combination of science, skills and beliefs that are directed to the maintenance and improvement of the health of the people through collective and social action. The programmes, services and institutions involved emphasise the prevention of disease and the health need of the population as a whole”.

The increasing recognition of geochemistry as a valuable component in epidemiological studies, combined with rapid growth in the field of environmental epidemiology, places the proposed program in an ideal situation to manage natural water resources in rural communities across a wide range of objectives, including the norms of health, product quality and environment. These objectives address a common theme of supporting sustained water resource management issues in rural communal agricultural systems, and also address specific objectives to each community with regard to the risk factors present.

Specific objectives may thus range from productivity issues of agricultural programmes from an optimal nutritional supplementation formulation to recommendations regarding household food preparation of high-risk agricultural products. The information derived serves a valuable shared role for many disciplines, with trace element risk assessments providing insight regarding human nutrition, iodine-deficiency disorders and endocrine disrupting contaminants and may allow for decentralised hubs to contribute to a national centralised database.

Communication and collaboration between the relevant fields of the multidisciplinary groups involved is vital and represents an opportunity for potential growth that may benefit agriculture and human health in rural communities. Commitment is not only needed from specialists but also from laboratories for successful implementation on a national basis to occur.

Some of the main epidemiological aspects applicable to the procedures and outputs in the proposed model are:

- **Causation**

The model proposed for this project reflects the importance of the identification of factors involved in the causation of adverse health effects. Through the use of risk factors in the risk assessments performed the model assists in identifying adverse health effects that may occur prior to them becoming clinically evident. The use of water quality as a tool for assessing potential geochemical anomalies affecting community health enables the differentiation between necessary and sufficient causes through the incorporation of PHCC exposure in identifying environmental factors that influence a wide range of toxic effects. The outputs of the model serve thus to increase understanding of host, agent and environment in modelling for multiple causation. As such, the model proposed accords with the increasing application of epidemiology to non-infectious diseases. The assessment of environmental indicators within the recognised classes of community health assist in the defining the relationship between a specific user group health status and environmental factors, particularly relevant to in the rural community context. The format of proposed program stems from the constraints in applying criteria for establishing causation to environmental causes of diseases, and accords with the use of non-experimental studies (observational) investigating causation. The format also follows more of a hierarchical approach, based on a rational appraisal of association, from which temporal relationships pertaining to causation may then be identified.

- **Prevention**

The model is thus aimed at environmental components of causation, and the risk factors identified serve to assist health programmes in developing appropriate interventions to prevent or control adverse health effects. Although serving as an initial starting point, the identification of PHCC provides a platform for increasing the incidence of primary prevention. This multidisciplinary approach is integral to placing health care services in a position where multiple causation aspects can be assessed in order to progress from secondary and tertiary prevention to primary prevention. Although the specific areas of primary prevention targeted are environmental controls and protection from natural

hazards, various forms of pollution may also be incorporated. The quantification of environmental baseline conditions relevant to adverse health effects is particularly useful in the preclinical phase. This is especially relevant in rural communities with respect to developmental toxicity, where affected individuals often depart from the rural community prior to the clinical phase only to present with symptoms in an urban setting later on. This approach accords with the epidemiological point of view that attempts to achieve interventions on as many levels as possible.

- **Adverse health effects**

The model provides health workers with information concerning marginal deficiencies and toxicities in addition to major deficiencies and toxicities. Multiple PHCC interactions that may precipitate either of these situations are also identified. Through this process, clinical data may be viewed more correctly, and additional insight regarding not only causation, but also incidence and prevalence, may be gained. Surveillance systems may become more complete with information regarding PHCC. Outputs from the model may therefore also aid in establishing appropriate adjustment of rates between subgroups. As an integral part of the model is to provide expert-specific information that may be shared, demography objectives may also be supported. In the final instance, the outputs serve to assist the integration of many health indicators as well as the selection of appropriate country-specific health indicators for monitoring purposes.

- **Ethical principles**

The ability of a community to assess the fitness of use of water is very limited. Reasons for this extend to highly toxic elements having little or no effect on aesthetic factors, and the high prevalence of low-level, long-term, chronic toxicity. Choices in how available water is used are often dictated by availability, cultural beliefs, and aesthetic properties that ma bear no correlation to quality. The impact of chronic toxicity is often underestimated due to the lack of clinical signs. The principle of beneficence is the central theme behind the various risk assessment procedures in the proposed model. The generic risk assessment outputs provide information regarding application in terms of ethical principles within the context of health research. Extensions to the specific risk assessments allow for actions from health workers regarding autonomy, and provide substance through relevant risk management strategies that may assist with community consent required for intervention and monitoring actions.

- **Community participation**

The interactions between the broad specialist groups embedded in the model assist community participation within a community development approach. Community participation referred to here implies a social process whereby community working groups are identified that actively take decisions regarding the implementation of risk management strategies, and most importantly, on an increasing basis. The interdependence between community, agriculture and the environment, allow for the different risk assessments performed to address aspects with which the community can identify with in terms of roles and targets. Perhaps more-so than for the other groups, the acquisition of data for the animal health group requires the assistance of advisory services that already have established forums for community participation. Successful application

of the risk management strategies is thus facilitated by the risk assessment procedure. Recommendations should be flexible according to community participation or participatory research objectives. Certain aspects will receive more attention depending on the type of agricultural production system present, for instance, poultry production and food plot projects may receive additional skills development benefits concurrent with risk assessments and risk management strategies. The involvement of existing advisory services and training programmes at agricultural colleges assists in bridging the communication gap that may exist between researchers and communities. The outcomes of risk assessments also identify the primary stakeholders in community health research, for example, inclusion of veterinary public health with respect to animal product quality hazards. As an additional example, the model provides information regarding the impact of PHCC at various stages of animal production that provides qualitative research with key questions of value to forming risk management strategies that may have the maximum beneficial behavioural result in a community. This may apply to a wide range of sub-disciplines, from traditional grazing practices to cultural food-preparation techniques. The involvement of both agricultural forums and Village Water Committees (VWC) are required for appropriate water use implementation.

## 6.3 The HMRWS model

The general process consists of the four phases referred to in section 6.2, with outputs from each phase provide inputs to later stages, and the HMRWS model may be regarded as a process that may occur simultaneously for animal and domestic exposures, separately for each, or sequentially from animal to domestic, but the latter variant should predominate. The application of generic and specific risk assessment modelling presented in previous WRC reports (Casey et al., 1998 & 2001a) is implied within the HMRWS and the reader is referred to those reports for the further detail. What is presented here is a model allowing the HMRWS to address potential hazards in the rural communal context by evaluating their impact on public health through a formal multi-step risk assessment process. Each community is regarded as a separate case, or site, which is assessed on a site-specific basis, for which appropriate steps are recommended.

The objectives are to provide the necessary information at identifiable steps to arrive at a quantitative end point of the risk assessment that may assist in forming management decisions regarding assessing and controlling the hazardous chemicals present. As each risk term is formulated for specific WQC, for each route of exposure, and for all receptor populations, the risk estimates provide public health researchers with a starting point for investigative and descriptive studies, and also assist clinicians with diagnostics. As the process is designed for primarily naturally occurring hazardous chemicals in the rural communal context, an additional evaluation of the rural communal production system is required above classic risk assessment processes pertaining to hazardous chemicals. The effects of water quality in agriculture, in the form of animal and plant production norms, on health of rural communities, receives more prominence in the model due to consequent effects on dietary exposure for sensitive user groups. In evaluating communities at risk from naturally occurring hazardous chemicals, a statement is required regarding an acceptable level of risk. This statement will depend on the

outcomes of the various phases in the HMRWS process that influence current and future predicted hazards. Although ecological risk assessments are applicable, the HMRWS is applied to three primary receptors, namely, animal, plant and human. Special prominence is accorded to the use of animal monitoring to assist in assessing toxicological effects on humans.

Although the assessment process for animal health is complicated due to variability between species, the simultaneous presence of mixed breeds, and the presence of insufficiently described ecosystems, the benefit of utilising the animal model is that biological monitoring may provide a quick cost-effective mechanism for predicting and directing human epidemiological studies. Each of these phases are presented separately, but it should be noted that although specialists within in each group may have specific procedures embedded within each phase that are different to those described here, the general sequence of tasks and objectives remain unchanged. An overview schematic is provided in figure 6.1.

### 6.3.1 Hazard identification phase

This consists of five Hazard Identification Phases, namely HIP-1 to HIP-5, with HIP-5 producing a Hazard Identification Report (HIP-5) that serves as the input and guide for the execution of the Exposure Assessment Phase. Basic objectives are to act as a first step providing information used to decide whether to initiate further source analysis and if so, to then describe the procedures for source evaluation. The phase should also capture information in a manner that enables further use as a case or site record.

The central departure point for this phase is water chemistry, although geochemistry predictions modelling for groundwater chemistry may serve equally well. This process focuses on those hazardous chemicals known to be of concern, but given the uncertainty surrounding many other trace elements those suspected of being potential hazards are also included, as are relatively safe chemicals involved in significant chemical relationships. Although not intended to be prescriptive, the process should provide a hazard score for each chemical by medium, with use of the following equations a possibility:

Medium = water
For non-carcinogens:

$$HS_{ij} = C_{ij}max / RfD_{ij}$$

Where,
$HS_{ij}$ =Hazard Score for Chemical *i* in Medium *j*
$C_{ij}$ = maximum concentration of Chemical *i* in Medium *j*
$RfD_{ij}$ = Reference Dose for Chemical *i* in Medium *j* ($mg/kgd^{-1}$)

A total HS is the sum of all hazardous chemicals in a specific medium according to:

$$HS_j = HSi_1 + HSi_2 + HSi_3 \ldots$$

For carcinogens appropriate slope factors may be applied to arrive at a toxicity value. For those PHCC for which reference doses or slope factors are not available, hazard assessments utilising assumptions (with appropriate models) and safety factors should be utilised. These equations are used to arrive at a Hazard Priority List produced during the HIP-4 phase as an output from the Hazard Risk Assessment – Priority Level 1 (HRA-PL1). This list forms part of the Data Capturing Request (DCR) forwarded to the relevant groups. Prior to utilising these equations a General Risk Assessment (GRA) is performed using CIRRA software (Casey et al., 1998; 2001a). Full detail of the GRA process may be obtained from the relevant WRC final reports as indicated in the introduction of this report (Casey et al., 1998; 2001a; 2001b), but briefly the assessment makes use of concentration-based guidelines utilising known cause and effect relationships to formulate a conservative risk assessment. This is seen as the first step to identifying PHCC as defined earlier in this report. The general detail of this phase is provided in Tables 6.1 and 6.2.

**Table 6.1. HIP 1. Hazard Identification Phases 1 to 4**

| **Components** | **HIP – 1** | **HIP – 2** | **HIP – 3** | **HIP – 4** |
|---|---|---|---|---|
| **Action** | Sampling – S1<br>(Water) | Chemical Analysis CA1 | Data Analysis DA1<br>(A / D / A&D) | Hazard Risk Assessment – PL1 |
| **Procedure** | Water sample acquisition (source, storage, point of use) | Full Quantitative: Macro<br>Semi-quantitative: Trace | CIRRA – Generic | CIRRA – HMS – PL1 |
| **Responsible Group** | Community:<br>Village Agricultural Forum<br>Extension Services<br><br>Researchers/Consultants:<br>AHG / GG / CHG/ NDA | Water Laboratory<br>Partner:<br>Local<br>Central | ARAD | ARAD |
| **Outputs** | Water sample<br><br>Input to HIP – 2 | Chemical Analysis<br><br>Input to HIP – 3 | Generic Risk Assessment<br>- A<br>- D<br>- A & D<br><br>Input to HIP - 4 | 1) **Hazard Priority List – AHG & / CHG:**<br>PHCC & COC<br>TOE<br><br>2) **Data Capturing Request**:<br>2.1) GG<br>2.2) AHG<br>2.3) CHG<br><br>3) **Database Entry** |

Where: AHG = Animal Health Group; GG = Geochemistry Group; CHG = Community Health Group; NDA = National Department of Agriculture; ARAD = Agricultural Risk Assessment Division; A / D = Agricultural, Domestic; PL = Priority List; TOE = Types of Effects

**Table 6.2. HIP 2. Hazard Identification Phase 5 variants**

| **Outcome** | **No PHCC / COC (A & D)** | **COC only (A &/ D)** | **PHCC &/ COC (A & D)** | | |
|---|---|---|---|---|---|
| **Action** | Database Entry | Monitoring Request (MR): HIP 4 GG MR | Data Capturing Request:<br>HIP 4 GG | Data Capturing Request:<br>HIP 4 AHG | Data Capturing Request:<br>HIP 4 CHG |
| **Procedure 1** | Field Entry | DCR (HIP 4 GG MR) | DCR (HIP 4 GG) | DCR (HIP 4 AHG) | DCR (HIP 4 CHG) |
| **Responsible Group** | ARAD | ARAD | ARAD | ARAD | ARAD |
| **Input** | | Supporting Document Request Field | Supporting Document Request Field | Supporting Document Request Field | Supporting Document Request Field |

| | | | | | |
|---|---|---|---|---|---|
| **Procedure 2** | | DCG – GG - PL1 MR | DCG – GG - PL1 | DCG – AHG - PL1 | DCG – CHG - PL1 |
| **Responsible Group** | | GG | GG | AHG:<br>ARAD | CHG:<br>MRC / NHLS / EDG / LCS |
| **Output** | Database entries | Desktop Study (Spatial; Predicted fluctuation; associated elements)<br><br>Monitoring Guide – Water | Desktop Study (Spatial; Predicted fluctuation; associated elements)<br><br>Sampling & Monitoring Guide – Water & Soil & Speciation | Sampling & Monitoring Guide –<br>Water<br>Soil<br>Plant (Grazing & Crop)<br>Tissue (Type I & Type II) | Sampling & Monitoring Guide – Interviews<br>Clinical Data / instruct<br>Samples |
| **HIP 5 Results** | Site/sample case created | ARAD – HIP 5 Report | ARAD – HIP 5 Report | ARAD – HIP 5 Report | ARAD – HIP 5 Report |

Where :MRC = Medical Research Council; NHLS = National Health Laboratory Services; EDG = Endocrine Disrupting Group; DCS = Local Community Services; Tissue Type I = Blood; Tissue Type II = specific tissue samples.

### 6.3.2 Exposure assessment phase

This phase consists of several Exposure Assessment Phases (EAP-1 to EAP-5), the final stage of which produces an Exposure Assessment Report – Priority Level 2 (EAP – PL2) that serves as the primary input to the Toxicity and Risk Assessment Phase. Basic objectives are to substantiate and describe the hazards observed, involving populations, pathways, concentrations and intakes, with information gathered regarding the magnitude, frequency, duration, and route of exposure to hazards identified. Additional objectives are to formulate appropriate monitoring programmes and, similarly to the HIP, capture information in a manner that enables further use in the form of a case or site record.

The purpose is thus to assess the hazards identified in terms of estimating the concentrations, forms and dosages that may place the user groups at risk. Phases utilised assess potentially exposed user groups (animal and human – including subgroups of these), potential exposure pathways (water, animal product, plant, soil), estimate hazard concentrations and speciation, and estimate ingestion values. The central two processes involving pathways and concentrations expand on results from the HIP in the form of addressing aspects such as chemical release mechanisms, transformations (groundwater and biotransformation) and transport. Point of use concentrations in relevant mediums are also assessed for ingestion estimates. Site-specific information (samples, community description and interviews) is required to characterise receptor populations (land use, household consumption patterns, traditional cooking practices). The use of GIS systems may also assist this phase to assess the extent of a geochemical anomaly within an area and the resultant communities affected. The output from this phase is required to estimate toxicity and to characterise risk in the following phase.

General mean exposure intake for the hazards identified may be incorporated to the following general equation, applicable to drinking water:

$$I = (CW \times IR \times EFD/BW) X (I/AT)$$

Where,

I = intake (normalised for body weight)
CW = exposure concentration (water)
IR = ingestion rate per unit time
EFD = exposure frequency and duration (days/y and years)
BW = average body mass during exposure period for user group
AT = average time of exposure

Additional estimates may be performed for food and soil ingestion. The use of either reference tissue concentrations or maximum acceptable concentrations may be applied to assess the fitness for use of agricultural products and should ideally also include the effects of cultural cooking practices. The concern for bioaccumulation is not limited to agricultural products from community projects or household production, but should also extend to include aquatic organisms where appropriate. Estimates of background concentrations and exposure routes need to also be included. Case-specific consumption factors may vary significantly between villages within the same community and also need to be assessed. The general detail of this phase is provided in Table 6.3.

**Table 6.3. EAP 1. Exposure Assessment Phases (EAP)**

| **Components** | **EAP –1 (SSS)** | **EAP – 2** | **EAP – 3** | **EAP – 4** | **EAP – 5** |
|---|---|---|---|---|---|
| **Action** | Sampling – S2<br>Water (AHG/ CHG / GG)<br>Soil (AHG / CHG / GG)<br>Plant / Crop (AHG / CHG)<br>Animal: Type I + Type II (AHG) | Chemical Analysis CA2<br>Pathology Examination | Population Assessment<br>Intake Assessment<br>Pathway Assessment | Data Analysis DA2<br>(A&D) | Exposure Assessment – PL2 |
| **Procedure** | Sample acquisition | Chemical Analysis (sample specific)<br>Pathology (sample specific) | SUGA (AHG / CHG)<br>ECI (AHG / CHG)<br>PA (GG) | CIRRA - Specific Risk Assessment | CIRRA – HMS – PL2 |
| **Responsible Group** | Community:<br>Village Agricultural Forum<br>Extension Services<br><br>Researchers/Consultants:<br>AHG / GG / CHG | Relevant Laboratories | Community:<br>Village Agricultural Forum<br>Extension Services<br><br>Researchers/Consultants:<br>AHG / GG / CHG | ARAD | ARAD |
| **Outputs** | Relevant samples<br><br>Input to EAP – 2 | Concentrations & exposure estimates & Causation Validations<br><br>Input to EAP – 4 | Assessments required for EAP – 4 | Specific Risk Assessment<br>- A<br>- D<br>- A & D<br>- Input to EAP - 5 | 1) **Exposure Assessment** Animal & Domestic<br><br>2) **Monitoring Guide**<br><br>3) **Database Entry** |

Where; SSS = site-specific sampling; SUG = Sensitive User Group; ECI = Epidemiological Community Investigation; PA = Pathway Assessment.

The HIP and EAP phases provide inputs to Toxicity and Risk Assessments. These include statements regarding subclinical, latent, and chronic health problems expected for further specialist group investigation.

### 6.3.3 Toxicity and risk assessment phase

The Toxicity Assessment (TA) portion of this phase consists primarily of evaluating the outputs of the previous HIP and EAP and formulating the Data Acquisition Requirements (DAR) required. It is important to note the EAP provides statements on subclinical, latent, and chronic health problems for the AHG and CHG to provide focus in terms of examination of biological tissues obtained for epidemiological investigations. Subsequent histopathological, chemical pathology and diagnostic reports assist in evaluating clinical evidence that may exist for communities. This is done in the form of an Evaluation of Toxicity (EOT), and is the primary output of the TA. The Risk Assessment portion of this phase is primarily required where reference doses and slope factors are not available. This often represents the primary obstacle to risk characterisation in rural communities with regard to water quality, and the use of animal biological monitoring (*in situ* evaluations) to substantiate hazards and risk. Development of the DAR for the CHG is the major benefit of the HMRWS process.

Basic objectives are to evaluate the effects of the hazards observed on user groups present and to formulate appropriate monitoring programmes. The risk assessment (RA) portion utilises the DAR to identify risk assessment end points that may relate to growth, metabolism, health or reproduction. Appropriate methods may be proposed by the relevant specialist groups, and may range from analytical detection to bioassays. Hazard indexes should be used where applicable. Although an obviously complicated phase, the TA and RA sequence may be summarized as:

**TA** (input from HIP & EAP) = **DAR** = **EOT** (input from DAR)
**RA** (input from EOT) = Final statement of calculation of risk

### 6.3.4 Risk management strategy phase

The RMSP is central to achieving safe use of available water sources, with the emphasis on increasing primary prevention, and consequently addresses the following aspects with an integrated approach through three steps (RMSP-1 to RMSP-3):

RMSP – 1: Formulate Strategy for:

- Water Resource Management
- Land Resources Management (Animal, Pasture and Crop Production)
- Health Indicators

RMSP – 2: Implement Strategies.

RMSP – 3: Monitor implementation.

Each RMSP phase will be community specific and as such may involve public health approaches to community development. Where possible participatory research should be encouraged with the relevant stakeholders assuming the responsible role applicable to the specialisation targeted. Although it is tempting to develop a fixed procedural guideline for these steps, the complexities specific not only communities, but also villages within communities, would negate much of the benefits thereof. It may be that following implementation of the model in several communities some standard guidelines may be developed for each of the five groups.

There are two variants to this phase. The first variant is applicable to the process described in this chapter with reference to existing groundwater sources. The second variant concerns the provision of new groundwater sources and requires some adaptation in the process as some site-specific data may not be available. It is proposed that the various projects currently being conducted by the Directorate Water Use and Irrigation Development at the NDA be incorporated as viable starting points for adaptations of the model as the current provision of new boreholes presents an ideal opportunity to apply most appropriate user group allocation for domestic and agricultural uses.

### 6.4 Component relationships and implementation

As described earlier, the HMRWS process functions as a multidisciplinary effort between five groups with specializations and commonalities catered for, with a discreet functioning unit referred to as a HUB. Specific stakeholders presented here are applicable to the Gauteng HUB and serve as an example of a working multidisciplinary effort and not meant to be prescriptive apart from the general roles played by each group. As the central requirement to risk assessment modelling is a software environment, the process is managed by a Central Administrator that may reside as a separate entity, or whose responsibilities may be assumed by one or more groups. Although there are subgroups, the Central Administrator receives, processes and directs information to the five main groups. In this example the role of the Central Administrator is assumed by the Animal Health Group. Reasons for this are primarily related to the pivotal role of animal risk assessment modelling and biological monitoring in assisting the public health stakeholders and in proposing best rural communal agricultural practices. Input on a technical service level to the Central Administrator function may be provided by an Internet Service Provider, or any suitably qualified entity. In this example Incasu (Pty Ltd) assumes these functions primarily due to the involvement of the company in the programming of the risk assessment software utilised. Although the primary stakeholders are the specialist groups, recipients of each group outputs may vary according to need, and level of application (local or provincial). Institutional arrangements and ownership in addition to the agreements already achieved in principle during various stakeholder consultations will thus be dependant on the specific need and application.

As previously stated, the development of a functioning HMRWS – HUB involves the integration of multidisciplinary specialist fields from several different institutions. The basic architecture of the information relationship fields were presented to various members of these groups, and the proposed model in this report is a consequence of numerous inputs from those groups. The processes in the HMRWS – HUB model all consist of stages of interactive involvement spanning researchers to community members. All groups with designated responsibilities in the HMRWS – HUB share the common dual objective of addressing public health issues in a collaborative environment. Acknowledgment of the central role of water quality in rural community health, and as an initial step to quantifying baseline conditions required for community epidemiology, was accepted by all the stakeholders, as is the urgency required to implement a system that may prevent and manage natural hazards that impact on developmental toxicities in rural communities.

It is proposed that the model be implemented through the following steps:

- **Model placed online for a functioning HMRWS-HUB:**
  - Completion of Specialist Group key stakeholder member association agreements for HMRWS-HUB –Gauteng addressing:
    - Objectives of association.
    - Required Procedures from members for each HMRWS Phase.
    - Required Actions from members for each HMRWS Phase.
    - Required Responsibilities from members for each HMRWS Phase.
  - Following completion of the association agreements specific hardware, software and IT infrastructure characterisation should be completed, allowing for final development of the software tool (HMRWS – HUB-Gauteng) in terms of the administration programme, database design and information flow catering for each Specialist Group requirement.
  - Loading of relevant Clarionet programmes for key stakeholders of each Specialist Group.
  - Linking of Specialist Groups to Central Administrator.

- **Completion of HMRWS Phases in three separate communities:**
  - A minimum of three case studies in three separate rural communities in which all four phases of the HMRWS are completed.
  - Community Participation Agreements with each community.
  - Identification of appropriate post-graduate candidates for Capacity Building Initiatives from each Specialist Group in which the critical knowledge gaps can be addressed.

- Necessary amendments to agreements, procedures and model as identified by Specialist Groups and Central Administrator during quarterly review sessions.

- **Continuance and Handover of functioning HMRWS-HUB:**

  - Formalisation of procedures relevant to community participants, with identification and training of community participants as required.

  - Identification and training of appropriate candidates for Capacity Building Initiatives for each Specialist Group and Central Administration function to allow the research team to handover a functioning HMRWS-HUB.

  - Yearly review session to amend, improve and expand the HMRWS.

In order to assess the feasibility of this planned implementation presentations were made to identified specialists and institutions that were regarded as being essential components with the following main outcomes:

- The SABS (Inorganic water division) and ISCW (ARC) have agreed to accord the researchers specialist advisory status regarding agricultural risk assessments. A working channel has been formalized that forms a key transfer of input required for the priority 1 level within the software design.

- The development and implementation of the Agricultural Risk Assessment Division (ARAD) at the Business Enterprises at the University of Pretoria (Pty Ltd) has been completed. This is an inter-Faculty mechanism for housing the Central Administrator function as described for the HMRWS-HUB. This provides a formal, 100% UP owned, mechanism for administrating core disciplines within the UP, and between the UP and collaborating partners and stakeholders in the HMRWS model. ARAD has been operational since mid-2003 and was project leader for the NDA Groundwater quality project presented earlier in this report.

- In principle agreement and collaboration with the Medical Research Council (MRC - Environmental and Health Office) for community health investigations relating to heavy metals.

- Areas have also been identified in which certain aspects of the model can directly assist the WRC Endocrine Disrupting Contaminants Program with reference to inorganic constituents.

- Discussions have been completed in terms of collaboration between the WRC, ARAD, and the International Water Management Institute (Pretoria). The IWMI has indicated they are prepared to:

- Engage in generic and specific risk assessment approaches in areas in South Africa (and later Africa) regarding health aspects relating to integrated water resources management in communities currently being addressed by the WRC and IWMI.
- Provide funding for a suitable post-graduate student from the Department of Animal and Wildlife Sciences (UP) in terms of their stated commitment to capacity building.
- Provide an already identified suitably qualified capacity building candidates engaged in IWMI research in Africa, with funding, for registration for a PhD at the Department of Animal and Wildlife Sciences (UP).

Many individuals have been identified throughout this process and although in reality the model needs to be driven by individual persons, successful functioning requires institutional commitment. Although not presented here, a working relationship between relevant government departments is seen as critical to ensuring a meaningful contribution can be made by the proposed model. A schematic overview is provided is Figure 6.1.

In many aspects the model is already in operation through numerous case studies that ARAD conducts in association with specialists in the private sector, including clinicians and veterinarians. Several common trends are experienced in these investigations, such as the inappropriate collection of inadequate samples, and the need for appropriate centralised animal clinical biochemical reference material. Another disturbing observation is the failure to consider adverse health effects on domestic users also exposed to the same potential hazards as the animals being investigated.

The current reality for the communities investigated for this report is that groundwater classified as potentially hazardous and/or completely unfit for use by animal and domestic users is still being used for these purposes, and continues to be a significant water source. The effect of groundwater quality on the relationship between the fitness for use of animal products, various additional affected exposure routes and community health is of serious concern for both household consumption and community agricultural projects. These concerns are promoted by the irreversible developmental insults characterised for many of the constituents involved and firmly place responsibility on the various specialist fields to proactively seek to reduce the risk as much as possible, as opposed to simply complying with upper threshold limits. In contrast to endocrine disrupting effects that are currently receiving much attention, the physiological significance and clearly established cause and effect relationships following exposure to the majority of potentially hazardous chemical constituents presented in this report are known and accordingly warrants research attention.

FIGURE 6.1.

# 7. GENERAL CONCLUSIONS AND RECOMMENDATIONS

## 7.1 General conclusions

As the technical discussions of the following points are presented in the relevant chapters in this report, only the primary aspects are considered here.

Groundwater provides an essential and, in the majority of instances a critical, water source for households, villages and communities in the rural areas investigated.

Groundwater is used for the recognized norms of domestic, animal and irrigation uses, varying from household subsistence to semi-intensive agricultural production systems in these communities.

The majority of the groundwater quality assessments in the rural communities observed water quality constituents (WQC) to be present at concentrations exceeding the upper limits for safe use, in terms of local and international water quality guidelines, both for domestic (human) and animal uses.

Water quality constituents observed at concentrations that exceeded the safe limits for use were designated as potentially hazardous chemical constituents (PHCC) as site-specific factors may alter the final outcome of effects following exposure. Constituents of concern (COC) were identified as WQCs that may conceivably become PHCCs due to the stochastic nature of the WQCs.

Both multiple PHCCs and COCs were noted for the majority of rural groundwater samples investigated, with PHCCs exceeding recognized guidelines by several orders of magnitude for several communities. Primary PHCCs noted were bromide, selenium, lead, cadmium, arsenic, iodine and fluoride, with the primary COCs noted being strontium and iron.

The implication thereof is that groundwater quality was found to pose a significant risk for both domestic and animal user groups in the communities investigated.

This leads to the following problem statement:

“Is groundwater chemistry assessed comprehensively, to a sufficiently satisfactory degree from a scientific perspective, prior to allowing access for domestic and animal uses in rural communities?”

The evidence presented in this report suggests that the answer to this problem statement is “No.”. The evidence presented in this report suggests further the primary hazards relate predominantly to trace elements as opposed to the more routinely observed macro elements. This observation accords with the growing recognition worldwide given to the role of trace element geochemistry in health and production related adverse effects.

Due to the complexity of element-element interactions, exposure to other hazards via different and simultaneously multiple routes, sensitive user group differences and other dose-related variability, a risk assessment is required in order to establish the probability of an observed potential hazard becoming a risk. This approach accords with basic environmental toxicology procedures.

The presence of PHCCs and COCs thus indicates a potential hazard and should be seen as an action level indicator to which site-specific investigations regarding risk be undertaken.

Hazards were found to present not only as direct toxicities, but also as induced deficiencies. Furthermore, the PHCCs and COCs notes are recognized as being involved in developmental disorders, many of which are irreversible. Endocrine disruption and carcinogenicity have also been demonstrated for them. Of additional concern is the role of these PHCCs and COCs in iodine-deficiency disorders.

Due to the low level, chronic and often subclinical route followed by many of these PHCCs and COCs, proactive primary prevention is required. It follows that detection, monitoring and risk management strategies are all required in order to allow for safe and optimal use of groundwater in rural communities.

The complexity and multidisciplinary fields relevant to assessing hazards and risk from geochemical anomalies require a collaborative effect to assess the fitness for use of groundwater in rural communities. In order to facilitate this experimentation was conducted in conjunction with site-specific rural community investigations in this study. The purpose was primarily to develop a formal procedure for detection and consequent site-specific investigations that could assess the risk posed. These studies noted:

- Concern for adverse effects for the recognized norms for domestic and animal uses.
- Concern for the fitness for use of animal products for human consumption within the context of usage in rural communities.
- Concern for the compliance of animal products with export criteria produced in rural communal agricultural production systems.
- Positive correlations between groundwater chemistry and environmental and biological samples.
- Complex multiple element-element interactions between different elements and routes of exposure and dosages.
- Potential alleviator treatments for some of the main PHCCs and COCs observed.

These led to the conclusion that a model needed to be developed and proposed as a mechanism for addressing the occurrence of PHCCs and COCs in rural groundwater supplies.

Concerns for the extent to which problems observed in the selected rural communities may occur elsewhere were addressed by a parallel study conducted in collaboration with

the National Department of Agriculture and Agricultural Research Council. The findings of over 500 groundwater supplies demonstrated a similar pattern to be present in terms of PHCCs and COCs, including specific elements and concentration ranges noted.

## 7.2 Recommendations

- Following a collaborative and participatory approach, a model was developed and is presented in this report. Major stakeholders and individual participants indicated a strong interest to participate in the implementation thereof. It is therefore the primary recommendation of the researchers that the model proposed be implemented at detailed in this report. This approach is seen as integral to fundamental epidemiological principles applicable to human and animal studies. The role of groundwater in assisting the diagnostic and clinical interpretations for diseases and disorders should be seen as an opportunity to not only accurately assess the consequences of exposure, but to also provide valuable assistance in the human health and agricultural sectors.

- All water quality investigations of relevance to the recognized norms for domestic and animal use should perform adequate comprehensive analytical procedures that allow for the determination of a full range of inorganic water quality constituents, from arsenic to zinc. Due to cost restrictions semi-quantitative ICP techniques are recommended as a first level generic assessment prior to full quantitative assessment of key constituents. Failure to do so negates the possibility of a study assessing fitness for use as a significant deterministic component is omitted. Failure to do so also results in an adequate description of baseline conditions and merely serves as a source of significant error in statements that may arise from cause and effect investigations regarding water quality.

- The presence of the specific PHCCs and COCs in rural groundwater supplies presented in this report should be seen as worthy of receiving urgent attention on a National scale. The potential for *in utero* and neonatal insults suggest that a conservative approach be adopted.

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