VOLUME 2

AN EXTENSION TO AND FURTHER REFINEMENT OF A WATER QUALITY GUIDELINE INDEX SYSTEM FOR LIVESTOCK WATERING

POULTRY PRODUCTION SYSTEMS AND WATER QUALITY FOR OSTRICH PRODUCTION

NH Casey • JA Meyer • CB Coetzee

WRC Report No 857/2/01

Water
Research
Commission

AN EXTENSION TO AND FURTHER REFINEMENT OF A WATER QUALITY GUIDELINE INDEX SYSTEM FOR LIVESTOCK WATERING

VOLUME 2

POULTRY PRODUCTION SYSTEMS AND WATER QUALITY FOR OSTRICH PRODUCTION

by
NH Casey, JA Meyer & CB Coetzee

Department of Animal and Wildlife Sciences

University of Pretoria

Volume 2 of a report to the Water Research Commission on the Project:
"An extension to and further refinement of a water quality guideline index system for livestock watering"

Project Leader	:	Prof NH Casey
Principal Researcher	:	Dr JA Meyer
Researcher	:	C B Coetzee
WRC Report No	:	857/2/01
ISBN No	:	1 86845 714 1
ISBN Set No	:	1 86845 715 X

EXECUTIVE SUMMARY

An extension to and further refinement of a water quality guideline index system for livestock watering

by

NH Casey and JA Meyer
Department of Animal and Wildlife Sciences
University of Pretoria

1. BACKGROUND TO THE STUDY

This is the third WRC project addressing water quality guidelines for animals and presents risk assessment modelling for three new user groups, namely, rural communal livestock production systems, wildlife and poultry production systems.

The growth and development of this research field has taken place over a number of years. An initial brief was obtained from the WRC in 1990 with the request to verify criteria for beef cattle utilising subterranean sources along the North and North Western border regions of South Africa. Other livestock types were subsequently included, and in the Final Report: K5/301, the guidelines then in use were shown to be inadequate and result in inaccurate estimates of risk. Through biological toxicological trials using sheep, cattle and poultry, it was shown how single value cut-off limits were poor indicators of risk under the majority of conditions, and often resulted in the limitation of efficient water utilisation. These trials indicated that animals could be exposed to highly toxic water quality constituents (WQC), far in excess of the guideline ranges, for specific production periods (weaning to market weight), without incurring any adverse effects on growth, health or performance. It was also shown how the omission of palatability effects by the guidelines could lead to financial losses for the livestock producer.

A second WRC project, K5/644, through further biological experimentation, extensive region trials, and modelling, delivered a computer software program called CIRRA, an acronym for Constituent Ingestion Rate Risk Assessment. CIRRA conducts site-specific risk assessment based on the modelling of risk factors from water, animal, environmental and nutritional data, to generate both risk assessment and possible solution options. This is based on a constituent ingestion rate, in mg/d/kg BW, corrected for metabolic water. This represents a radical departure from existing static tabulated guidelines which are all independent of production system effects, nutrition, environmental and animal factors, and appear in the form of a mg/L guideline recommendation. CIRRA caters for beef cattle, dairy cattle, goats, sheep, pigs and horses, in the commercial context.

Through the outputs of these two WRC projects, two guideline editions for livestock watering emerged for the Department of Water Affairs and Forestry, one in 1993, and a second in 1996. These are, however, still largely generic guidelines. As they appear in a tabulated format, utilising a target water quality range concept, they fail to accommodate significant site-specific toxicokinetic and toxicodynamic factors, rendering their application to a conservative, at best generic, estimation of risk. It is recommended that the WRC Report No 644/1/98 is read prior to this report, as it contains much of the scientific basis for the models described in this report.

2. PROBLEM STATEMENT AND STUDY OBJECTIVES

2.1 Rural communal livestock production systems (RCPLS)

As described in previous reports (K5/301; K5/644) many local subterranean water supplies exceed local and international guidelines by large margins. By virtue of the mg/L design, current guidelines do little more than alert users to the possibility of adverse effects occurring, at times arguably being overly conservative in estimation, a necessity brought about by safety factors incorporated due to the reliance on mg/L guidelines independent of the environment. The benefit of developing a risk assessment tool capable of a multidisciplinary approach, is that it allows for the incorporation of mutually antagonistic factors which may effectively allow for the safe use of water containing constituents in excess of the guideline limits.

CIRRA, as developed for commercial systems, provides risk assessments and solutions that are specific for livestock type, breed, production-category, and production-environment. A solution may be proposed by CIRRA to reduce both the severity of fluorosis, and adverse palatability effects of saline water, for non-pregnant Dorper ewes, weighing 55 – 60 kg, fed a maintenance ration under semi-extensive conditions. Whilst this approach is necessary for an accurate risk assessment, it is not appropriate for RCLPS, nor does it find application for WPS. Two primary reasons are the utilisation of a single watering point by multiple livestock species, and mixed breeds, and the lack of identifiable production-category detail within a herd/flock as an input variable.

Important complicating factors arise due to the association between the animals and humans. This became apparent whilst investigating the feasibility of applying alleviator treatments, used to reduce fluorosis in beef cattle under extensive conditions at the Delftzyl Agricultural Research Station, under RCLPS in the adjacent communities.

Important observations made in the communal areas were that the water source tended to be shared by both humans and animals, and that products from these animals formed a large part of the human diet.

The research conducted under WRC Project K5/644 formulated, and implemented, under extensive on-farm conditions at the Delftzyl Agricultural Research Station, an alleviator treatment for fluorosis in cattle. The following advantages and disadvantages apply:

Advantages: Easy administration of treatment
No trained technician required
Cheap cost of chemicals and equipment used
No brine to be removed
Can adapt stock incrementally
Can manipulate treatment for seasonal and WQC changes.

Disadvantages: Treatment must be administered continuously.

The shared utilisation of subterranean water sources by animals and humans require that consideration of the health norm for animals alone is not sufficient. It also poses a serious ethical concern and modelling consideration.

The ethical concern is that solutions cannot be recommended for use in communal areas, even if they alleviate the adverse effects of hazardous constituents in livestock, whilst knowledge exists of shared utilisation of the water by humans. This is because the solutions recommended will in most instances render the water even more unfit for use by humans. Note that the water is in many cases already unfit for human consumption, as indicated in this report. The modelling considerations are that a best-fit option is required to cater for alleviator responses in both user groups, and that animal product quality for consumers (specifically rural subsistence users) must receive increasing attention.

A number of uncertainties exist:

1. To what extent does the presence of other WQCs mitigate or exacerbate adverse effects due to a single WQC.
2. To what extent do high WQC concentrations contribute significantly to alleviate existing trace mineral deficiencies in the diet of the communities involved.
3. To what extent do WQCs present in animal products such as milk, meat and organs, add to the dose intake already experienced by humans from the WQC present in water.
4. To what extent can alleviator treatments demonstrated to be effective for livestock be used to mitigate adverse effects in humans.
5. Is it financially viable to design and build the necessary structures to enable a single water source to receive multiple treatments, each specific to a different water user?

These considerations and uncertainties served to motivate for the development of a separate CIRRA model, designed specifically for RCPLS.

2.2 Wildlife production systems (WPS)

Wildlife production systems pose a number of complex challenges to water quality management. The most obvious is the diverse nature of the user groups, ranging from aquatic organisms requiring permanent water of acceptable quality, to desert animals with adaptive mechanisms which significantly reduce their dependence on drinking water. The user groups differ in physiology, water turnover, territory, feeding spectrums, and water provision design requirements. Perhaps not so obvious is the difficulty of predicting where, how much, and when, an animal drinks. The net risk in terms of actual ingestion of a potentially hazardous constituent for certain wildlife species may be acceptable under conditions where multiple watering points form part of a territory.

It follows that some water sources will pose a greater risk to certain wildlife species than to others. Although this makes for complex guideline models, it affords the manager to opportunity to allocate poor quality water to least sensitive species. This is accomplished by matching habitat, territory, water provision design and immediate habitat with species.

The degree to which management can, or wants to, intervene in a WPS, affects the degree to which alleviator treatments may be used, from the feeding of supplements to the application of water treatments. An additional issue requiring a new CIRRA model for WPS is that of the ecological impact of actually providing, designing, placing, and managing, water used for drinking and other purposes by wildlife. The effect of the presence, or absence, of wildlife on sacrifice zones, herbaceous plant communities and ultimately successful wildlife ranching, are but a few of the water quality considerations that needed to be addressed by the new CIRRA model.

2.3 Poultry production systems (PPS)

The poultry industry has become an important component of our agricultural sector. South Africa is the second biggest producer of eggs (total of 4500 million in 1994) in Africa. Concerns regarding the use of poor quality water within the poultry sector were presented in a previous WRC report (K5/644) and based on results of water quality investigations across the whole of South Africa. Narrow profit margins within commercial poultry production (high feed costs) imply that any decline in health, or the efficiency of feed conversion, can reduce profit.

The primary requirement for a poultry model is a combination of a lack on knowledge of the types and concentrations of WQCs present in water used for poultry production, inadequacies and conflicting guidelines used. This leads to a significant area of concern regarding the influence of water quality on the health and production parameters for both broiler and layer production systems, many of which are as yet not quantified. An additional reason for proposing a modelling approach was the lack of existing guidelines for poultry to incorporate information on the important role played by site-specific factors.

2.4 Ostrich production in the Oudtshoorn district

This report also presents data regarding the influence of water quality on the mineral content of various biological tissues in ostriches. Research regarding water quality for ostrich production systems in the Oudtshoorn District was initiated by the State Veterinary Inspector at the Oudtshoorn Abattoir due to observations of carcass defects that appeared to be more prevalent in birds originating from certain areas within the district. Certain producers had also noted significant seasonal fluctuations in growth rates that appeared to be linked to water quality.

3. METHODOLOGY AND REPORT LAYOUT

This report is divided into two volumes. The first addresses the rural and wildlife production system models developed, whilst the second presents the poultry model and research on the effect of water quality on mineral values in selected ostrich tissues.

The general format employed is to present the supporting information prior to the models proposed. An overview of each model is then followed by a detailed description thereof. This is followed by a section presenting water quality investigations appropriate to each user group. The methods used differ dependent on the purpose of the investigation and nature of the area involved, and are dealt with where appropriate.

Technical information is presented in the first volume only. Due to the extensive nature of the modelling methodology employed, for each volume the reader is referred to WRC Report No: 644/1/98 for a more comprehensive description.

4. SUMMARY OF MAJOR RESULTS AND CONCLUSIONS

4.1 Rural Communal Livestock Production Systems

The rural communal livestock production system model presented in this report attempts to cater for the complex requirement of balancing risk and hazard identification in the realm of environmental toxicology, with the significant role of water quality in improving the health of animals and humans. During the rural area investigations the association between animal and man was observed to be a limiting factor to the successful application of solutions generated by CIRRA for problematic water sources. Shared utilisation effectively prohibits the application of treatments to it, due to the potential for adverse effects in humans.
The effect of animal product quality on human health was an additional area of concern. An accumulation of constituents such as lead and cadmium in renal cortex tissue during intensive commercial systems do not

present a significant consumer hazard, as concentrations and dilution within the urban diet, effectively provide for sufficient safety. This does not hold true for the rural production systems.

The production phase is seldom as short, or well defined, as in commercial systems. Exposure periods are therefore longer, with ingestion rates typically greater due to a number of associated risk factors (e.g. temperature, moisture percentage of ration). Secondly, and possibly quantitatively more important, the nature of the diet differs in terms of input origin variability. Potentially hazardous constituents in the water may find their way into the diet of sensitive user groups, such as reproductively active women and children, through a number of routes. These may be direct via the drinking water, indirect via food preparation and irrigation of subsistence crops, and indirectly via the consumption of animal products from animals exposed to the water source.

A number of other routes incorporating bioaccumulation and bioconcentration may also apply, such as the consumption of aquatic organisms, and the practice of providing reverse-osmosis brine to livestock, which may find its way back into the human diet through the consumption of organs, eggs, or milk. This may be at even greater levels than those occurring naturally in water, partly due to the increased concentration of hazardous constituents in the brine, as compared to raw feed water, and the active transport mechanisms that may increase the concentrations thereof in milk. Localised geochemical anomalies may be magnified in semi-arid regions, and there is increasing evidence that the additional effect of geophagia, incidental and deliberate, by both animals and humans, is significant.

In the developing communities this project reports on, both for livestock and humans, dietary deficiencies in terms of quantity and quality are real challenges. The link between livestock production, animal product quality, and human nutrition, when viewed in context of the additional risk factors in rural communal production systems, takes on a more central role to the modelling of water quality guidelines for the user group. The ramifications of retaining the focus of water quality guidelines for livestock on the health of livestock, and failing to account for norm of product quality, would be grossly negligent. There is much evidence of animal products which may contain potentially hazardous concentrations of constituents with clinically accepted toxicity risks for humans, without the animal presenting with any clinical manifestations of a trace element disorder. As such, livestock health may not be a sufficiently accurate measure of the fitness for use of consumption products.

However, livestock products offer abundant and bioavailable forms of micronutrients, and calcium, iron, zinc, vitamins A and B_{12}, *if managed appropriately*. Low birth weight due to fetal malnutrition has been associated with deficient maternal intakes of iron, zinc, iodine and vitamin B_{12}, as have an increased risk for fatal infections, neuorlogic and cognitive impairment. Not only are animal products compact and efficient sources of many of these nutrients, but they are almost the exclusive source of dietary vitamin B_{12}, and a good source of pre-formed vitamin A. The inclusion of health norms for water quality guidelines for livestock is warranted as successful production has been shown to be a valuable means of income generation for rural households.

A high incidence of specific water quality constituents present in the water at potentially hazardous concentrations was found for all communities. Most were typified by a localised, often isolated, association between the environment, water, animals and humans. The communities had a varied spectrum of user groups, but all included sensitive user groups, namely women of reproductive age, infants and children. The valuable, and at time essential role, played by livestock was evident for most communities. Most systems lacked the required infrastructure to allow for separate alleviator treatments formulated for livestock to be administered to the watering system.

Animal data regarding risk of an environmental toxicological nature, may be used to the benefit of identifying similar risks for humans. The localised geochemical factors shared by both animals and humans allow for some valuable information to be gained regarding the types of effects that may occur due, in varying degrees, to water quality.

The drinking water quality guidelines formulated by the WHO, USEPA, and the Department of Water Affairs and Forestry, are primarily based on hazard identification from single constituent exposure toxicological studies. The outcomes of exposure to multiple constituents, as found to occur in the areas investigated, are not described by local and international guidelines. Ameliorating effects may be negligible, partial, or complete. Further research is required in this regard.

With this, and many other areas of uncertainty, animal health studies can provide a valuable means of determining the risk present due to potentially hazardous water quality constituents with the incorporation of significant site-specific factors. Animal health studies can provide valuable guidance to community health based studies. They afford an opportunity to gather tissue samples, not readily available from humans, for histopathological examination, and various assays, which may provide an indication of possible subchronic, subclinical, effects that may occur in humans. The Data Capturing Guides developed aid in the collection of the required site-specific data.

Finally, the investigations indicate that potential problems are not isolated occurrences, but rather localised anomalies, which have an additional problem of creating the lack of a comparative norm, as large number of animals, and humans, tend to be affected.
The order by which the recommended guidelines are exceeded, and the intrinsic high risk of the product system and related environment, suggest that the possible solution option within CIRRA be expanded further. The identification of points in the ingestion route between water quality and types of health effects

where risk is increased, or decreased, is of great value to proposing solutions to reduce risk. In the modelling of the rural communal livestock production system, this aspect was taken into account in the setting up of different data capturing screens, and in the design of the presentation of the evaluation results. Although perhaps too complex at first glance, once familiar, these screens offer a tool for identifying, and testing, outcomes based management decisions.

4.2 Wildlife Production Systems

With the rapid increase in scientific investigations pertaining to game ranching, more game ranches are changing from an initial "untouched wilderness" concept to one that recognises the active-adaptive approach. There is an increased awareness relating to the profit-based business potential in game ranching. The ecological responsibility of providing water to game is also gaining recognition. The increased demand this places on management is accompanied by an increased requirement for specialist knowledge.

The effect of water quality on wildlife has typically received little attention. Most studies do not include chemical information on water quality, and when they do, it is usually inadequate and extended only to a handful of macro-element values. Studies elucidating the role of water quality constituents on issues such as reproductive health and immune responsive disorders are increasing, but the beginning point of such studies requires knowledge of the quality of water, spatial and temporal, as a fundamental basis.

The water quality investigations presented in this report suggest that sufficient variability in water quality constituents exist, in terms of palatability and toxicology, to require management attention. The availability of multiple water sources, and the presence of multiple wildlife species comprising different physiological stages, makes risk assessment a fairly complex task. A software environment not only enables these complexities to be handled, but also guides the user as to the possible types of site-specific information to be obtained. These information types will find application for game ranch management decisions other than those regarding water quality.

4.3 Poultry production systems

Water quality constituents may impact on several norms, ranging from poultry health to equipment failure, all of which affect profitability. Apart from the obvious disadvantages to production from adverse effects on poultry health due to mineral imbalances, pathogens and parasites, knowledge of water quality is also required for managerial and nutritional purposes. For intensive commercial systems a constituent affecting nutrient bioavailability or feed intake negatively, or increasing nutrient requirements for specific production defined parameters, can increase production cost.

For systems operating on large volumes and narrow feed margins, the contribution that water quality makes towards mineral requirements, and significant dietary and drug interactions, must be taken into account for feed formulation to be accurate and representative of true requirements. A system incorporating those site-specific factors influencing the adverse effects that may occur due to potentially hazardous constituents, allows for increased measurement and observations of these factors. It is hoped that this will allow for more efficient usage of water, and also prevent the incorrect classification of water sources that pose a "potential" hazard based on rudimentary guidelines, and encourage water users to acknowledge water with a high mineral content as not simply water with poor quality, but rather as a potentially valuable source of minerals.

4.4 Ostrich production in the Oudtshoorn district

The occurrence of significant differences in mineral concentrations found, and the consistency with which these differences occurred within treatment groups, indicates the need to incorporate the role of water chemistry and geochemistry in formulating the dietary requirements on a farm-specific basis. Pre-scribing a ration or nutritional programme for a district runs the risk of under, and over-estimating the mineral requirements of ostriches. As a result, imbalances may precipitate deficiencies, with consequent loss of productivity, and as appears to be the case in at least several of the farms, may even result in skeletal-related slaughter-process problems.

Where initially a concentration viewed only in water will represent a portion of the dietary requirement, when additional sources of ingestion taken and inter-mineral effects (even only within a water source) are taken into account, the same constituent concentration may well increase the final risk that is posed. Although PHCs such as the constituent Se were present in the vast majority of the samples collected, large differences in the concentrations recorded between areas (North versus south of the Groot Swartberge), and the lack of such differences within an area (South of Groot Swartberge and North of Kamannasie Berg), suggest that there is merit in formulating supplementary alleviator feeds that are area (or valley) specific.

5. RECOMMENDATIONS FOR FURTHER RESEARCH

5.1 Rural Communal Livestock Production Systems

Due to the complexities of modelling relevant risk factors and the varied fields of specialisation that are addressed, achieving a guideline and risk assessment system that is manageable by a wide user audience, is best done in a software environment. Main reasons for this are access to large amounts of data, complex modelling performed, and Internet connectivity enabling sample files that represent a site-specific system to be e-mailed to persons from which specialised insight may be requested.

- On the basis of the potential hazardous found in the water sources sampled, it is recommended that research focus on identifying, and testing, outcomes based system manipulations that allow for the continued use of a water source containing potentially hazardous constituents.

- The efficacy of alleviator chemical treatments for livestock administered to the water supply should be tested in the rural communal production system context.
- The effect of using brine for stock watering in the rural communal production system context on animal product quality, and animal health, should be investigated.
- It is proposed that a formal procedure be developed in which the effect of water quality in rural communal production systems be determined through a series of clearly defined steps. Recommended steps in this regard are:
  1. Commencing with a risk assessment for livestock addressing health and product quality norms, that identify specific potentially hazardous water quality constituents and water quality constituents of concern;
  2. Substantiating the potential risk identified in Step 1 by using clinical evaluations of herd health, animal tissue histopathology and assays for relevant constituents, geochemistry, and feed samples;
  3. Formulating possible risk implications for human health on the basis of the results obtained in Step 2, incorporating direct and indirect, site-specific factors;
  4. Preliminary community-based epidemiological studies to assess the risk factors present;
  5. Substantiating the potential risk identified in Step 4 through community health investigations;
  6. Depending on the outcome of Step 5, viable means of reducing risk in both animals and humans should be identified;
  7. It is proposed that these steps form part of a formal procedure in a software program that consists of different components encompassing the fields of knowledge required. It is envisaged that such a program would enable the identification the probability of risk in potential areas to be based on geochemistry-related data, thus in effect guiding animal and veterinary scientists for step 1. The program can also contribute to the building of Provincial and National databases by linking the relevant data capturing screen information to the relevant specialist field. A program can also accommodate frequent updates as new research evidence and procedure become available.

A specialist component-based software program catering for the variable types of databases (animal, geological, hydrological, climatic, epidemiological, etc.) would aid in encouraging collaborative research, with the central theme of improving the quality of life for humans in the rural communal context, by allowing the correct detection, and management, of critical issues pertaining to water quality to be recognised and addressed.

5.2 Wildlife Production Systems

Although water quality aspects for aquatic systems have, and continue to, receive attention, these monitoring programmes do not always lend themselves to conducting risk assessments for wildlife health. Those who are of the opinion that water quality for wildlife has no place in wildlife management not only neglect the impact thereof on wildlife health, but also on the ecological environment. Choosing not to obtain information on water quality effectively prevents the management of those resources, and the wildlife that rely on them. In order to manage, measurement is a pre-requisite.

- It is recommended that a water quality monitoring programme be designed for the National Parks of South Africa, and that management decisions regarding water provision, placement and design thereof, include water quality risk assessments, for wildlife health and ecological impact norms directly influenced by wildlife, as a pre-requisite to the information types on which the decision making process rests.
- It is recommended that research be conducted regarding the use of mineral licks, and supplementary feeding for wildlife, as corrective and/or alleviator treatment for water sources with potentially hazardous water quality constituent concentrations.

Possible contamination of groundwater and the environment by both production systems, although not typically intensive, should also receive attention.

The recommendations proposed for the rural communal livestock production systems, and wildlife production systems, should be seen in context of the mission of the Department of Water Affairs and Forestry as custodian of South Africa's water resources, part of which is to "maintain the fitness for use of water on a sustained basis", with specific reference to two recognised categories of water use, namely, domestic and agricultural purposes.

5.3 Poultry Production Systems

Due to the intensive nature of commercial poultry production systems, it is recommended that the micro-biological water quality criteria not dealt under the targets formulated for this project be incorporated into the model, with the initial phase consisting of the collection of background data relating to the occurrence of pathogens and parasites in the water sources, and watering systems.

Further research is recommended regarding the fitness of poultry products for human consumption in the rural subsistence context, and indigenous breed differences with regard to tolerances to potentially hazardous constituents.

5.4 Ostrich production in the Oudtshoorn district

Recommendations are made regarding which tissue to use as an indicator of mineral status for specific elements, for example renal tissue for Mn, bone for K and liver for Cu. However, in order to place a high or low value in a tissue in perspective, for example bone values for Mg and Ca, levels for liver and kidney may also required.

As a precautionary measure, it is recommended that Ca and P intake be reduced in breeding males for those producers within the relevant tissue treatment groups, as levels satisfactory for eggshell formation in the female may reduce Mn, Zn and Fe absorption in the male, and given the Ca concentrations in water and several of the tissues investigated, excessive exposure is a definite risk. As far as growing birds destined for slaughter are concerned, a farm-specific risk assessment is required as the results indicate the in some cases bone resorption may be occurring, suggestive of a Ca-deficiency.

Given the low Mn values that accompanied many of the high Ca values observed, and the propensity for fast growing chicks to develop porosis of the stifle between two to eight months, Mn supplementation ranges may have to be increased.

Further areas of research that require attention include the incorporation of additional farm-specific geochemistry data to ascertain the total exposure, seasonal variations in water quality, and detailed profiling of minerals in various tissues in ostriches that pose problems during the slaughter process.

ACKNOWLEDGEMENTS

The research and related outputs presented in this report emanated from a project funded by the Water Research Commission entitled:

"An extension to and further refinement of a water quality guideline index system for livestock watering"

The Steering Committee responsible for this project consisted of the following persons:

Mr DS van der Merwe	Water Research Commission (Chairman)
The late Mr AG Reynders	Water Research Commission
Dr H Meissner	Agricultural Research Council
Dr FK Siebrits	Agricultural Research Council
Dr JPJ Joubert	Agricultural Research Council
Prof NH Casey	University of Pretoria
Prof NFG Rethman	University of Pretoria
Dr JA Meyer	University of Pretoria
Mrs CB Coetzee	University of Pretoria
Ms M Hinch	Department of Water Affairs and Forestry
Mr AT van Coller	National Department of Agriculture
Dr CHM de Brouwer	North West Agriculture Development Institute
Dr A Bekker	KKK Abattoir
Dr WP Burger	Klein Karoo Kooperasie
The Director	SA National Parks
Mr AM Mahanjana	South African Agricultural Union
Mr JF Taljaard	Water Research Commission (Secretary)
Mrs CM Smit	Water Research Commission (Committee services)

The following people are thanked for their specialist input:

Mr T Marais from Incasa (Pty) (Ltd) for his invaluable assistance in all software programming aspects.

Dr J Myburgh from the Department of Community and Herd Health, Faculty of Veterinary Science, at the University of Pretoria for his assistance in collecting data from the Jericho District.

The late Mr P du Toit from Delftzyl Agricultural Research Station for his help and assistance in conducting experimentation and research in the Delftzyl and Immerpan Districts.

Prof TS Kellerman from the Department of Toxicology at the Onderstepoort Veterinary Institute, Agricultural Research Council, for his guidance in all matters toxicological.

Prof J DuP Bothma from the Department of Animal and Wildlife Sciences at the University of Pretoria for guidance regarding the wildlife aspects addressed.

Mr G van Dyk of the Pilanesberg National Park for the collection of data.

Ms K Wilson for assistance with the collection of data from the Klaserie Reserve.

Prof JBJ van Ryssen from the Department of Animal and Wildlife Sciences at the University of Pretoria for guidance in matters pertaining to mineral nutrition.

Dr C de Brouwer for guidance in the investigations conducted in the North West Province.

Mr K Ntshangase from the Potchefstroom ADC for assistance in the collection of data from the Barolong Community.

Mr R Moiloa from the Rustenberg ADC for assistance in the collection of data from the Zeerust District.

Mr EB Spreeth from the Department of Animal and Wildlife Sciences at the University of Pretoria for his assistance with laboratory procedures.

Mrs E Snyman from the Department of Animal and Wildlife Sciences at the University of Pretoria for her assistance with laboratory analysis.

Mr R Coertze from the Hatfield Experimental Farm at the University of Pretoria for his advice concerning the statistical analysis of data.

Prof HT Groeneveld from the Department of Statistics at the University of Pretoria for his assistance regarding the statistical analysis of data.

Dr PD Toens from Toens & Associates in geological aspects with reference to groundwater.

Prof B de Villiers from the Department of Community Health at the University of Stellenbosch.

Prof MC Williams from the Department of Pathology, Faculty of Veterinary Sciences, at the University of Pretoria.

The financing of the project by the Water Research Commission and the contribution by the members of the Steering Committee is gratefully acknowledged.

ABBREVIATIONS

AV	Antagonistic variable
Cat C/D/E	Category level C/D/E
CIRRA	Constituent Ingestion Rate Risk Assessment
COC	Constituent of Concern
CL	Crisis level
DWA&F	Department of Water Affairs and Forestry
DMI	Dry Matter Intake
EPA	(United States) Environmental Protection Agency
FI	Feed Intake
HA	Health Advisory
MPL	Maximum Permissible level
MRL	Maximum recommended limit
mg /L	milligrams/liter
RA	Risk Assessment
RefDoc	Reference Document
RCLPS	Rural Communal Livestock Production System
RL	Recommended Level
PHC	Potentially Hazardous Constituent
TWQR	Target Water Quality Range
TDS	Total Dissolved Solids
TOE	Types of Effects
WI	Water Intake
WQC	Water Quality Constituent
WQG	Water Quality Guideline
WRC	Water Research Commission
WPS	Wildlife Production System
WHO	World Health Organisation

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION TO WATER QUALITY GUIDELINES FOR POULTRY

1.1 Background information to water quality for livestock

The growth and development of this research field has taken place over a number of years. An initial brief was obtained from the Water Research Commission (WRC) in 1990, with the request to verify criteria for water quality for beef cattle utilising subterranean sources along the North and North Western border regions of South Africa. This first project was expanded to include other livestock types, and in the Final Report: K5/301 (Casey *et al.*, 1996), the design of the guidelines then in use were shown to be inadequate, resulting in inaccurate estimates of risk. The first report indicated how single value cut-off limits were not only poor indicators of risk under the vast majority of conditions, but more importantly, often resulted in the limitation of efficient water utilisation. This was demonstrated by conducting biological toxicological trials using sheep, cattle and poultry. These trials indicated that the animals could be exposed to concentrations of highly toxic water quality constituents (WQC), far in excess of the guidelines, for specific production periods (weaning to market weight for sheep and cattle), without incurring any adverse effects on growth, health or performance.

A second WRC project, K5/644 (Casey *et al.*, 1998), developed the theme of a water quality guideline index system, formulated for project K5/301, even further. Through further biological experimentation, extensive region trials, and modelling, the project delivered a computer software program called CIRRA, an acronym for Constituent Ingestion Rate Risk Assessment (Meyer, 1998). CIRRA conducts site-specific risk assessment based on the modelling of water, animal, environmental and nutritional data, to generate both risk assessment and possible solution options. The risk assessment generated is based on a water quality constituent ingestion rate, in mg/d/kg BW, corrected for metabolic water, and represents a radical departure from existing static tabulated guidelines (DWAF, 1996; EPA, 1998; WHO; 1993) which are all independent of production system effects, nutrition, environmental and animal factors, and appear in the form of a mg/L guideline recommendation. CIRRA caters for beef cattle, dairy cattle, goats, sheep, pigs and horses, but with the modelling emphasis on the commercial production system context (Meyer, 1998). This volume presents the models proposed for poultry production systems.

The Department of Water Affairs and Forestry (DWA&F) also engaged in reviewing water quality guidelines (WQG) for agricultural use, which included livestock watering. Through the outputs of these two WRC projects, two guideline editions for livestock watering emerged for the DWA&F, one in 1993 (DWA&F, 1993), and a second in 1996 (DWA&F, 1996). These are, however, still largely generic guidelines, and provide the user with superficial guideline information.

This report is the third WRC project concerning water quality guidelines for animals, and consists of two volumes. The first volume deals with risk assessment modelling for two new CIRRA models, addressing two separate user groups, namely, rural communal livestock production systems (RCLPS) and wildlife production systems (WPS). This volume, the second, presents the models proposed for poultry production systems, and data regarding the effect of water quality on mineral status of selected tissues in ostriches. An appendix to the report touches on refinements made to existing models in the software program CIRRA. It is recommended that the reader familiarize themselves with the final report from WRC project K5/644 (Casey *et al.*,1998) as it contains much of the scientific basis for the models described in this report.

1.1.1 Broiler and layer production systems

Since poultry consume about twice as much water as feed on a weight basis, it would seem logical that water content and quality should be considered in poultry nutrition. Good quality water is an essential feature of poultry management (Coetzee *et al.*, 1997). Growing broilers need about 4 liters of water for every one kilogram of weight gain, about 75% of which comes from drinking water and the rest from the feed (Ross Broiler Management Manual, 1996). A laying flock of hens consumed over 4kg additional water for each dozen eggs produced (Howard, 1975). If access to water is limited or water quality is substandard, growth rates and production will be reduced. Largely due to the narrow profit margins within commercial poultry production systems (high feed costs), any decline in the efficiency of feed conversion will reduce profit.

The poultry industry has become an important component of our agricultural sector. South Africa is the second biggest producer of eggs (total of 4500 million in 1994) in Africa and the world's 30[th] largest producer (Liebenberg, 1996). The relative share of broilers in the meat market in terms of value for 1993/4 was:

Beef	38.11%
Mutton	12.03%
Pork	6.45%
Chicken	43.41%

The gross production value of eggs and broilers amongst the 9 provinces of South Africa, is provided in Table 1.1.

Table 1.1 Gross production value of eggs and broilers amongst the 9 provinces.

Province	Eggs %	Broilers %
Western Cape	24.25	27.10
North West	15.25	10.96
Gauteng	26.75	13.15
Northern Province	6.58	2.28
Mpumalanga	2.55	12.64
Natal	13.3	27.17
Eastern Cape	4.71	5.22
Free State	5.71	1.20
Northern Cape	0.89	0.28

A strong link exists between the poultry industry and the maize industry. Changes, which occur in the poultry industry, will have a major impact on the maize industry and therefore the livestock feed industry and vice versa. Broiler farms employ some 30 000 workers directly with fringe industries indirectly employing about 10 000 workers (Finance Week, 1995:7).

1.1.2 Ostrich production systems

This report also presents data regarding the influence of water quality on the mineral content of various biological tissues in ostriches. Research regarding water quality for ostrich production systems in the Oudtshoorn District was initiated by the State Veterinary Inspector at the Oudtshoorn Abattoir due to observations of carcass defects that appeared to be more prevalent in birds originating from certain areas within the district. Certain producers had also noted significant seasonal fluctuations in growth rates that appeared to be linked to water quality. These water quality issues are presented in Chapter 3.

1.2 Water quality and poultry production systems

Water quality affects three types of norms with reference to poultry production systems.

1.2.1 Type 1:Poultry health

This norm deals with those adverse effects on the health of poultry due to the presence of single, or multiple, water quality constituents (WQCs) in the water at concentrations ranging from those which may precipitate a deficiency, to those which may induce toxicity. There are two broad categories within this norm, namely adverse effects due to direct and indirect factors. Direct effects may be due to a high concentration of bacteria, or potentially hazardous constituents (PHCs), in the water that can have an adverse effect on the normal physiological processes of the body, resulting in inferior performance, poor health, and reduced immunity. These may be due to a single PHC, or the net effect of multiple PHCs. Indirect effects usually involve effects of the WQC on the watering system. An example of an indirect effect may be high concentrations of minerals in the water that lead to clogging of the water system that subjects the birds to water deprivation which can impact negatively on performance. Flooding of the drinkers can also occur, causing the litter to become wet, which in turn can lead to leg problems and breast blisters in broilers raised on the floor.

1.2.2 Type 2: Product Quality

This norm deals with the potential hazard that a poultry product, such as eggs or meat, may present to the consumer, due to an accumulation of PHCs present in the water source in these biological tissues. This norm is of particular importance in rural subsistence production systems were poultry may form a significant part of the household diet. Risk is increased in the rural context due to the prevalence of sensitive user groups (pregnant women, infants, children, and the elderly), unfavourable production condidtions, and localised geochemical anomalies that may increase the exposure (and ingestion) of PHCs from multiple sources.

1.2.3 Type 3: Watering system

This norm deals with the water system effects such as clogging, scaling, encrustation and sedimentation. These can create managerial problems in terms of equipment replacement and problems with water delivery.

1.3 Aim of establishing models for broilers and layers

The aim of this study was to further refine a Water Quality Guideline Index System (WQGIS) for poultry watering, with the emphasis on subterranean water sources.

Many subterranean water sources in South Africa do not comply with the existing guidelines for water quality that are available. However, these sources are often the only sources available. This project's purpose was to develop a Water Quality Guideline Index System, to address this reality, and the system may perhaps be described as one that attempts to increase the accuracy of the decision making process with regard to assessing the fitness of use of a water source for poultry production, within the environmental constraints.

The primary requirement for such as system is a combination of a lack on knowledge of the types and concentrations of WQCs present in water used for poultry production systems, and inadequacies in the guidelines used in assessing the fitness for use of a water source for the various types of poultry production systems found in South Africa. This leads to a significant area of concern regarding the influence of water quality on the health and production parameters for both broiler and layer production systems, many of which are as yet not quantified. Meyer, Casey and Coetzee (1997) reported that there is no national database on the WQC profile of water sources utilized for livestock production in South Africa. They suggested a water quality monitoring system be formulated in which the relevant water quality constituents for the specific areas and production systems be identified, primarily based on:

- the potential for adverse effects; and
- the occurrence in the natural aquatic environment of potentially hazardous constituents.

An additional reason for proposing a modelling approach was the lack of existing guidelines for poultry to incorporate information on the important role played by site-specific factors. The merits of this approach as it pertains to risk assessment formulation are dealt with in Volume 1 of this report.

1.4 Supporting information for broiler and layer production systems

Prior to the formulation of a poultry model, selected poultry producers were contacted and permission obtained to collect water samples. As part of an initial investigation into water quality guidelines for poultry, water samples were collected from selected poultry producers in five provinces, namely, the Western Cape, Eastern Cape, North-Western Province, Gauteng and the Free State. Fluoride, nitrates, chlorides, bicarbonates, phosphates, sodium, titanium, manganese, mercury and iron were identified as potentially hazardous constituents (PHC) and chlorides, lanthanum and zirconium were identified as constituents of concern (COC).

Tables 1.2 to 1.3 provide some of the results that were obtained for broiler and layer producers in the Gauteng province. The reader is referred to the WRC Final Report No 644/2/98 for the complete results.

Table 1.2.1. Macro-element results for water collected from broiler farms in the Western Cape.

Variable	Unit	n	Mean	SD	Minimum	Maximum
Fluoride	mg/l	15	1.3120	2.1358	0	7.2000
Nitrite	mg/l	15	0	0	0	0
Nitrate	mg/l	15	7.3667	5.9920	1.5000	22.4000
Chloride	mg/l	15	406.5333	166.0076	166.1000	703.5000
Sulphate	mg/l	15	35.1333	33.4180	7.0000	87.0000
Phosphate	mg/l	15	0.3467	1.3426	0	5.2000
Carbonate	mg/l	15	0	0	0	0
Bicarbonate	mg/l	15	98.8333	35.2394	18.3000	158.6000
Sodium	mg/l	15	187.9667	89.6888	73.7000	357.0000
Potassium	mg/l	15	5.5733	4.7260	1.8000	20.7000
Calcium	mg/l	15	37.6800	18.9660	9.5000	68.5000
Magnesium	mg/l	15	27.0533	10.6463	10.0000	52.3000
Boron	mg/l	15	0	0	0	0
TDS	mg/l	15	758.3467	283.4137	283.5000	1216.0000
Hardness	mg/l	15	80.6000	28.9206	15.0000	130.0000
pH		15	7.4987	0.2995	7.1000	7.9300
pHs		15	8.0840	0.40033	7.7000	9.2400
NAV		15	5.7387	2.3933	2.7400	9.7500
Electrical conductivity	mS/m	15	130.2667	47.1858	53.0000	208.0000
Titanium	µg/l	15	216.9951	141.7601	32.7400	430.6800
Vanadium	µg/l	15	0.0467	0.1886	0	0.7305
Chromium	µg/l	15	36.3655	5.1641	29.9810	47.1700
Manganese	µg/l	15	881.4839	756.7397	27.1570	2204.7000
Cobalt	µg/l	15	3.8091	5.1169	9.5572	20.1790
Nickel	µg/l	15	34.4715	14.0243	20.1550	62.0970
Copper	µg/l	15	17.3472	8.7965	7.7187	39.0700
Zinc	µg/l	15	253.1835	426.9618	51.9140	1661.8000

Table 1.2.2 Trace mineral results for water collected from broiler farms in the Western Cape.

Variable	Unit	n	Mean	SD	Minimum	Maximum
Arsenic	µg/l	15	2.1987	2.9639	0	9.8117
Selenium	µg/l	15	0.1763	0.6829	0	2.6448
Strontium	µg/l	15	427.1184	356.9295	58.8960	1328.4000
Zirconium	µg1	15	0.6314	0.4040	0.2771	1.5902
Molybdenum	µg/l	15	0.5421	1.0994	0	4.1876
Cadmium	µg/l	15	0.9111	1.6201	0	5.54590
Indium	µg/l	15	0	0	0	0
Tin	µg/l	15	0.4707	0.5521	0.0701	2.2817
Antimony	µg/l	15	0.1956	0.07933	0.1192	0.4287
Caesium	µg/l	15	8.7079	12.4483	0.0133	32.9180
Barium	µg/l	15	80.3705	62.6902	20.2520	243.2800
Lanthanum	µg/l	15	1.0185	0.2314	0.7346	1.5180
Cerium	µg/l	15	0	0	0	0
Tungsten	µg/l	15	0.5087	0.6835	0.0464	2.0718
Platinum	µg/l	15	0.2103	0.1590	0.0048	0.4926
Mercury	µg/l	15	1.1981	1.4682	0	4.1168
Lead	µg/l	15	24.3771	10.1747	12.43200	49.9570
Bismuth	µg/l	15	0.0545	0.0229	0.0264	0.1162
Uranium	µg/l	15	0.6554	0.7743	0.0469	2.1026
Iron	mg/l	15	3.7031	6.5832	0.0930	26.3100
Bromine	µg/l	15	73.6986	27.8037	38.2500	123.3300
Scandium	µg/l	15	0	0	0	0
Rubidium	µg/l	15	12.6698	8.9190	0.4856	27.4630
Iodine	µg/l	15	123.1329	65.2710	46.1280	271.6500

Table 1.3.1. Macro-element results for water obtained from layer farms in the Western Cape.

Variable	Unit	n	Mean	SD	Minimum	Maximum
Fluoride	mg/l	18	0.7222	0.7694	0	2.0800
Nitrite	mg/l	18	0	0	0	0
Nitrate	mg/l	18	8.9444	11.2332	0	48.5000
Chloride	mg/l	18	237.3000	156.0385	82.7000	598.1000
Sulphate	mg/l	18	17.5778	10.5907	4.9000	39.6000
Phosphate	mg/l	18	0.6833	2.8991	0	12.3000
Carbonate	mg/l	18	0	0	0	0
Bicarbonate	mg/l	18	120.6667	47.4647	33.6000	216.6000
Sodium	mg/l	18	111.9722	65.0735	42.4000	263.0000
Potassium	mg/l	18	4.1444	1.9865	1.6000	7.70000
Calcium	mg/l	18	30.9667	11.8867	9.3000	46.2000
Magnesium	mg/l	18	21.3000	13.6962	6.7000	53.7000
Boron	mg/l	18	0	0	0	0
TDS	mg/l	18	493.9056	248.1916	201.4000	1037.2000
Hardness	mg/l	18	96.2778	36.4301	28.0000	151.0000
pH		18	7.6716	9.4356	6.8000	8.2200
pHs		18	8.0456	0.3783	7.7000	9.0200
NAV		18	3.6633	1.3584	2.2400	6.7500
Electrical conductivity	mS/m	18	85.6667	42.2388	37.0000	175.0000
Titanium	µg/l	18	143.3945	63.8083	26.4570	241.2500
Vanadium	µg/l	18	0.8418	1.7283	0	6.1314
Chromium	µg/l	18	35.1343	3.3244	25.4840	40.2250
Manganese	µg/l	18	513.5167	552.9931	28.8010	1739.2000
Cobalt	µg/l	18	4.4561	8.2260	0.8077	27.1660
Nickel	µg/l	18	46.5736	24.3839	19.3420	109.9600
Copper	µg/l	18	34.4574	47.0702	5.0815	194.9900
Zinc	µg/l	18	281.1741	383.3708	50.3190	1559.8000

Table 1.3.2. Trace element results for water obtained from layer farms in the Western Cape.

Variable	Unit	n	Mean	SD	Minimum	Maximum
Arsenic	µg/l	18	0.7321	1.0429	0	2.9596
Selenium	µg/l	18	0	0	0	0
Strontium	µg/l	18	174.8442	122.2377	36.2060	561.7900
Zirconium	µg/l	18	0.8023	0.71067	0.2367	2.9055
Molybdenum	µg/l	18	1.0573	2.0462	0	8.1478
Cadmium	µg/l	18	1.9061	3.2696	0	12.6940
Indium	µg/l	18	0	0	0	0
Tin	µg/l	18	0.6852	0.7912	0.0755	3.2807
Antimony	µg/l	18	0.6365	0.9436	0.1436	4.2226
Caesium	µg/l	18	1.5123	1.2893	0	4.9097
Barium	µg/l	18	65.2765	74.6995	9.7954	252.1000
Lanthanum	µg/l	18	0.8431	0.4817	0.2715	2.3040
Cerium	µg/l	18	0	0	0	0
Tungsten	µg/l	18	0.4483	0.5599	0.0718	2.0301
Platinum	µg/l	18	0.2648	0.1558	0.0165	0.5680
Mercury	µg/l	18	0.7756	1.0104	0	4.1819
Lead	µg/l	18	55.5712	46.1305	17.5350	202.8000
Bismuth	µg/l	18	0.0760	0.0370	0.01512	0.1484
Uranium	µg/l	18	51.7452	132.0892	0.0143	423.4200
Iron	mg/l	18	4.0713	9.3119	0	37.1900
Bromine	µg/l	18	36.7868	16.5836	20.1030	70.21600
Scandium	µg/l	18	0	0	0	0
Rubidium	µg/l	18	4.3434	3.1371	1.3159	15.2950
Iodine	µg/l	18	101.4346	99.4504	43.1310	485.4700

The results obtained highlighted the need for a WQGIS to be developed. The range between the minimum and maximum levels of a specific constituent present in the water varied markedly, and the presence of constituent levels far in excess of the existing guidelines, were also prevalent.

Constituents identified to be of concern in these results, were subjected to further investigation and their effect on poultry production was established. The bulk of the biological work conducted that contributed to the formulation of the WQGIS are contained in previous reports to the WRC (Casey *et al.*, 1996; 1998) and are not presented again, but should be seen as required reference material for the poultry models proposed in this report.

Existing water quality guidelines for poultry watering are contradictory and often merely adapted from guidelines established for human watering (Table 1.4). This would imply that valuable water sources may inadvertently be discarded.

Table 1.4. Existing Water Quality Guidelines for poultry watering.

WQC	MAXIMUM ACCEPTABLE LEVEL	EFFECTS	REFERENCE
Alkalinity		See pH	
Aluminium	0.25 mg/l 0.2 mg/l *5 mg/l*	Reduced growth, Rickets.	Kempster, *et al.*, 1981 Zimmerman, 1995 Mancl *et al.*, 1991.
Ammonia	2 mg/l	Dissolve copper from piping and appliances	Kempster, *et al.*, 1981
Antimony	0.006 mg/l	Emetic and a cardio-toxin	Zimmerman, 1995
Arsenic	0.2 mg/l 1 mg/l 0.05 mg/l	Toxic substance, affects normal physiological processes of the body.	Carter, 1985, Keshavarz, 1987 & Mancl *et al.*, 1991 Kempster, *et al.*, 1981 Vohra, 1980 & Zimmerman, 1995
Bacteria	Total = 100/ ml Coliform = 50/ml	Infections/ solve problem with 1 mg/l chloride, for 3 minutes and pH 8 Respiratory diseases, bloody droppings.	Schwartz, 1994 & Waggoner *et al.*, 1994 Schwartz, 1994 & Waggoner *et al.*, 1994
Barium	1 mg/l 2 mg/l	Reduced growth, death	Vohra, 1980 Zimmerman, 1995
Beryllium	0.004 mg/l	Not a priority pollutant, may be carcinogenic.	Zimmerman, 1995
Bicarbonate (CO_3^{2-})	98 mg/l 500 mg/l	Alone, no problem and some are desirable if sulphate or sodium are present	Keshavarz, 1987
Boron	5 mg/l	Not a priority pollutant	Mancl *et al.*, 1991
Cadmium	50 mg/l 0.01 mg/l 0.005 mg/l 0.05 mg/l	Excess cause severe health effects Reduced growth, decreased egg production	Kempster, *et al.*, 1981 Vohra, 1980 Zimmerman, 1995 Mancl, *et al.*, 1991
Calcium	402 mg/l 600 mg/l 200 mg/l	Desirable if sodium is present Non toxic, clog up pipes	Kempster, *et al.*, 1981 Carter, 1985 & Keshavarz, 1987 Vohra, 1980
Chloride	250 mg/l 1500 mg/l 200 mg/l 600 mg/l	Detrimental when combined with 50 mg/l of Na. Increased water intake, wet litter	Schwartz, 1994, Waggoner *et al.*, 1994, Ernst, 1989 & Zimmerman, 1995 Carter, 1985 Keshavarz, 1987 Vohra

Chromium	5 mg/l 0.05 mg/l 0.1 mg/l 1 mg/l	May contribute to hardness of water, low toxicity, nutritionally essential, absence causes diabetes Reduced growth.	Kempster, *et al.*, 1981 Vohra, 1980 Zimmerman, 1995 Mancl *et al.*, 1991
Cobalt	1 mg/l	Nutritionally essential, toxic in excess, reduced growth	Kempster, *et al.*, 1981 & Mancl *et al.*, 1991
Colour	15 colour units	Aesthetic, should be colourless red brown = due to iron bluish = due to copper	Zimmerman 1995
Conductivity	1980 mS/m		Kempster, *et al.*, 1981
Copper	0.06 mg/l 2 mg/l 2.5 mg/l 0.5 mg/l 1.5 mg/l 0.6 mg/l 1.3 mg/l	Bitter, causes liver damage, reduced growth, mortalities, exudative diathesis, muscular dystrophy, gizzard erosion.	Schwartz, 1994 & Waggoner *et al.*, 1994 Kempster, *et al.*, 1981 Good, 1985 Carter, 1985, Keshavarz, 1987 & Mancl *et al.*, 1991 Vohra, 1980 Ernst, 1989 Zimmerman, 1995
Cyanide	0.2 mg/l		Zimmerman, 1995
Fluoride	2 mg/l 0.9-1.7 mg/l (air temp 10-12□C) 0.06-0.08 mg/l (air temp 26.2-32.6□C) 4 mg/l	Lower feed intakes and growth rates	Carter, 1985, Keshavarz, 1987 & Mancl *et al.*, 1991 Vohra, 1980 Zimmerman, 1995
Hardness	> 180 = hard < 60 = soft	Ca and Mg in sulphate form only affects performance with regard to its calcium contents. Blocks water system >200 mg/l Ca leads to excessive deposit and scale formation	Schwartz, 1994 & Waggoner *et al.*, 1994
Iron	0.3 mg/l 1.2 mg/l 6 mg/l 0.1 mg/l	Aesthetic - clog pipes, bad taste and odour up to 25 mg/l no effect on performance, may contribute to hardness	Schwartz, 1994, Waggoner *et al.*, 1994 & Ernst, 1989 Kempster, *et al.*, 1981 Keshavarz, 1987 Vohra, 1980
Lead	0.02 mg/l 0.1 mg/l 0.5 mg/l 0.05 mg/l 0.015 mg/l	Toxic element, affects normal physiological processes of body. Decreased performance, reduced egg size and hatchability	Schwartz, 1994, Waggoner *et al.*, 1994 & Ernst, 1989 Carter, 1985, Keshavarz, 1987 & Mancl *et al.*, 1991 Kempster, *et al.*, 1981 Vohra, 1980 Zimmerman, 1995
Magnesium	125 mg/l 350 mg/l 50 mg/l 150 mg/l (if 250 mg/l sulphate is present)	Decreased performance if 50 mg/l of sulphate is present, intestinal irritation, laxative effect, watery droppings, hardness, taste, lethargy.	Schwartz, 1994, Waggoner *et al.*, 1994 & Ernst, 1989 Carter, 1985 Keshavarz, 1987 Vohra, 1980

Magnesium sulphate ($MgSO_4$)	200-400 mg/l	Lower egg production high sulphates is detrimental to waters with high chloride (> 100 mg/l) content Increased salinity of water	Kempster, *et al.*, 1981
Manganese	4.6 mg/l 0.05 mg/l 0.6 mg/l	May contribute to hardness and turbidity deposits in pipes and bitterness of water. Mortalities	Kempster, *et al.*, 1981 Carter, 1985 & Vohra, 1980 Keshavarz, 1987
Mercury	10 mg/l 0.002 mg/l 0.01 mg/l	A toxic element with no beneficial physiological function, reduced egg production, reduced growth.	Kempster, *et al.*, 1981 Vohra, 1980 & Zimmerman Mancl *et al.*, 1991
Molybdenum	10 mg/l	Reduced growth, poultry more tolerant than ruminants.	Kempster, *et al.*, 1981
Nickel	0.001 mg/l 1 mg/l	> 1000 mg leads to minor toxic effects. Reduced growth.	Zimmerman, 1995 Mancl *et al.*, 1991
Nitrates	25 mg/l 200 mg/l 20 mg/l 10 mg/l	Reduced growth Increased mortality	Schwartz, 1994, Waggoner *et al.*, 1994, Ernst, 1989 & Mancl *et al.*, 1991 Kempster, *et al.*, 1981 Good, 1985 and Keshavarz, 1987 Zimmerman, 1995
Nitrites	4 mg/l 1 mg/l 3 mg/l	High toxicity, decreased Vit A in liver and thyroid enlargement.	Schwartz, 1994, Waggoner *et al.*, 1994 & Ernst, 1989 Zimmerman, 1995 Mancl *et al.*, 1991
Oxygen ($KMnO_4$)	200 mg/l	Measures the amount of organic matter in a sample	Kempster, *et al.*, 1981
pH	> 6.0 2 – 10 > 5.9	Lower performance, lower egg quality, lower effectiveness of vaccines. Solve with mild solutions of NaOH Acidic water - corrode pipes	Schwartz, 1994 & Waggoner *et al.*, 1994 Kempster, *et al.*, 1981 Good, 1985
Phosphate	5 mg/l 0.7 mg/l	Alone no problem, high levels indicate sewage contamination	Kempster, *et al.*, 1981 Carter, 1985
Radioactivity (α+ß)	0.20 Bq/l		Kempster, *et al.*, 1981
Salinity	3000 mg/l	Unsuitable for poultry NaCl, Na2SO4, MgSO4	Mancl *et al.*, 1991
Selenium	0.05 mg/l 0.01 mg/l	Toxic substance, affect normal physiological processes in the body. Reduced growth	Kempster, *et al.*, 1981, Zimmerman, 1995 & Mancl *et al.*, 1991 Vohra, 1980
Silver	0.05 mg/l	Argyria (bluish discoloration of skin). Exudative diathesis (prevented by Cu and Se). Anaemia, enlarged hearts.	Vohra, 1980
Sodium sulphate (Na_2SO_4)	1200 mg/l	Increase in diarrhoea Increased salinity	Kempster, *et al.*, 1981

Sodium	200 mg/l 50 mg/l 75 mg/l	Not detrimental if 500 mg/l of bicarbonate is present. Reduced performance if 50 mg/l SO_4 or 14 mg/l chloride is present Increased water intake, wet litter. Reduced egg production and growth	Ernst, 1989 Keshavarz, 1987
Sodium chloride (NaCl)	1500 mg/l	Later sexual maturity Higher mortalities, higher salinity of water, reduced growth.	Kempster, *et al.*, 1981
Sulphate	250 mg/l 60 mg/l 400 mg/l (if Na & Mg are present) 300 mg/l	Reduced performance if 50 mg/l of magnesium or 50 mg/l of Na is present, laxative effect, wet litter, reduced egg production	Schwartz, 1994, Waggoner *et al.*, 1994 & Ernst, 1989 Keshavarz, 1987 Vohra, 1980 Mancl et al., 1991
Thallium	0.002 mg/l	Neurotoxin	Zimmerman, 1995
TDS	3000 mg/l	Saline or brackish water	Kempster, *et al.*, 1981
Vanadium	0.1 mg/l	Nutritionally essential. Reduced growth, depressed albumin quality. Reduced body weight. Depressed hatchability.	Mancl *et al.*, 1991
Zinc	1.5 mg/l 2.5 mg/l 15 mg/l 25 mg/l	Astringent taste, may contribute to hardness. Lower growth, decreased fertility, skin disease, exudative diathesis, muscular dystrophy, reduced bone ash (0.5 mg/l Se in diet)	Schwartz, 1994, Waggoner *et al.*, 1994 & Ernst, 1989 Carter, 1985 & Keshavarz, 1987 Vohra, 1980 Mancl *et al.*, 1991

One of the objectives in establishing a new set of water quality guidelines for poultry production systems, was to provide producers with a system that is not as contradicting and static as those depicted in Table 1.4. These guidelines will be presented in the form of an index system, which will incorporate all the site-specific influences on water intake of a specific production system. The only way to arrive at such a solution is through a modelling approach, in which the relationship between biological responses and their causes are predicted within the relevant site-specific factors that may apply.

CHAPTER 2

MODEL FOR POULTRY PRODUCTION SYSTEMS

2.1 Introduction

The objectives of the model were to:

- Identify the main production systems within the poultry production spectrum and the water sources available to them.
- Identify the main influences on the ingestion of these water sources and their effect on poultry production.
- Develop a WQGIS for each production system.
- Provide supporting information to make a proper risk assessment with appropriate managerial and alleviator solutions.

2.1.1 Main production systems in poultry production

The main production systems within the poultry production spectrum are the following

1. Broilers
2. Layers
3. Breeders
4. Dual Purpose

Drinking water for poultry is obtained from the city supply (human potable water), from subterranean sources (boreholes, wells), streams, rivers, lakes, ponds, rainfall catchments and springs. For the purpose of this project the main emphasis will be on the subterranean water sources.

2.1.2 Primary effects of water quality on poultry production

Water is involved in every aspect of poultry metabolism. It plays important roles in regulating body temperature, digesting food and eliminating body wastes. At normal temperatures, poultry consume at least twice as much water as feed. When heat stress occurs, water consumption will double or quadruple. A safe and adequate supply of water is therefore essential for efficient poultry production.

Water quality is characterized by its taste, acidity, alkalinity, odor, color, turbidity, salinity, electrical conductivity, pH, biochemical oxygen demand, hardness, presence of nitrites, nitrates, bicarbonates, silicates, phosphates, carbonates, cations, microbial and industrial contaminants and toxicants. And due to its very chemical constitution and potential hydrogen bonding capacity, water is an excellent solvent for both inorganic and organic substances. Water does not exist in an absolutely pure form despite all the attempts at distillation and purification, which reduce its electrical conductivity, a measure of its purity (Vohra, 1980).

2.1.3 Need for separate models

The rationale behind the development and use of a WQGIS was explained in WRC Final Report No. 644/1/98, but the main points are:

Objectives of the WQGIS:

- Provide a flexible management tool for decision making purposes concerning water quality
- Provide a means for incorporating site-specific information in risk assessment
- Provide supporting information regarding the various components and their interactions in biological systems required for decision making
- Provide a water quality guideline index system that can be updated, as new research information becomes available.

These objectives were achieved by:

- Modelling water quality guidelines on a livestock type site-specific basis
- Demonstrating principles of water quality and poultry production relationships
- Developing of a software program
- Providing the user with 2 water quality guideline systems:
  - Generic WQGIS
  - Specific WQGIS

To make a risk assessment in terms of water quality is a complex task that can only be achieved by a simulation model. The ingestion rate of the WQC is directly linked to water intake. If the water intake can therefore be predicted, the ingestion rate of a specific WQC can be calculated. The curvilinear nature of many of the factors influencing water intake, such as – feed intake and temperature, makes the use of simulation models the ideal tool with which to tackle the complexities of the problem.

A systems diagram of each of the applications of the model has been developed to illustrate how the components of the model interact.

2.2 Water Quality Guideline Index System

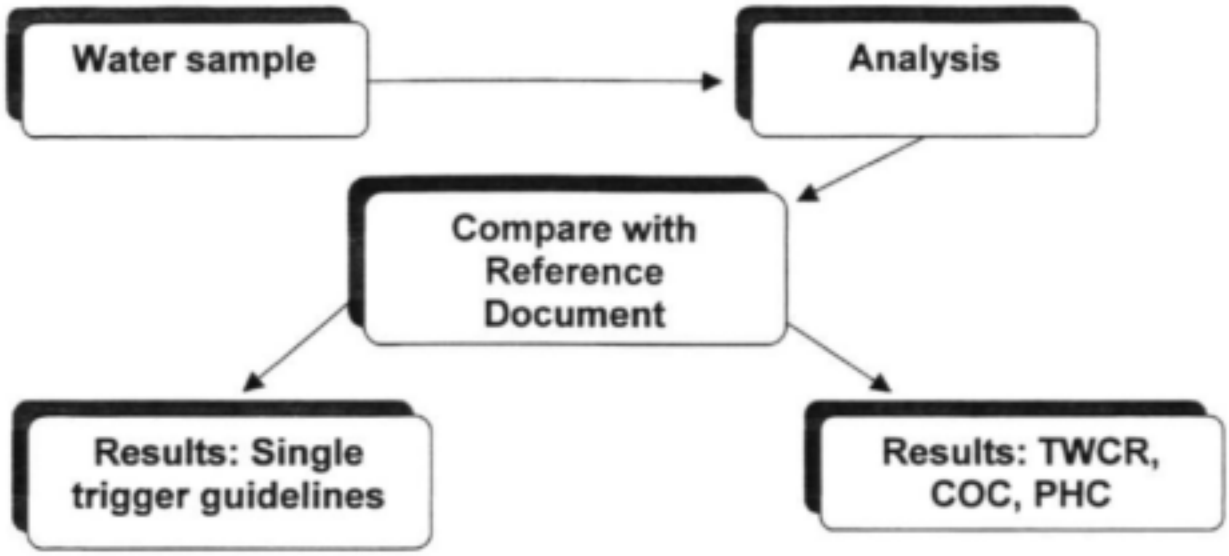
The system consists of two application levels, a generic and a specific, each of which will be presented separately.

2.2.1 Generic WQGIS

2.2.1.1 Introduction

The generic application level is a static water quality guideline application level, in that it makes use of single value comparisons. It does however exceed previous guidelines in that it also indicate possible effects on poultry at given levels. The generic WQGIS is based on the Interim Water Quality Guidelines for Livestock Watering (Casey & Meyer, 1996).

Figure 2.1. Systems diagram of the Generic application level.



In order to allow the user to record the necessary water quality data, a complete constituent list was compiled for CIRRA (Meyer, 1998). This incorporates constituents most frequently found in the natural aquatic environment, those detected in previous water quality investigations conducted for livestock watering, and in the literature cited.

Table 2.1 Water Quality Constituent List for CIRRA (Meyer, 1998).

Element Code	Element Name	Unit
Al	Aluminium	mg/L
NH_4	Ammonium as N	mg/L
Sb	Antimony	mg/L
As	Arsenic	mg/L
BACT	Bacteria	colonies/ml
Ba	Barium	mg/L
Be	Beryllium	mg/L
HCO_3	Bicarbonate	mg/L
Bi	Bismuth	mg/L
B	Boron	mg/L
Br	Bromide	mg/L
Cd	Cadmium	mg/L
Cs	Caesium	ug/L
Ca	Calcium	mg/L
CO_3	Carbonate	mg/L
Ce	Cerium	mg/L
Cl	Chloride	mg/L
Cr	Chromium	mg/L
Co	Cobalt	mg/L
COLOUR	Colour	CU
Cu	Copper	mg/L
CN	Cyanide	mg/L
$KMNO_4$	Dissolved oxygen	% saturation
EC	Electrical conductivity	mS/m
F	Fluoride	mg/L
Au	Gold	ug/L
HARDN	Hardness (as $CaCO_3$)	mg/L
H2.4-D	2,4-D (Herbicide)	ug/L
H2,4,5-T	2,4,5-T (Herbicide)	ug/L
H2,4,5-T	2,4,5-T (Herbicide)	ug/L

H_2S	Hydrogen Sulphide	ug/L
In	Indium	ug/L
I	Iodide	mg/L
Fe	Iron	mg/L
La	Lanthanum	ug/L
Pb	Lead	mg/L
Li	Lithium	mg/L
Mg	Magnesium	mg/L
$MgSO_4$	Magnesium sulphate	mg/L
Mn	Manganese	mg/L
Hg	Mercury	ug/L
Mo	Molybdenum	mg/L
Ni	Nickel	mg/L
NO_3	Nitrates	mg/L (NO3)
NO_2	Nitrites	mg/L (NO2)
ODOUR	Odour	Threshold odour number
CHPAL	Aldrin	ug/L
CHPCH	Chlordane	ug/L
CHPDD	DDT	ug/L
CHPDI	Dieldrin	ug/L
CHPEN	Endrin	ug/L
CHPHE	Heptachlor	ug/L
CHPLI	Lindane	ug/L
CHPME	Methoxychlor	ug/L
CHPTO	Toxaphene	ug/L
OPPA	Parathion	ug/L
OPMA	Malathion	ug/L
pH	Ph	H+
PO_4^{3}-	Phosphate	mg/L
K	Potassium	mg/L
RA	Radio-activity	picocurie/l
Rd	Radium	mg/L
Rb	Rubidium	ug/L
Sc	Scandium	ug/L
Se	Selenium	ug/L
Si	Silica	mg/L
Ag	Silver	mg/L
$NaHCO_3$	Sodium bicarbonate	mg/L
Na_2SO_4	Sodium sulphate	mg/L
Na	Sodium	mg/L
NaCl	Sodium chloride	mg/L
Sr	Strontium	mg/L
SO_4	Sulphate	mg/L
Te	Tellurium	mg/L
Tl	Thallium	mg/L
Th	Thorium	mg/L
Sn	Tin	mg/L
Ti	Titanium	mg/L
TDS	Total Dissolved Solids	mg/L
W	Tungsten	mg/L
TURB	Turbidity	NTU
U	Uranium	mg/L
V	Vanadium	mg/L
Y	Yttrium	mg/L
Zn	Zinc	mg/L
$ZnSO_4$	Zinc sulphate	mg/L
Zr	Zirconium	ug/L

A total of 20 water quality constituents are addressed in the Generic Guidelines within three incidence categories, based on local research (WRC Report 301/1/96; 644/2/98).

Table 2.2 Potentially hazardous water quality constituents for poultry watering, selected on the basis of incidence of occurrence in the natural aquatic environment: (Casey & Meyer, 1996)

Potentially hazardous water quality constituents for poultry watering, selected on the basis of **incidence of occurrence** in the natural aquatic environment:		
High incidence	**Medium incidence**	**Low incidence**
Bicarbonates Calcium Chloride Chromium Lead Magnesium Nitrate Sodium Sulfate Total Dissolved Solids Zinc	Arsenic Cadmium Copper Iron Manganese Mercury	Fluoride Nitrite Selenium

The Generic guidelines are presented in alphabetic order for quick access in two main formats. The first provides the user with probable types of effects that can be expected with increasing concentrations (available from the Types of Effects Button from the Results Screen), and the second provides only cut-off Trigger Value Guidelines.

2.2.1.2 Generic Guidelines – Types of Effects

Potentially hazardous water quality constituents which have either a:

- high incidence of occurrence in the poultry aquatic environment - designated as *High Incidence*, or
- medium incidence of occurrence in the poultry aquatic environment - designated as *Medium Incidence*, or
- low incidence of occurrence in the poultry aquatic environment - designated as **Low Incidence**.

The following symbols are used:

Symbol/acronym	**Definition**
TWQR	Target Water Quality Range This is the range where adverse effects are ***unlikely*** to occur.
>	Refers to the fact that the range in question, although ***likely*** to result in adverse effects, may be tolerated in either the short or long term dependent on primarily the following site-specific factors: • synergistic and antagonistic interactions between constituents in the feed and the water; • poultry production system design; and • actual water ingestion

Arsenic - Medium incidence

Arsenic Range (mg/l)	**Effects Poultry**
TWQR 0 - 0.05	*No adverse effects*
0.05 - 0.2	**Adverse chronic effects such as depression, diarrhea, leg weakness and depressed growth may occur. Short-term exposure could be tolerated>.**
> 0.2	**Adverse chronic effects** such as - reduced egg production - reduced body weights and - reduced feed intakes may occur, although short-term exposure could be tolerated>.

Bicarbonate - High incidence

Bicarbonate Range (mg/l)	**Effects Poultry**
TWQR 0 - 200	*No adverse effects*
200 – 500	As bicarbonate increases, body weight also increases. This observation may be more valid during periods of heat stress.
> 500	Long term exposure> could be tolerated if sodium or sulfate is present

Cadmium - Medium incidence

Cadmium Range (mg/l)	**Effects Poultry**
TWQR 0 - 0.005	*No adverse effects*
0.005 - 0.01	**Adverse chronic effects** such as reduced growth and decreased egg production may occur, but are unlikely if the following interactions are observed: - Added dietary ascorbic acid protects against Cd induced anemia. - Added Se and Zn reduce the effect of Cd toxicity. - Zn deficiency leads to increased liver Cd. - Fe deficiency leads to increased kidney Cd.
>0.01	**Adverse acute effects** such as nephritis and enteritis may occur. Immature birds are more susceptible than adults are.

Calcium - High incidence

Calcium Range (mg/l)	**Effects Poultry**
TWQR 0 - 75	*No adverse effects*
75 - 600	**Adverse chronic effects** such as a decrease in body weight, lowered feed intakes and an increase in condemnations may occur. This may be correlated with a negative effect on vaccines given in drinking water. Excessive scale deposits and scale formation may occur in water pipes. Dietary Ca:P ratio (1.1-2.0:1) very important in growers. Excess Zn reduces Ca availability and thus egg production. Excess Ca reduces P, Mn and F absorption. Excess dietary fat renders Ca less available. Could be tolerated in the long term>.
> 600	**Adverse chronic effects** as above may occur. **Adverse acute effects** such as embryonic abnormalities may occur. Could be tolerated in the long term>.

Chlorides - High incidence

Chlorides Range (mg/l)	**Effects Poultry**
TWQR 0 - 200	*No adverse effects*
200 - 500	**Adverse chronic effects** such as wet feces, excessive water consumption, ascites and reduced eggshell strength may occur. Can be detrimental when more than 50 mg/l Na is present. Affects the taste of the water, and may corrode the water pipes. Can tolerate short and medium term exposure>.
>500	**Adverse chronic effects** such as osmotic disturbances, hypertension, dehydration and renal damage may occur. Chicks are more tolerant than turkey poults. Tolerance in chicks increases after 3 weeks of age>.

Chromium - High incidence

Chromium Range (mg/l)	**Effects Poultry**
TWQR 0 - 0.1	*No adverse effects*
0.1 – 1	**Adverse chronic effects** such as a decreased growth rate may occur but are unlikely if feed concentrations are normal. Low toxicity. Fe, Zn and Vanadium are antagonistic to Cr. Long term exposure could be tolerated>.
> 1	**Adverse chronic effects** may occur, although short-term exposure could be tolerated>.

Copper - Medium incidence

Copper Range (mg/l)	**Effects Poultry**
TWQR 0 - 0.002	*No adverse effects*
0.002 - 0.6	**Adverse chronic effects** such as decreased body weight and increased feed conversions may occur. It gives a bitter taste to water. Could be tolerated in the long term>.
> 0.6	**Adverse acute effects** such as muscular dystrophy and liver damage may occur. **Adverse chronic effects** such as reduced body weight and feather loss may occur. Short-term exposure could be tolerated>.

Fluoride - Low incidence

Fluoride Range (mg/l)	**Effects Poultry**
TWQR 0 - 2	*No adverse effects*
2 - 10	**Adverse chronic effects** such as reduced feed and water intakes, lower growth rates and egg production may occur but are unlikely if: - feed concentrations are normal - exposure is short term>.
> 10	**Adverse chronic effects** as above and **adverse acute effects** such as skeletal fluorosis may occur. Excess Ca and Al reduce F toxicity and availability Short-term exposure could be tolerated>.

Iron - Medium incidence

Iron Range (mg/l)	**Effects Poultry**
TWQR 0 - 0.2	*No adverse effects*
0.2 - 0.4	**Adverse chronic effects** such as lower body weights and feed intakes might occur but is unlikely if: - feed concentrations are normal - exposure is short. Could be tolerated long term? if adequate Cu is present.
> 0.4	**Adverse chronic effects** (as above) may occur. Clogging of pipes and coloration of water. Can interfere with vaccination programs. Long term exposure could be tolerated>.

Lead - High incidence

Lead Range (mg/l)	**Effects Poultry**
TWQR 0 - 0.015	*No adverse effects*
0.015 - 0.1	**Adverse chronic effects** such as decreased egg size, lower hatchability and a decrease in performance may occur, but are unlikely if : - feed concentrations are normal; - exposure is short>.
> 0.1	**Adverse chronic effects** as above and **adverse acute effects** such as drowsiness, thirst, weakness, anorexia, diarrhea, anemia, crop stasis and peripheral paralysis may occur. It reduces the immune response, growth rate and egg production. Short-term exposure could be tolerated>.

Magnesium - High incidence

Magnesium Range (mg/l)	**Effects Poultry**
TWQR 0 - 125	*No adverse effects*
125 - 250	**Adverse chronic effects** such as diarrhea, intestinal irritation, watery droppings and lethargy may occur, but are unlikely if: - the sulfate level is low; - exposure is short>.
> 250	**Adverse chronic and acute effects** such as: Increased mortality and bone deformity, depressed growth rate and bone calcification, depressed egg production and watery feces may occur. Possibly interferes with vaccination programs. Short-term exposure could be tolerated>.

Manganese - Medium incidence

Manganese Range (mg/l)	**Effects Poultry**
TWQR 0 - 0.05	*No adverse effects*
0.05 - 0.6	Discoloration of water and turbidity deposits in pipes. Gives a bitter taste to water.
> 0.6	**Adverse chronic effects** such as a decrease in growth rate may occur. Excess P reduced Mn availability and excess Mn reduces Fe utilization. Short-term exposure could be tolerated>.

Mercury -Medium incidence

Mercury Range (mg/l)	**Effects □ Poultry**
TWQR 0 - 1	*No adverse effects*
1 - 2	**Adverse chronic effects** such as lowered feed intakes, weight loss, weakness and eggshell thinning may occur if mercury is in the organic form, but should be tolerated if their is adequate intake of Se and Vit E and the exposure time is short>.
> 2	**Adverse chronic and acute effects** such as neuro, hepato- and renal toxicity may occur although short-term exposure> could be tolerated.

Nitrates - High incidence and Nitrites - Low incidence

Nitrates Range (mg/l)	**Effects □ Poultry**
TWQR **0 - 25 (NO_3)** **0 - 4 (NO_2)**	*No adverse effects*
25 - 300 (NO_3)	**Adverse chronic effects** such as a decrease in performance could occur but is unlikely if: - more than 8000 IU of Vit A is present; - exposure is short>. Poultry are more resistant than ruminants.
> 300 (NO_3)	**Adverse chronic effects** such as decreased feed and water intakes, lower body weights and undesirable levels of methaemoglobin in the blood may occur. Condemnations may increase.

Selenium - Low incidence

Selenium Range (mg/l)	**Effects □ Poultry**
TWQR 0 - 10	*No adverse effects*
10 - 50	**Adverse chronic effects** such as severe fatty metamorphosis, reduced weight gains, reduced reproductive performance, lowered hatchability, deformed embryos, liver necrosis, muscle atrophy and degeneration and emaciation may occur. Short-term exposure could be tolerated>.
> 50	**Adverse chronic effects** as above, but short-term exposure can be tolerated>.

Sodium - High incidence

Sodium Range (mg/l)	**Effects □ Poultry**
TWQR 0 - 50	*No adverse effects*
50 - 250	**Adverse chronic effects** such as increased water consumption and wet litter may occur. Chloride and sulfate enhances effect. Could be tolerated if 500 mg/l bicarbonate is present.
> 250	**Adverse chronic effects** as above and **adverse acute effects** such as ascites resulting from pulmonary hypertension, increased mortality, reduced egg production, feed efficiency and egg weight, and reduced growth rate, particularly in males may occur. Short-term exposure can be tolerated>.

Sulfate - High incidence

Sulfate Range (mg/l)	**Effects Poultry**
TWQR 0 - 125	*No adverse effects*
125 - 250	**Adverse chronic effects** such as decreased performance, if the Mg or Cl levels are high may occur.
> 250	**Adverse chronic effects** as above may occur. Mg sulfate is more toxic than Na sulfate. May interfere with vaccination programs. Short-term exposure could be tolerated>.

Total Dissolved Solids - High incidence

Total Dissolved Solids Range (mg/l)	**Effects Poultry**
TWQR 0 - 1000	*No adverse effects*
1000 - 3000	Slightly saline. **Adverse chronic effects** such as decreased feed intakes, water intakes and performance may occur. Short-term exposure could be tolerated6.
> 3000	3000 - 10000 = Moderately saline 10000 - 35000 = Very saline > 35000 = Brine **Adverse chronic effects** as above may occur. Poultry more sensitive to high TDS than ruminants.

Zinc - High incidence

Zinc Range (mg/l)	**Effects Poultry**
TWQR 0 - 1.5	*No adverse effects*
1.5 – 15	**Adverse chronic effects** such as decreased growth and fertility, skin disease, muscular dystrophy and reduced bone ash may occur. Gives an astringent taste to water. Long term exposure could be tolerated>.
> 15	**Adverse chronic effects** as above may occur. The composition in the diet affects Zinc toxicity. Zinc carbonate is more toxic than Zinc oxide. Short-term exposure could be tolerated>.

2.2.1.3 Generic Guidelines – Trigger Values

The following constituents are presented in the form of single trigger guidelines. The rationale for the use of single trigger guideline format is predominantly one of insufficient guideline information necessary for the formulation of generic guidelines. Furthermore, constituents not normally encountered in the aquatic environment do not form the focus of poultry watering guidelines, but are included for the sake of providing a guideline. The trigger values and affected constituents are provided in Table 2.3.

Table 2.3 WQC addressed as Single Trigger Guidelines for the Generic System.

CONSTITUENT	TWQR
Aluminium	0 - 5 mg/l
Ammonium	0 - 2 mg/l
Antimony	0 - 0.006 mg/l
Bacteria	Total = 0 - 100 colonies / ml Coliform = 0 - 50 colonies / ml
Barium	0 - 2 mg/l
Beryllium	0 - 0.004 mg/l
Bismuth	0 - 0.001 mg/l
Boron	0 - 5 mg/l
Bromide	0 - 3 mg/l
Cesium	0 - 50 000 mg/l
Carbonate	0 - 500 mg/l
Cerium	0 - 2 mg/l
Cobalt	0 - 1 mg/l
Colour	0 - 15 colour units
Cyanide	0 - 0.2 mg/l
Dissolved oxygen	0 - 10 % saturation
Electrical conductivity	0 - 1980 mS/m
Gold	0 – 5mg/l
Hardness (CaCO3)	> 180 mg/l = hard < 60 mg/l = soft
Herbicides: 2,4-D 2,4,5-T 2,4,5-TP	 0 - 100 mg/l 0 - 100 mg/l 0 - 10 mg/l
Hydrogen Sulfide	0 - 0.3 mg/l

Indium	0 - 1 mg/l
Iodide	0 -1 mg/l
Lanthanum	0 - 1 mg/l
Lithium	0 - 5 mg/l
Magnesium sulfate ($MgSO_4$)	200 mg/l
Molybdenum	0 - 10 mg/l
Nickel	0 - 1 mg/l
Odour	0 - 3 threshold odour number
Pesticides:	
Aldrin	0 - 0.03 mg/l
Chlordane	0 - 0.3 mg/l
DDT	0 - 1 mg/l
Dieldrin	0 - 0.03 mg/l
Endrin	0 - 0.2 mg/l
Heptachlor	0 - 0.1 mg/l
Lindane	0 - 4 mg/l
Methoxychlor	0 - 30 mg/l
Toxaphene	0 - 5 mg/l
Parathion	0 - 500 mg/l
Malathion	0 - 500 mg/l
pH	6.4 – 9
Phosphate	0 - 2 mg/l
Potassium	0 - 2000 mg/l
Radio-activity	
Gross alpha	0 - 3 picocurie/l
Gross beta	0 - 30 picocurie/l
^3H (tritium)	0 - 1000 picocurie/l
Radium	0 - 1 mg/l
Rubidium	0 - 5 mg/l
Scandium	0 - 1 mg/l
Silver	0 - 0.05 mg/l
Sodium Bicarbonate	0 - 1000 mg/l

Sodium sulfate (Na_2SO_4)	0 - 1200 mg/l
Sodium chloride (NaCl)	0 - 1500 mg/l
Strontium	0 - 10 mg/l
Tellurium	0 - 0.005 mg/l
Thallium	0 - 0.002 mg/l
Thorium	0 - 0.0005 mg/l
Tin	0 - 0.05 mg/l
Titanium	0 - 0.2 mg/l
Tungsten	0 - 0.5 mg/l
Turbidity	0 - 5 NTU
Uranium	0 - 0.2 mg/l
Vanadium	0 - 0.1 mg/l
Yttrium	0 - 0.001 mg/l
Zinc Sulphate	0 - 10 000 mg/l
Zirconium	0 - 1 mg/l

2.2.1.5 Generic WQGIS - Software environment

The basic sequence of screens for the Generic WQGIS application level are as follows:

Screen 1 – 4

When using the software programme the first screens that appear are where the options between the two application levels can be chosen. Once either of the options was chosen the Animal Production System screen becomes active and the option for "poultry" can be chosen. This will prompt the user to press the "Finish" button, to proceed.

Screen 5 and 9

Livestock detail can be entered on this screen, click on the "insert" button to choose livestock types. The livestock type options in screen 9 then appears. The "General" tab prompts the user to enter general information about the specific borehole, its district and general information on the client.

Screen 6

In the sample Results Screen (Screen 6), the water analysis results are entered. Water Quality Constituents are chosen using the "Insert" button. The poultry constituent list is then presented and constituents can be chosen to represent the water sample analyzed. The "water source" tab gives the user the choice of water source, sample sites and precise location of the water source.

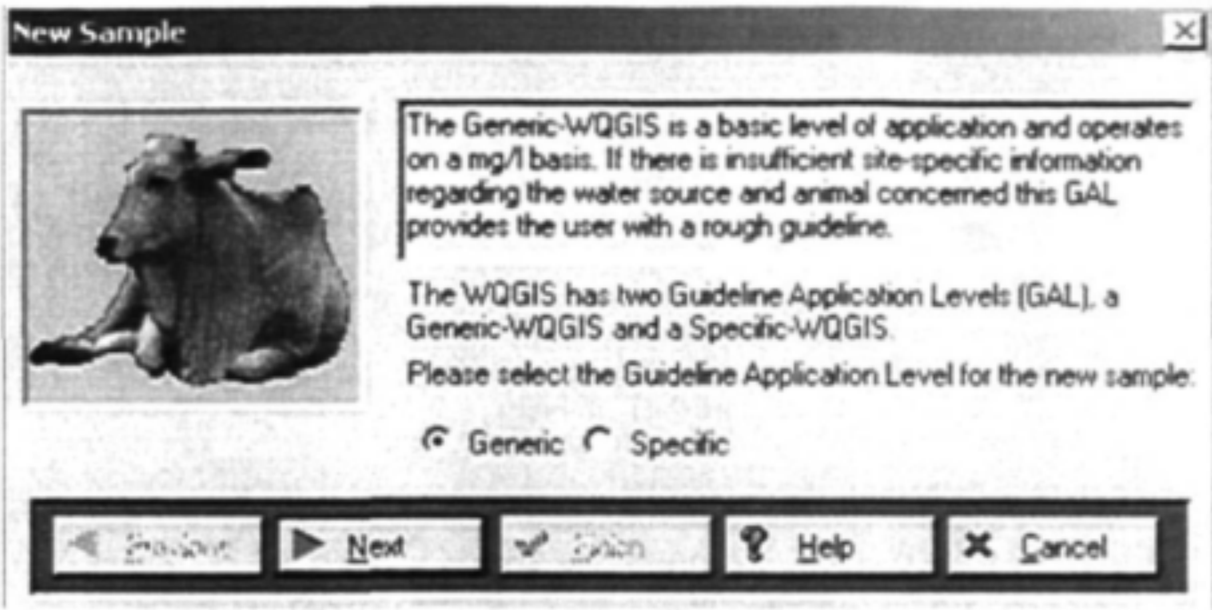
Screen 7

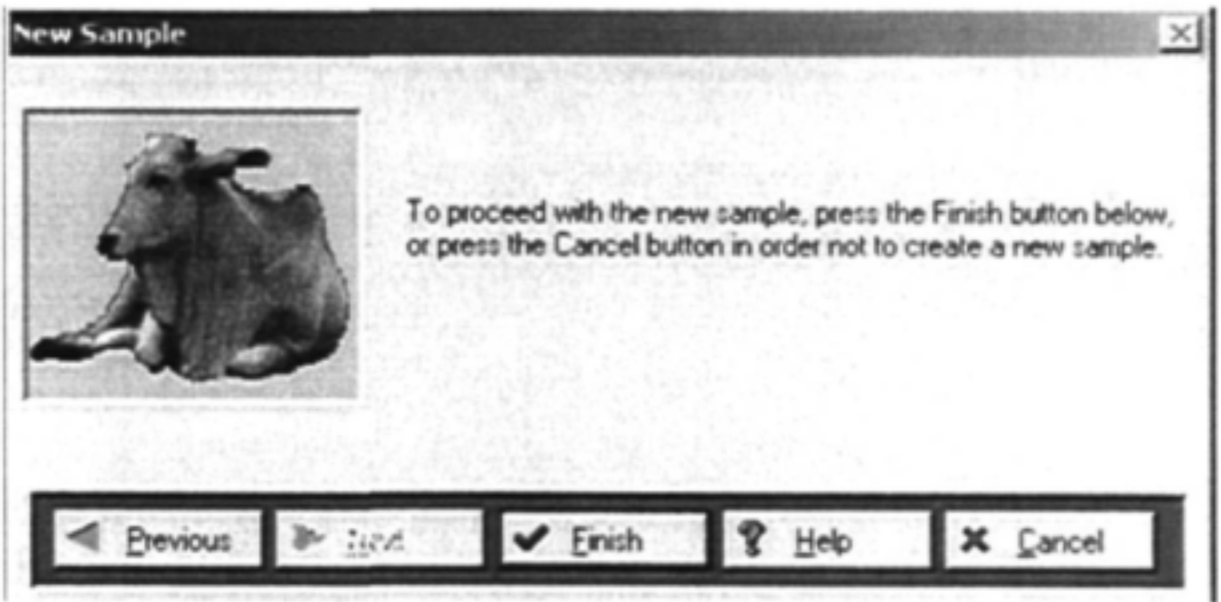
Gives the user the opportunity to describe specific problems and acts as reference for program users not on site, to get a "feel" for the circumstances of the client.

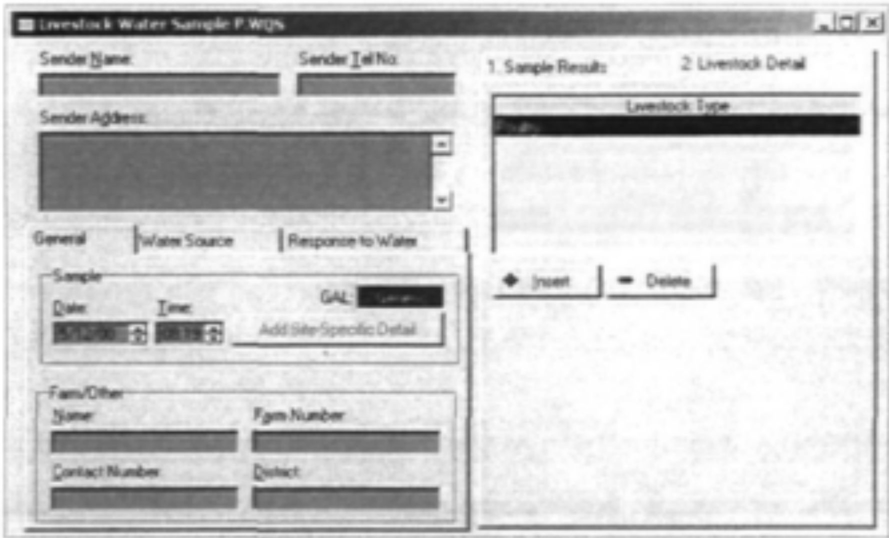
Screen 8

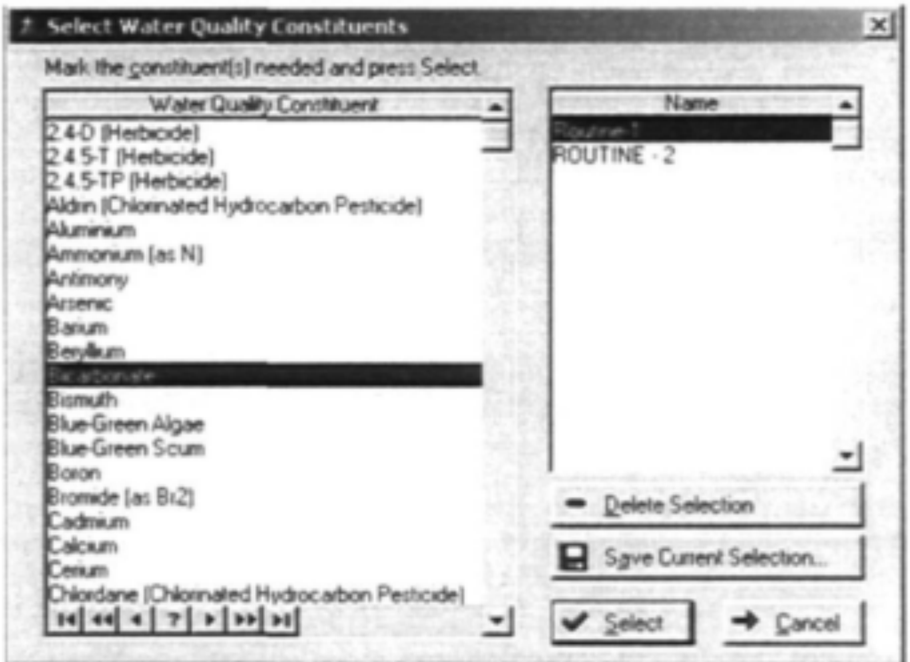
Once the sample results have been entered, it is possible to change it, by choosing the "change sample results" tab.

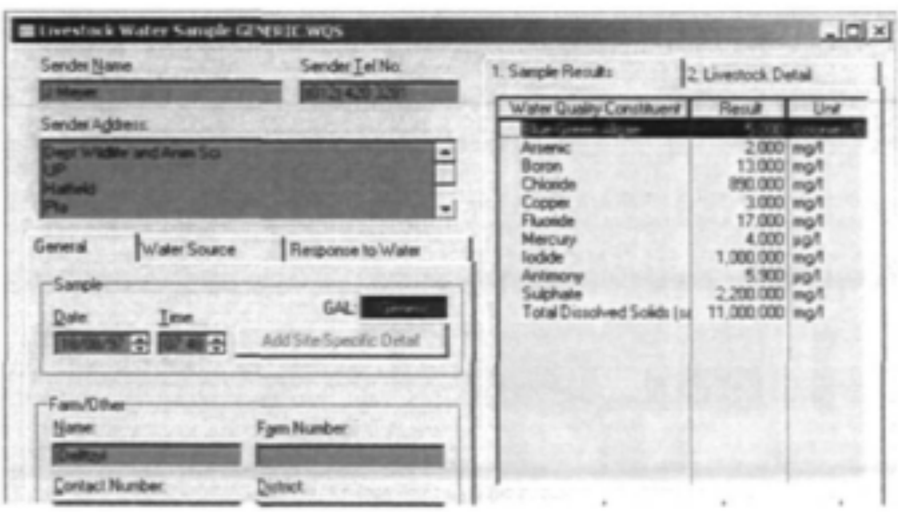
Examples of some of these screens are provided next.

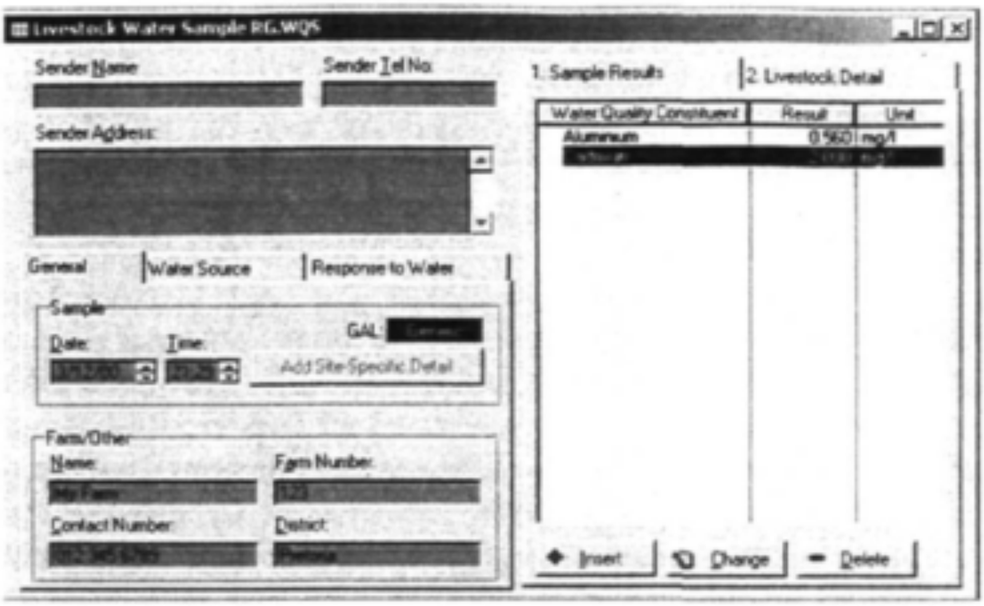

New Sample
The Generic-WQGIS is a basic level of application and operates on a mg/l basis. If there is insufficient site-specific information regarding the water source and animal concerned this GAL provides the user with a rough guideline.
The WQGIS has two Guideline Application Levels (GAL), a Generic-WQGIS and a Specific-WQGIS.
Please select the Guideline Application Level for the new sample:
Generic
Specific
Next
Help
Cancel

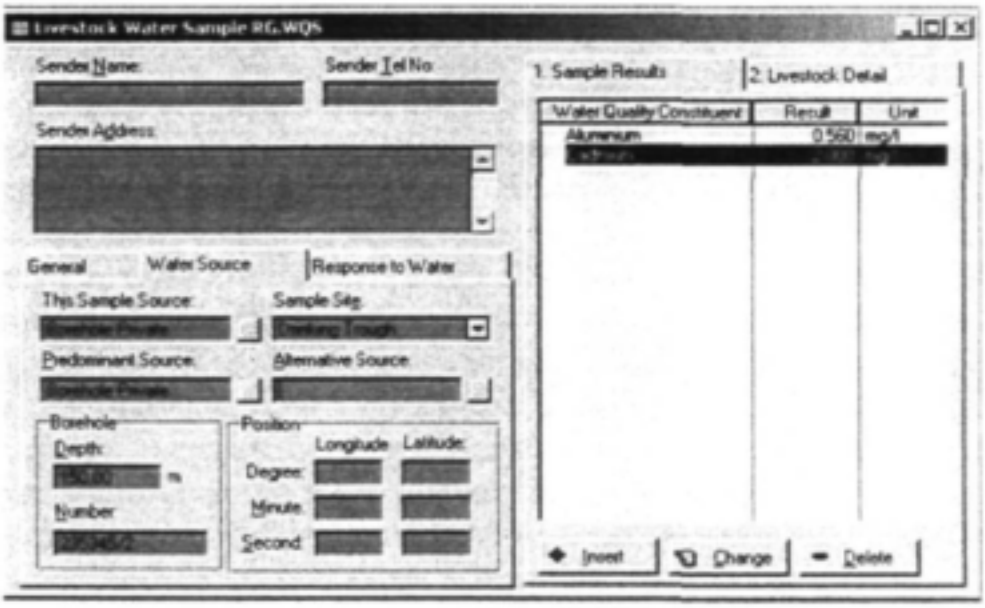

New Sample
To proceed with the new sample, press the Finish button below, or press the Cancel button in order not to create a new sample.
Previous
Finish
Help
Cancel

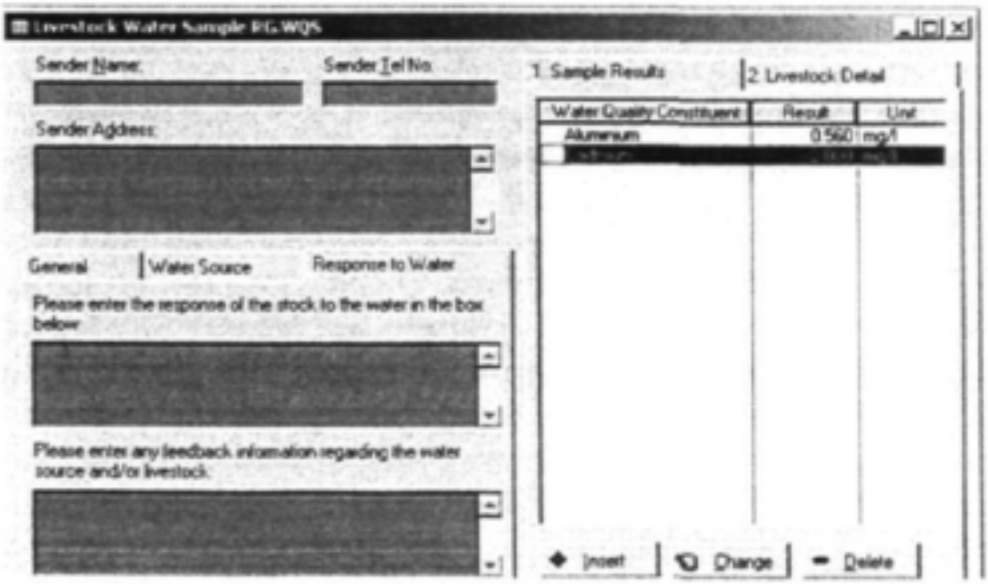

Livestock Water Sample P.WQS
Sender Name
Sender Tel No
Sender Address
1. Sample Results
2. Livestock Detail
Livestock Type
Insert
Delete
General
Water Source
Response to Water
Sample
Date
Time
GAL
Add Site-Specific Detail
Farm/Other
Name
Farm Number
Contact Number
District

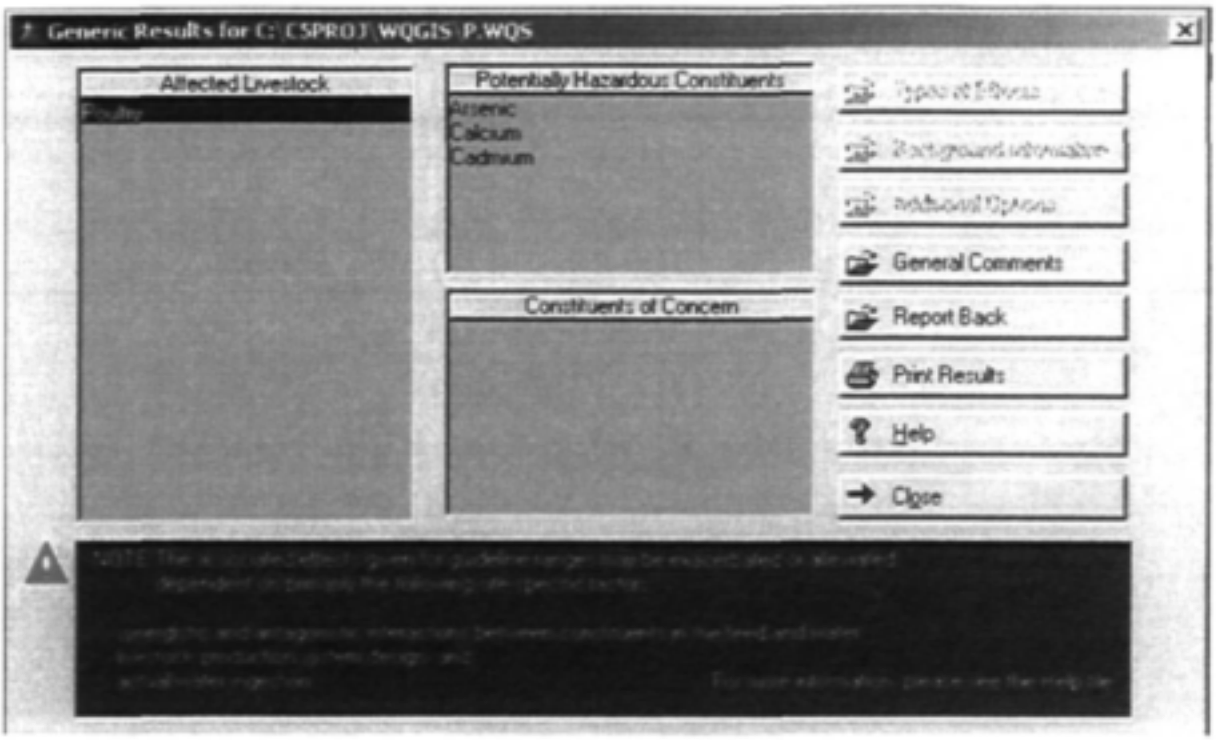

Select Water Quality Constituents
Mark the constituent(s) needed and press Select
Water Quality Constituent
2,4-D (Herbicide)
2,4,5-T (Herbicide)
2,4,5-TP (Herbicide)
Aldrin (Chlorinated Hydrocarbon Pesticide)
Aluminium
Ammonium (as N)
Antimony
Arsenic
Barium
Beryllium
Bismuth
Blue-Green Algae
Blue-Green Scum
Boron
Bromide (as Br2)
Cadmium
Calcium
Cerium
Chlordane (Chlorinated Hydrocarbon Pesticide)
Name
ROUTINE - 2
Delete Selection
Save Current Selection...
Select
Cancel

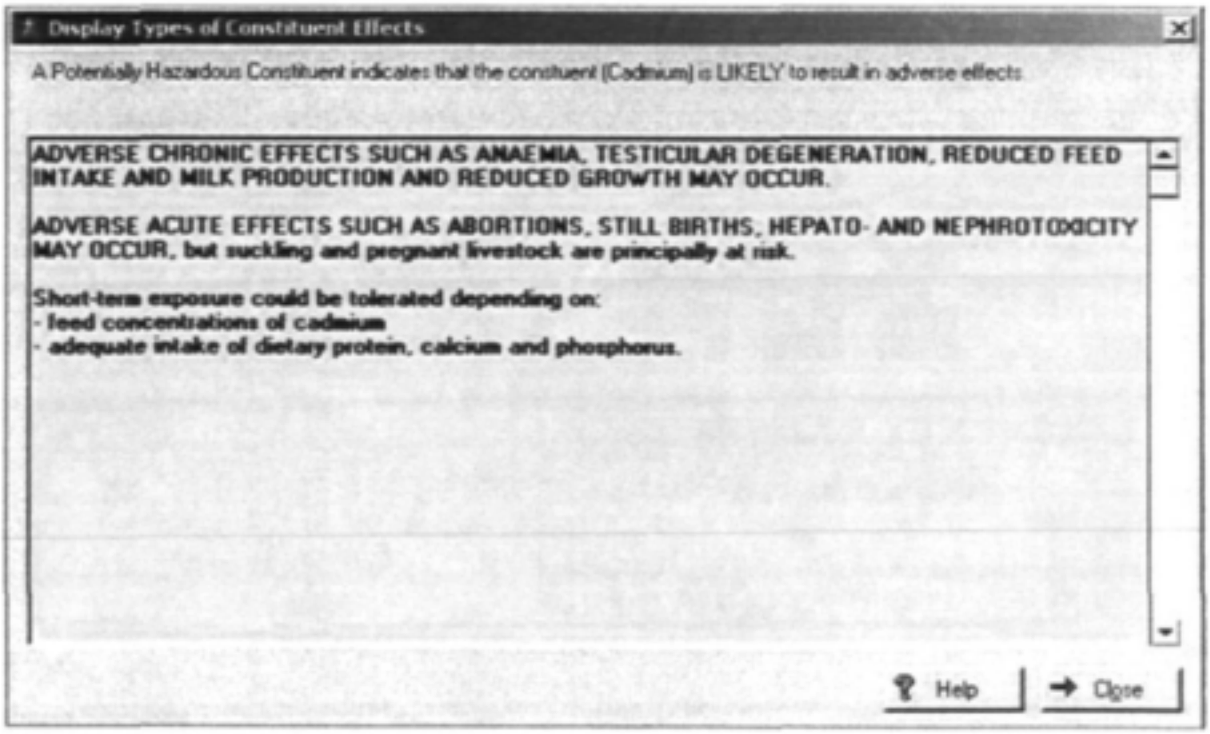

Livestock Water Sample GENERIC.WQS
Sender Name
Sender Tel No
Sender Address
1. Sample Results
2. Livestock Detail
Water Quality Constituent
Result
Unit
Arsenic 2.000 mg/l
Boron 13.000 mg/l
Chloride 890.000 mg/l
Copper 3.000 mg/l
Fluoride 17.000 mg/l
Mercury 4.000 µg/l
Iodide 1,000.000 mg/l
Antimony 5.900 µg/l
Sulphate 2,200.000 mg/l
Total Dissolved Solids 11,000.000 mg/l
General
Water Source
Response to Water
Sample
Date
Time
GAL
Add Site-Specific Detail
Farm/Other
Name
Farm Number
Contact Number
District

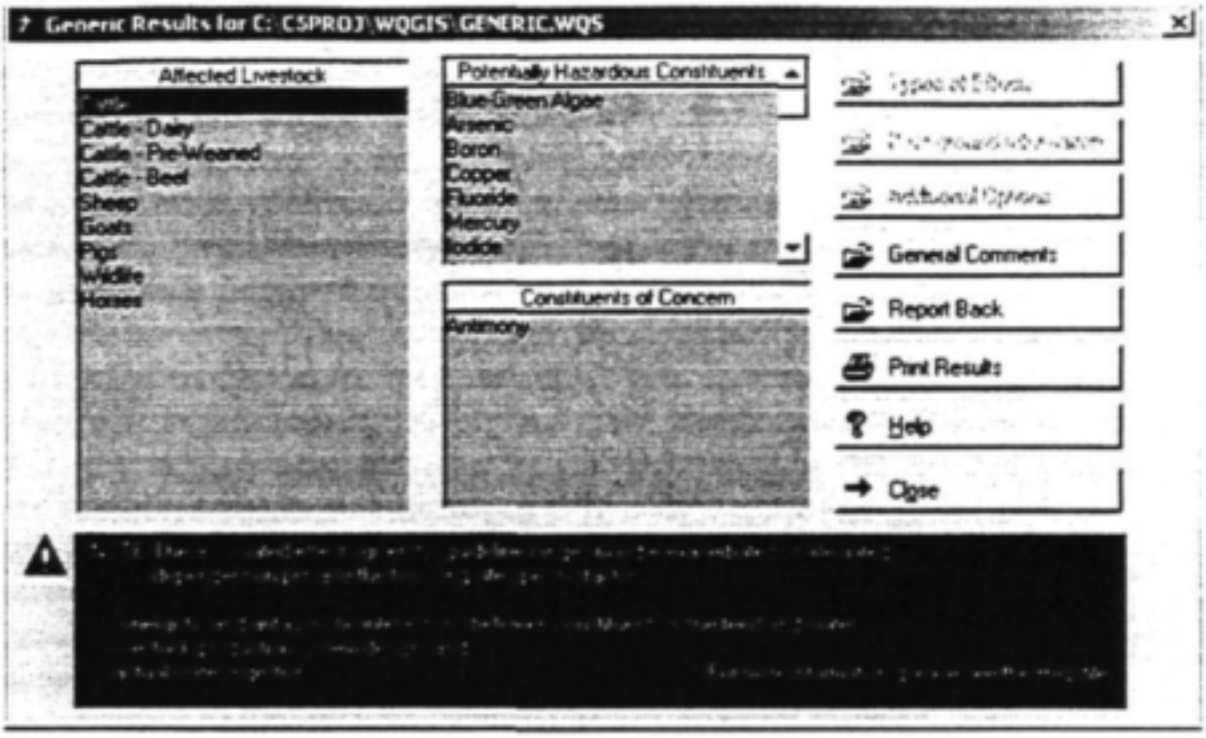

Livestock Water Sample RG.WQS
Sender Name:
Sender Tel No:
Sender Address:
General
Water Source
Response to Water
Sample
Date:
Time:
GAL:
Add Site-Specific Detail
Farm/Other
Name:
Farm Number:
Contact Number:
District:
1. Sample Results
2. Livestock Detail
Water Quality Constituent
Result
Unit
Aluminium
0.560
mg/l
Insert
Change
Delete

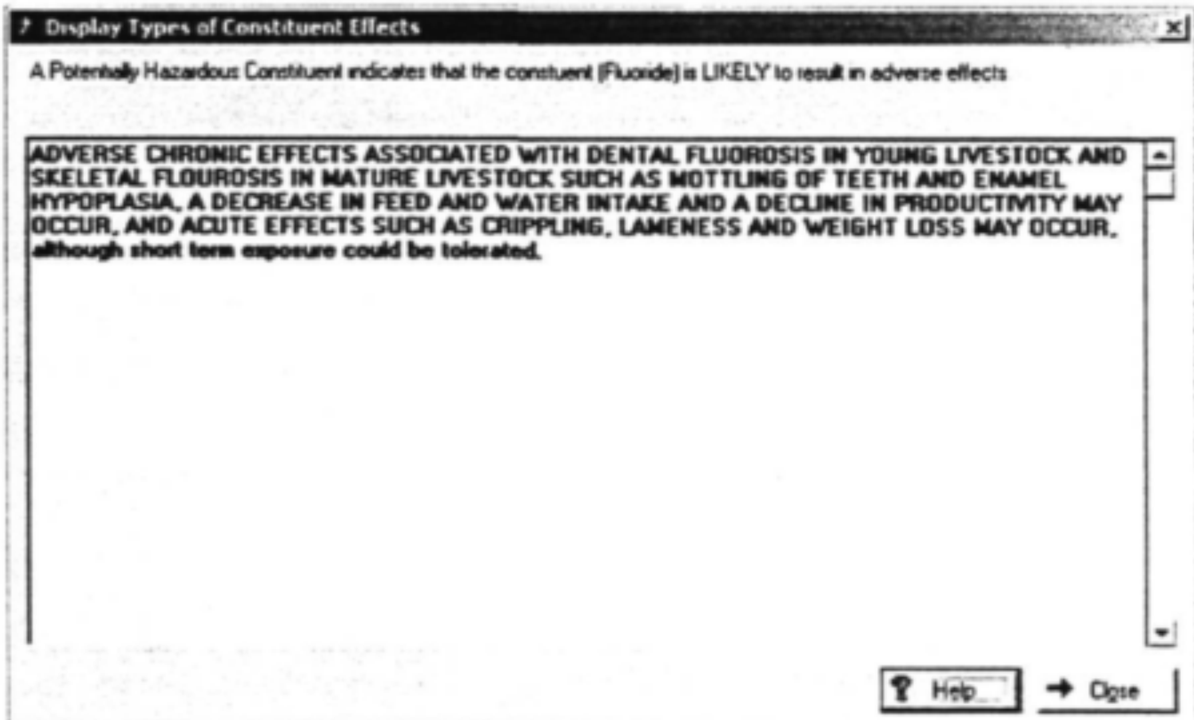

Livestock Water Sample RG.WQS
Sender Name:
Sender Tel No:
Sender Address:
General
Water Source
Response to Water
This Sample Source:
Sample Site:
Predominant Source:
Alternative Source:
Borehole
Depth:
m
Number:
Position
Longitude
Latitude
Degree:
Minute:
Second:
1. Sample Results
2. Livestock Detail
Water Quality Constituent
Result
Unit
Aluminium
0.560
mg/l
Insert
Change
Delete


Livestock Water Sample RG.WQS
Sender Name:
Sender Tel No:
Sender Address:
General
Water Source
Response to Water
Please enter the response of the stock to the water in the box below
Please enter any feedback information regarding the water source and/or livestock
1. Sample Results
2. Livestock Detail
Water Quality Constituent
Result
Unit
Aluminium
0.560
mg/l
Insert
Change
Delete


Generic Results for C:\CSPROJ\WQGIS\P.WQS
Affected Livestock
Potentially Hazardous Constituents
Arsenic
Calcium
Cadmium
Constituents of Concern
General Comments
Report Back
Print Results
Help
Close


Display Types of Constituent Effects
A Potentially Hazardous Constituent indicates that the constuent (Cadmium) is LIKELY to result in adverse effects
ADVERSE CHRONIC EFFECTS SUCH AS ANAEMIA, TESTICULAR DEGENERATION, REDUCED FEED INTAKE AND MILK PRODUCTION AND REDUCED GROWTH MAY OCCUR.
ADVERSE ACUTE EFFECTS SUCH AS ABORTIONS, STILL BIRTHS, HEPATO- AND NEPHROTOXICITY MAY OCCUR, but suckling and pregnant livestock are principally at risk.
Short-term exposure could be tolerated depending on:
- feed concentrations of cadmium
- adequate intake of dietary protein, calcium and phosphorus.
Help
Close


Generic Results for C:\CSPROJ\WQGIS\GENERIC.WQS
Affected Livestock
Cattle - Dairy
Cattle - Pre-Weaned
Cattle - Beef
Sheep
Goats
Pigs
Wildlife
Horses
Potentially Hazardous Constituents
Blue-Green Algae
Arsenic
Boron
Copper
Fluoride
Mercury
Iodide
Constituents of Concern
Antimony
General Comments
Report Back
Print Results
Help
Close


Display Types of Constituent Effects
A Potentially Hazardous Constituent indicates that the constuent (Fluoride) is LIKELY to result in adverse effects
ADVERSE CHRONIC EFFECTS ASSOCIATED WITH DENTAL FLUOROSIS IN YOUNG LIVESTOCK AND SKELETAL FLOUROSIS IN MATURE LIVESTOCK SUCH AS MOTTLING OF TEETH AND ENAMEL HYPOPLASIA, A DECREASE IN FEED AND WATER INTAKE AND A DECLINE IN PRODUCTIVITY MAY OCCUR, AND ACUTE EFFECTS SUCH AS CRIPPLING, LAMENESS AND WEIGHT LOSS MAY OCCUR, although short term exposure could be tolerated.
Help...
Close

2.2.2 SPECIFIC WQGIS

2.2.2.1 Introduction

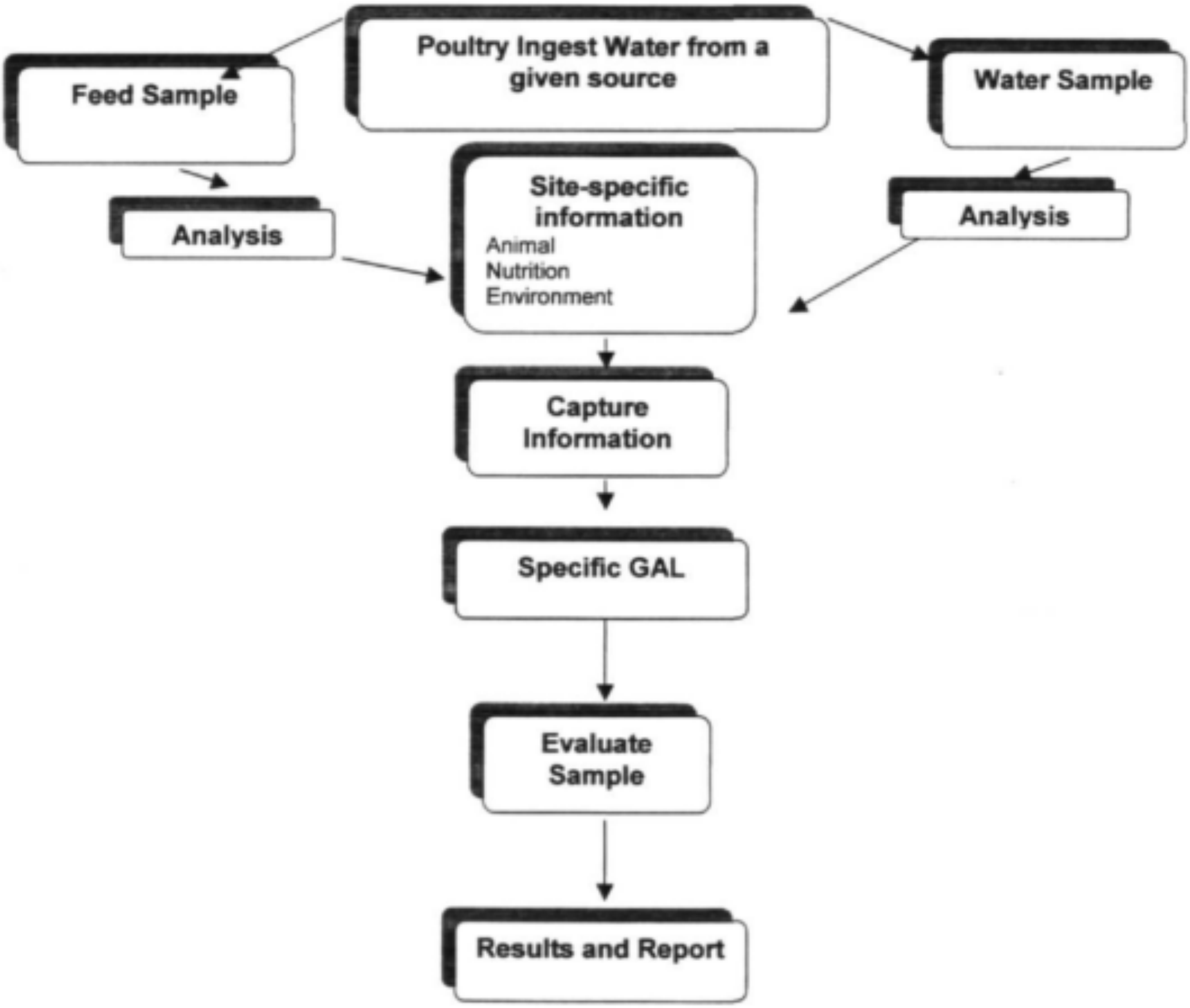
The specific GAL is the preferred application for poultry watering as it incorporates the site-specific influences on water ingestion as well. This is achieved by making use of simulation modelling.

The specific GAL can:

- Establish the ingestion rate of a specific water quality constituent;
- Take system factors into consideration – Animal
  Environment
  Nutrition
- Do a risk assessment;
- Make proposed solutions.

Figure 2.2 presents a brief schematic outline of the primary procedures applied in the Specific WQGIS.

Figure 2.2 Procedures used for the Specific WQGIS for poultry.



2.2.2.2 Key aspects addressed by the Specific WQGIS

2.2.2.2.1 Water turnover

In addition to being a vital nutrient, some of the other more important and essential functions water provides includes:

- Assisting in softening the feed in the crop and form a carrier for feed during its passage trough the digestive tract, and to act as an aid in certain digestive processes;
- Helping cool the bird by evaporation through the lungs and air sacks;
- Making up a large percentage of the body (85% water in one week old chicks);
- It is an important part of blood and lymph; and
- Using as a medium through which medications can be administered to the birds, (Muirhead, 1995).

A study of water metabolism is not complete until one equates the water intake with that lost from the body through all routes. Commercial and free-range chickens have 3 main water sources:

- Free water in the form of streams, lakes, puddles, rain, snow or dew, boreholes and municipal sources, which they drink;
- Pre-formed water contained in the food, which they eat; and
- Oxidative or metabolic water produced incidental to their oxidation of organic compounds containing hydrogen.

2.2.2.2.2 Water intake

2.2.2.2.2.1 Drinking water

Most of the water intake of birds comes from the water drunk, this is in contrast with other animals that eat a succulent diet.

The amount of water consumed increased with increased air temperature, live weight and rate of egg production. The addition of increasing amounts of salt to the ration causes a progressive increase in water intake per gram of feed consumed. Increasing the protein content of the feed also increases the water consumption. Environmental temperature increases water intake drastically. Feed particle size has no effect on water consumption. Rate of egg production also increased water intake. Egg production however was not the only reason for increased water consumption in hens, oestrogen could also have an effect, since non-producing hens also had higher water turnover rates (Medway & Kare, 1959).

It is expected that water consumption, like evaporative loss, will increase with increasing environmental temperature. Evaporative water loss and percent body water are higher in one-day-old chicks than in older birds. Domestic fowl can survive approximately a 45% body water loss before death (Mulkey & Huston, 1967).

2.2.2.2.2.2 Moisture in the feed

The water taken in with the feed can easily be calculated from feed consumption data and the water content of the feed.

2.2.2.2.2.3 Metabolic water

Water turnover.

The half-life of water in the pool may be calculated from the turnover constant by means of the following relationship.

$$t½ = 0.693 / K$$

The half-life of the body water in hens ranged from 2.6 tot 4.4 days, with an average value of 3.61 ±0.33 days. In cocks the t½ ranged from 6.3 to 8.2, with an average value of 7.3 ± 0.32 days.

The half-life for body water in the hen is similar to that in cattle and the rat. On the other hand, the longer half-life for body water in the cock is in the same range as that for the dog and the horse. The total body water in percent of body weight is 64.1 ± 2.9 % for the cocks and 62.0 ± 4.2 % for the hens.

Approximately 10 % of the body water pool turns over per day in cocks and roughly 20 % per day in hens. The flux through the body water pool amounted to 60 and 125 ml per day per kg of body weight for cocks and hens, respectively.

The t½ for the body water pool of hens, regardless of their rate of egg production, was significantly less than that for cocks (Chapman & Black, 1967). In the 1-week-old chick, total body water was found to be 85,2% of the body weight, this percentage dropped rapidly to begin with and decreased to 55.0% in the mature bird. Plasma water content had a very narrow range from 95.5% in the 1-week-old to 94,6% in the mature hen (Medway, 1958).

Metabolic water.

A comparison of the amount of oxidative water produced with the amount of water lost through evaporation and other routes allows an estimate of the general importance of metabolic water in avian physiology. The maximum and minimum amounts of oxidative water which a bird of a given size will produce at rest can be calculated if the following assumptions are made.

The relation of body weight to basal metabolism is expressed by Brody's (1945) formula:

- kcal/day = 89(wt. in kg) to the power of 0.64
- The oxidation of 1g of fat yields 1.07g of water and 9.2 kcal.
- The oxidation of 1g of carbohydrate yields 0.56 g of water and 4.10 kcal
- The oxidation of 1g of protein yields 0.40g of water and 4.10 kcal (Bartholomew & Cade, 1963).

2.2.2.2.3 Water loss

Water loss occurs from predominantly pulmocutaneous and evaporative water loss. In the absence of temperature stress, an inverse relationship between evaporative water loss and body weight occurs. This relationship is generally independent of taxonomic affinities and habitat. Presumably most of the evaporated water is lost from the respiratory system and air sacs and relatively little through the skin and plumage.

It is to be expected that water consumption, like evaporative loss, will increase with increasing environmental temperature. There can be little doubt that the increased water consumption offsets the loss of water incidental to an increase in heat dissipation by the evaporation of water from the respiratory tract. The fact that birds store heat in hot environments, and consequently undergo a rise in body temperature, results mainly form the inability of their panting to produce adequate evaporative cooling. The severity of water loss through evaporation under natural conditions is even more acute than indicated because the ratio of water evaporated to oxygen consumed becomes increasingly more unfavourable the higher the environmental temperature (Bartholomew & Cade, 1963).

It is not known why small birds have a greater weight-relative evaporative water loss than large ones, but the greater loss of birds compared wth mammals probably reflects a higher rate of respiratory loss owing to expiration of warmer air of greater moisture-carrying capacity than expired by rodents. *Ad libitum* water consumption is inversely related to body weight and the curve is strikingly similar to the comparable one for evaporative water loss. Thus the data on water consumption are consistent with the generalisation that the high level of evaporative water loss in most small birds necessitates substantial intake of water by drinking or from succulent food (Bartholomew & Cade, 1963).

The amount of water lost in the 1-day-old chick is appreciably higher than that of the adult expressed as a ratio of body weight (1-day-old chicks 0.63 gm H2O/gm body wt/day, 8-month old pullet 0.31 gm H2O/gm body wt/day). This large loss is believed to be in part the result of a marked respiratory loss due to a rapid rate of breathing during the first day. This is thought to be related to the changeover from allantoic respiration to pulmonary respiration, which results in a relative anorexia. Evaporative water loss decreases as the chicken matures. Some workers feel that in the adult bird, the cutaneous water loss is negligible and that the evaporative water loss is entirely of respiratory origin.

The authors did not however agree with the above statement, since a chicken is soft and pliable, they feel that there must therefore be an appreciable amount of water lost through the skin and this should not be overlooked.

The basal metabolic rate is below that of the adult at hatching, rises sharply to a peak between 2 to 4 weeks of age, then gradually tapers of to that of the adult hen. (Medway & Kare, 1957).

- Osmoregulation and electrolyte excretion.

  The kidney contributes to the regulation of the total osmotic concentration of the body fluids and also to the relative concentrations of the various ions in the body fluids by controlling the volume of water and the concentrations of ions entering the urine. The blood plasma is a convenient sample of the body fluids, and the clear liquid, which is voided with the uric acid and faecal materials, can be treated as a sample of the urine.

  The amount of chloride in the urine increases directly with the salinity of the drinking solution. Adaptation of birds to dry climates involves decrease in relative evaporative water loss (mechanism unknown), decrease in GFR, and high urine osmolality in the dehydrated state in conjunction with cloacal resorption parameters, which allows the urine to enter the cloaca without a further water loss. Birds tolerate a 7 to 13% increase in plasma osmolality (Skadhauge, 1976)

- Dehydration.

  Weight loss is not the most accurate index for degree of dehydration, because water deprivation sometimes reduces food consumption.

  Since evaporative loss and *ad libitum* consumption of water are both inversely related to body weight, large birds can be expected to lose weight less rapidly than small ones when denied water and maintained on a dry diet. (Bartholomew & Cade, 1963).

- Urine output.

  Like all animals, birds produce water by their metabolism. Because of their high metabolic rates, the quantity of water thus produced by birds is greater in relation to body size than for other vertebrates. Moreover from the standpoint of water conservation, birds have an important physiological advantage over mammals: their nitrogen excretion involves uric acid instead of urea. Molecule for molecule twice as much nitrogen can be excreted as uric acid as in urea. Furthermore, uric acid can be excreted in a semi-solid suspension, whereas urea must be excreted in aqueous solution, which, inevitably, involves a considerable loss of water. Most mammals require approximately 20ml of water to excrete 320 mg of urea, whereas a comparable amount of uric acid can be excreted in 0.5 - 1.0 ml of water.

  The avian kidney however is much less effective than the mammalian kidney in excreting electrolytes. Electrolytes are not reabsorbed from the urine contained in the cloaca. From a physiological basis this would indicate that the role of the cloaca resembles that of the urinary bladder of other mammals. The role of the cloaca in water metabolism is therefore a minor one.

  During the period when an egg is formed, a marked increase in water intake is observed. The overall increase in fluid intake is associated with a fall in plasma osmolarity of up to 14% and an increase in urine minute volume, this can be explained as a simple osmotic adjustment.

  Plasma osmolarity changes follow alterations in ingestive activity with a phase lag of less than 0.5 h, indicating rapid assimilation of ingested water, but changes in renal output are much slower (1.5 h later) and are quantitatively insufficient to account for the increased fluid intake which occurs at that time.

  Only 8g more urine was produced on a laying than on a non-laying day, and the water content of an egg is approximately 32g, though the extra water ingested amounted to 140g, the accountable fluid loss on a lying day is only 40g (Howard, 1975). There is a direct association between the drinking response and urine excretion via the kidneys (Benoff & Buss, 1976). Birds can excrete uric acid in a concentration some 3000 times greater than that in the blood (Mulkey & Huston, 1967).

2.2.2.3 Primary model components

The establishment of water quality guidelines for poultry depends on the interaction among a great many factors. Some of these factors relate to the animal, some to its diet, some to its environment, some to the prevalence of disease and some to circumstances outside the production enterprise, such as breeding stock etc.

Although there has been a great deal of research into many of these factors, the complexity of the interactions between them makes it virtually impossible for the human mind to access accurately the complexities of this problem. By transforming the concepts and knowledge into mathematical equations and integrating them in computer programs using simulation modelling techniques, this vast store of information can be applied directly.

The simulation model should as far as possible, be based on descriptions of the mechanisms perceived to determine animal function, not on empirical relations of correlation and association (Black *et al*,. 1993).

2.2.2.3.1 Basis of the Specific Water Quality Application Level

The basis of the Specific WQG application is a water ingestion rate reference document, or WIRRD (Casey *et al*., 1998; Meyer, 1998). The reader is referred to the WRC Final Report 644 for a detailed description and supporting information of the WIRRD concept. This section describes the modifications made to the WIRRD used for the modelling of risk assessment for cattle, sheep, goats, horses and pigs, as employed by the software program CIRRA (Meyer, 1998). These modifications allow for the inclusion of poultry production systems to the list of potential user groups.

This reference document consists of:

- Categories per production system (NRC), which addresses different production systems and ages;
- Body weights (broilers);
- Body weights (broilers);
- Feed intakes;
- Egg production (layers);
- Moisture content of the feed;
- Total water intakes; and
- Constituent ingestion rates.

After all the above information has been incorporated into the WIRRD, the end result is a water quality ingestion rate guideline.

The water ingestion of a bird can either be predicted, using regression formulae, or it can be provided by the user. The Water intake derived from the formulae or the input is then converted to a

$$TWI = WI + \%\ \text{moisture in the feed}$$

An exponential relation exists between standard energy metabolism and body weight in organisms that is described by the generalized equation:

$$\text{Metabolic Rate} = a\,(\text{Body weight})^{b}$$

Where a and b are empirically derived constants.

The equation can be rewritten as:

$$\text{Log Metabolic rate} = \log a + b \log \text{Body Weight}$$

The above is a straight line. A b-value of 0.75 best describes the relation of energy metabolism to body size in all organisms. Lasiewski (1967), however found that passerine birds have a higher weight-specific metabolic rate than nonpasserines, although the weight-metabolism regression coefficients (b-values) are virtually identical (0.724 and 0.723, respectively). An equation for all groups of birds is an artifact of combining passerine and nonpasserine data.

Fig2.3 A comparison of the regression lines for passerine birds, nonpasserine birds and all birds (Lasiewski; 1967)

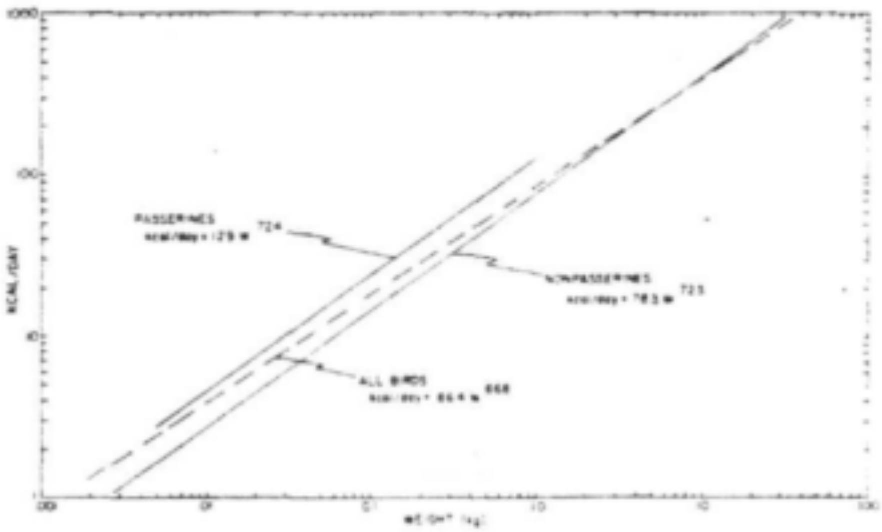
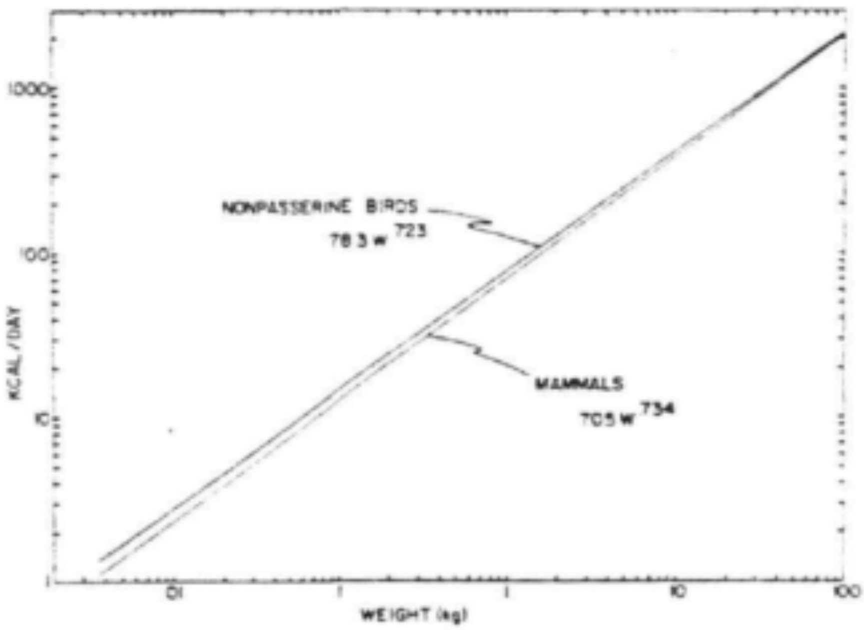


Fig 2.4 A comparison of the regression lines for passerine birds and for mammals.



The TWI is then converted to a WIR per day in l/kg metabolic mass using the exponent 0.75.

An example of a WIRRD for the WQC arsenic is provide in Figure 2.5.

Figure 2.5 Example of a WIRRD for Arsenic.

Category Body weight	Age	Feed intake	% Moisture	Range A	Range B
Broiler 1.237 kg	4 (3-6weeks)	0.119	11	0.0088	0.0352

WI = 0,1928

TWI = 0.1928 + 0.0131

= 0.206

Metabolic water intake:

$= 0.206/BW^{0.75}$

= 0.176

Ingestion Rate of Arsenic:

Range A = 0.176 * 0.05

COC= 0.0088

Range B = 0.176 * 0.2

PHC= 0.0352

2.2.2.3.2 Modifying system factors

Each of the site-specific factors will effect the WIR and therefore the results of the risk assessment. Site specific factors alter the water concentration at which a given constituent will cause an adverse effect. A risk assessment can not be made on a water concentration analysis alone, but requires all variables altering the intake or ingestion rate of a constituent to be taken into account. The model includes an option of including site-specific factors or excluding them. The WIRRD is modified according to the effect of the variable on the TWI and WIR.

For example: A broiler in a back yard venture, will not have the same production capability in terms of live-weight gain as a broiler in a commercial venture with environment controlled housing, the correct lighting schedule, stocking densities and feeder and drinker space. Some variables will therefore benefit the WIR and some will penalize the WIR.

2.2.2.3.3 Site-specific factors addressed

The site-specific factors affecting water intake and thus the WIRRD of poultry are the following:

- **Poultry detail:**

*Production system	*Breed
*Category	*Application
*Age	*Sex

The production systems addressed are the following:

- Broiler
- Layer
- Dual purpose (indigenous) – Meat/egg
- Egg/meat
- Breeders

Each of these production systems can be operated at one of the following application levels:

- Commercial
- Semi-intensive
- Back yard
- Free ranging

- **Animal detail:**

General

*Feed intake	Water intake
*Body weight	Mortalities
Life cycle length	Wet droppings
Flock size	Gender ratio
Beak trimming	

Broilers

*Target body weight
*Body weight gain
Feed conversion ratio

Layers

*Egg production
Egg weight
Egg shell strength
Age at first egg

Breeders

Gender ratio
*Egg production
Egg weight
Eggshell strength
Age at first egg

Dual purpose

All the above

- **Environmental detail:**

Housing
Ventilation rate
Lighting
Stocking density
Air velocity
Feeder space/type
Drinker space/type
Relative humidity
Altitude
Temperature
Floor type

- **Nutrition:**

General

Feeding program
Watering program
Feed texture/Pellet size
Phase feeding
Raw materials
Additives
Vaccines/medication
Vitamin and trace mineral premixes
Nutrient interrelationships
Palatability
NaCl
Protein
Energy
Lysine
Ca:P

Some of the above factors are attributes to the model, which need to be known, and others are optional or just for record keeping purposes. Attributes that are required are marked with and * and are the minimum information required to run the model. More detail on the method of inclusion of the site-specific factors is provided later in this section.

2.2.2.3.4 WIRRD Constituents

The Generic- WQGIS values were used as the trigger values for a PHC in the WIRRD.

A Mineral Reference Document (MINRD) is built into the model. This reference document contains mineral requirements for poultry. The model adds the content of a specific mineral in both the feed and the water, then compares it to the MINRD to see whether requirements are met or not.

The results of both the comparisons between the WIRRD and MINRD with the sample-information, are presented on a result screen, with supporting information and a risk assessments. PHC and COC are pointed out and suggestions are made to alleviate problems.

Water quality constituents which are addressed in the WIRRD for poultry are presented in Table 2.4.

Table 2.4 Water quality constituents with a WIRRD.

Water Quality Constituents with a WIRRD
Arsenic
Bicarbonates
Calcium ,Cadmium, Chloride, Chromium, Copper
Fluoride
Iron
Lead
Magnesium, Manganese, Mercury
Nitrate, Nitrite
Selenium, Sodium, Sulfate
Total Dissolved Solids
Zinc

2.2.2.4 The specific model for poultry production systems

The basic model used for poultry in the Specific-WQGIS is depicted in figure 2.6. The model evaluates information concerning the water, the animal, the environment and the nutrition of the animal. This evaluation happens within a category, production system, application, sex and age of the water user group. The black arrows depict user-input information, red arrows depict calculations. The results are presented with green arrows.

POULTRY PRODUCTION SYSTEM

Broilers Layers Dual purpose Breeders

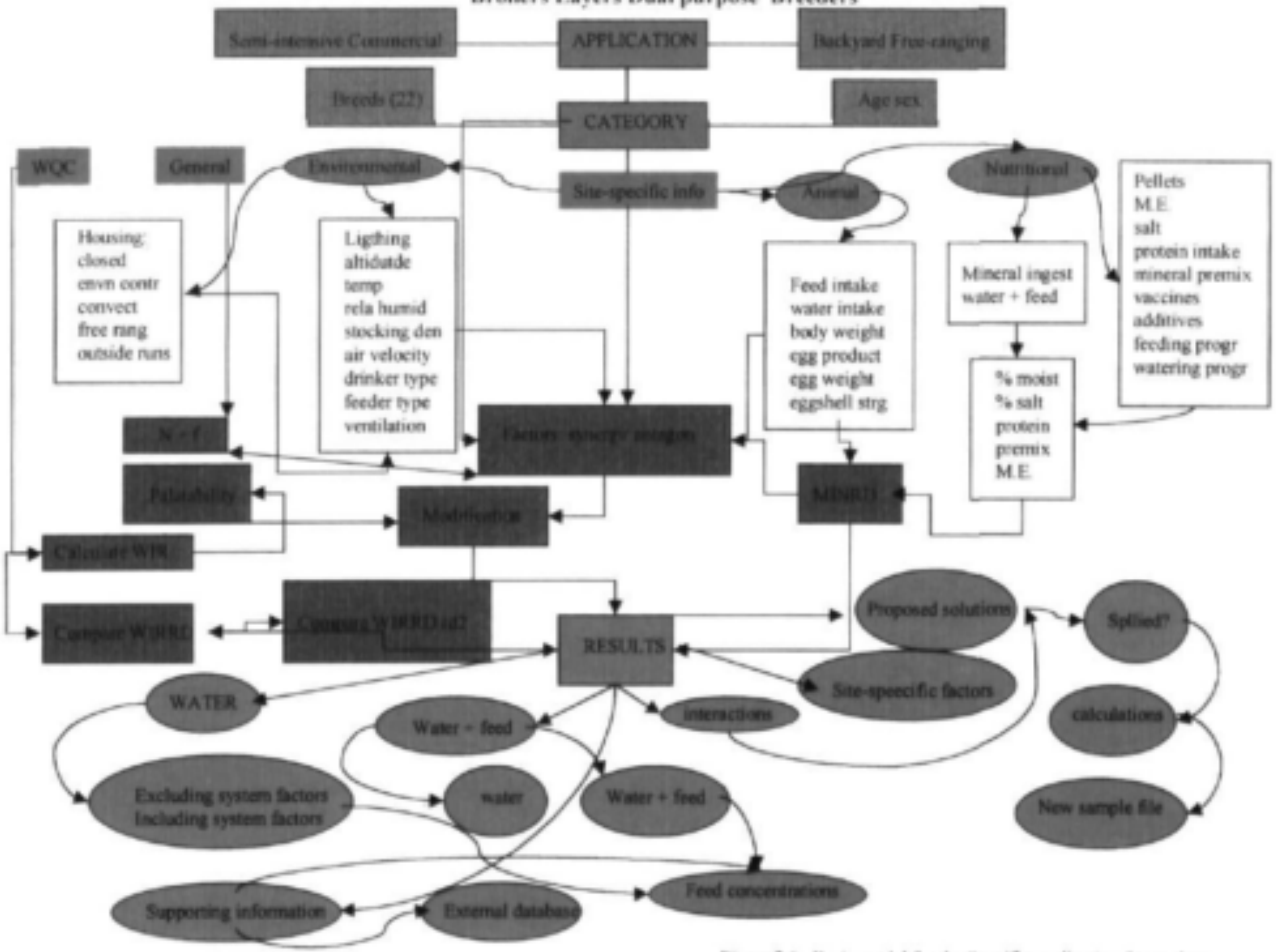


Figure 2.6 Basic model for the Specific application for poultry.

2.2.2.4.1 Set user format

The set user format contains the following poultry information:

- Poultry production systems
- Applications
- Categories
- Breeds
- Age
- Sex
- Housing type

- Poultry production system, breed, category and age detail:
    - Category/production system/ breed water turnover rate.

      Breeds with a low water turnover rate are benefited by modifying the WIR calculated by using a factor 0.8 or 0.9, whereas those with high water turnover rates are penalised by using a factor 1.1 or 1.2 (WRC Report No.644/1/98).

Livestock Production System : Broiler

Breeds	Category	
Cobb (Rainbow)	Category 1	Broiler (0 - 3 wks)
	Category 2	Broiler (3 - 6 wks)
	Category 3	Broiler (6 - 8 wks)
Hybro	Category 1	Broiler (0 - 3 wks)
	Category 2	Broiler (3 - 6 wks)
	Category 3	Broiler (6 - 8 wks)
Ross 308	Category 1	Broiler (0 - 3 wks)
	Category 2	Broiler (3 - 6 wks)
	Category 3	Broiler (6 - 8 wks)

Livestock Production System : Layer

Breeds	Category	
Dekalb - Amberlink	Category 4	Brown egg laying strains - 0 - 6 wks
	Category 5	Brown egg laying strains - 6 - 12 wks
	Category 6	Brown egg laying strains - 12 - 18 wks
	Category 7	Brown egg laying strains - 18 wks – first egg
	Category 8	Brown egg laying strains at 110 g feed intake per hen daily
Dekalb - Gold	Category 4	Brown egg laying strains - 0 - 6 wks
	Category 5	Brown egg laying strains - 6 - 12 wks
	Category 6	Brown egg laying strains - 12 - 18 wks
	Category 7	Brown egg laying strains - 18 wks - first egg
	Category 8	Brown egg laying strains at 110 g feed intake per hen daily
Hy-line – Brown	Category 4	Brown egg laying strains - 0 - 6 wks
	Category 5	Brown egg laying strains - 6 - 12 wks
	Category 6	Brown egg laying strains - 12 - 18 wks
	Category 7	Brown egg laying strains - 18 wks - first egg
	Category 8	Brown egg laying strains at 110 g feed intake per hen daily

Hy-line - Silver Brown	Category 4	Brown egg laying strains - 0 - 6 wks
	Category 5	Brown egg laying strains - 6 - 12 wks
	Category 6	Brown egg laying strains - 12 - 18 wks
	Category 7	Brown egg laying strains - 18 wks – first egg
	Category 8	Brown egg laying strains at 110 g feed intake per hen daily
Lohmann - Silver	Category 4	Brown egg laying strains - 0 - 6 wks
	Category 5	Brown egg laying strains - 6 - 12 wks
	Category 6	Brown egg laying strains - 12 - 18 wks
	Category 7	Brown egg laying strains - 18 wks - first egg
	Category 8	Brown egg laying strains at 110 g feed intake per hen daily
Lohmann - Brown	Category 4	Brown egg laying strains - 0 - 6 wks
	Category 5	Brown egg laying strains - 6 - 12 wks
	Category 6	Brown egg laying strains - 12 - 18 wks
	Category 7	Brown egg laying strains - 18 wks - first egg
	Category 8	Brown egg laying strains at 110 g feed intake per hen daily

Dual purpose (indigenous)

Black Australorp	Category 13	Dual purpose birds (meat/egg types)
Black Australorp	Category 14	Dual purpose birds (egg/meat types)
Leboa -Venda	Category 14	Dual purpose birds (egg/meat types)
Naked Neck	Category 13	Dual purpose birds (meat/egg types)
New Hampshire	Category 13	Dual purpose birds (meat/egg types)
Ovambo	Category 13	Dual purpose birds (meat/egg types)
Potch. Koekoek	Category 14	Dual purpose birds (egg/meat types)
Rhode Island Red	Category 13	Dual purpose birds (meat/egg types)

Broiler breeders

Cobb (Rainbow)	Category 9	Meat type hens for breeding purposes
	Category 10	Meat type males for breeding purposes 0 - 4 weeks
	Category 11	Meat type males for breeding purposes 4 - 20 weeks
	Category 12	Meat type males for breeding purposes 20 - 60 weeks
Hybro	Category 9	Meat type hens for breeding purposes
	Category 10	Meat type males for breeding purposes 0 - 4 weeks
	Category 11	Meat type males for breeding purposes 4 - 20 weeks
	Category 12	Meat type males for breeding purposes 20 - 60 weeks
Ross 308	Category 9	Meat type hens for breeding purposes
	Category 10	Meat type males for breeding purposes 0 - 4 weeks
	Category 11	Meat type males for breeding purposes 4 - 20 weeks
	Category 12	Meat type males for breeding purposes 20 - 60 weeks

- Water turnover turnover rates for the production systems addressed

Commercial	1.2
Semi-intensive	1.0
Backyard	0.8
Free ranging	0.8

- Water intake factors for sex:

  Male: 1.37

  Female: 1

  Mixed: 1.185

- Housing water turnover rate:

Housing type	Broilers	Layers	Breeders	Dual purpose
Convection (open-sided) with floor with litter	0.9	0.9	1	1
Convection (open-sided) with Slats	0.9	1	0.9	1
Convection (open-sided) with cages	0.9	1	0.9	1
Environmentally controlled house with floor with litter	1	0.9	1	1.1
Environmentally controlled house with slats	1	0.9	1	1.1
Environmentally controlled house with cages	0.9	1	0.9	1.1
Closed house (not environmentally controlled) with floor with litter	0.9	0.9	0.9	1
Closed house (not environmentally controlled) with slats	0.9	1	1	1
Closed house (not environmentally controlled) with cages	0.9	0.9	0.9	1
Outside runs	0.8	0.9	0.9	1
Free ranging	0.7	0.8	0.8	1

2.2.2.4.2 Help files

A comprehensive Helpfile was incorporated into the system. This gives the user detailed information on each constituent, its effect on poultry, normal tissue levels, toxicity, toxicity signs and interactions (Puls, 1994). A problem solving RD is also included into the Helpfile. This document enables the user to do on the spot problem solving, gives possible causes for problems and suggests actions to take in case of a certain problem.

2.2.2.4.3 User Interface of the Specific WQGIS

The general sequence of screens encountered by the user are as follows:

Screens 1 – 5

Screen 1 enables the user to make a choice of livestock type. Once "poultry" has been selected, the option of application level appears (Screen 2). If "specific" is chosen, the next screen (Screen 3) indicate, sender information, general water source and response to water information to be filled in.

In the sample Results Screen (Screen 4), the water analysis results are entered. Water Quality Constituents are chosen using the "Insert" button. The poultry constituent list is then presented and constituents can be chosen to represent the water sample analyzed.

The poultry detail screen (Screen 5) contains information tabs for production system, breed, category, application, age and predominant gender. To add more site-specific information, select the Add Site-specific Detail tab. Screens 6– 13 are then enabled.

Screen 6:

Animal

The animal tab contains growth and egg production detail. There is also a tab to indicate the flock size and whether wet droppings occur or not.

Screen 7:

Environment

The environment tab gives the user the opportunity to select a specific housing type, drinker type/space, feeder type/space, lighting program (hours lit vs. hours dark), temperature, RH, air velocity, ventilation rate, litter type and altitude.

Screens 8 – 13:

Nutrition

The nutrition tab is subdivided into:

Raw materials – screen 8

Growth promoters – screen 9

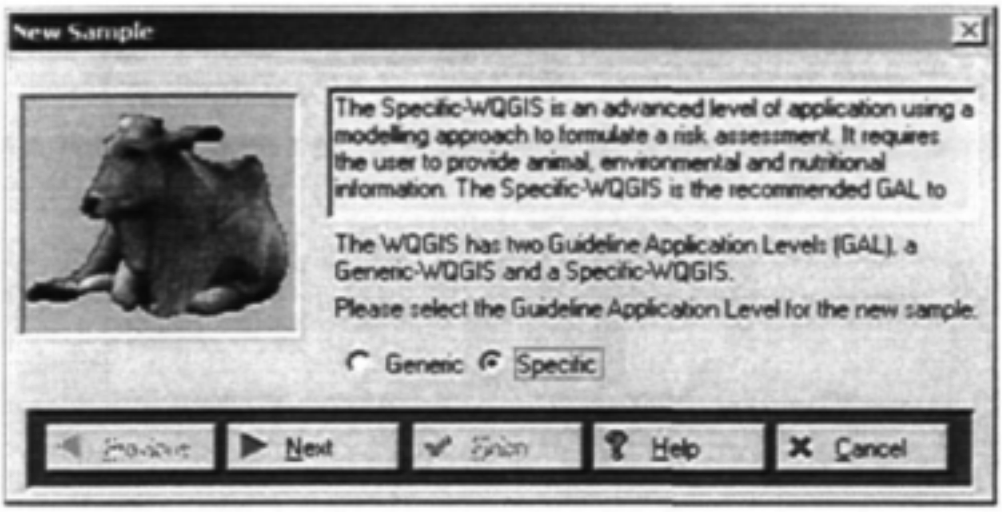
Anticoccidials, antifungals and probiotics – screen 10

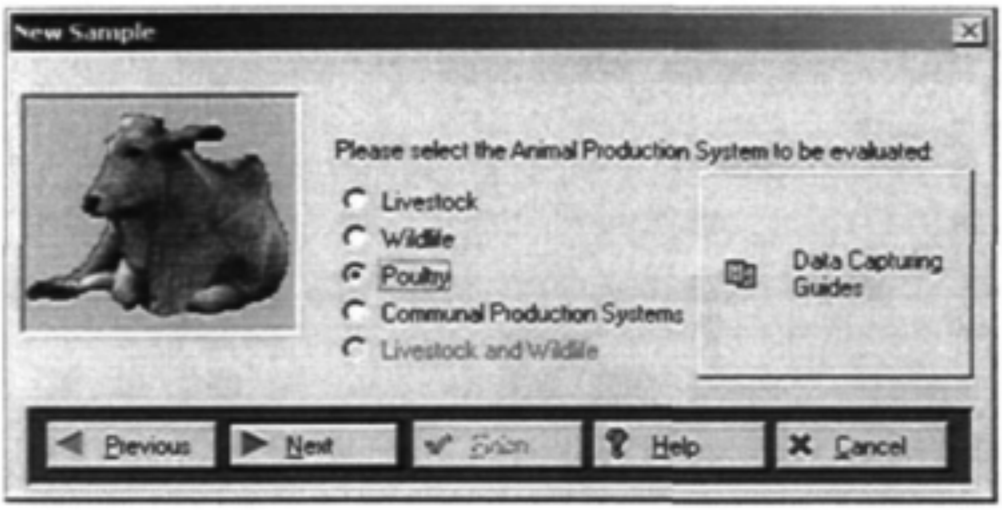
Vitamins and trace minerals – screen 11

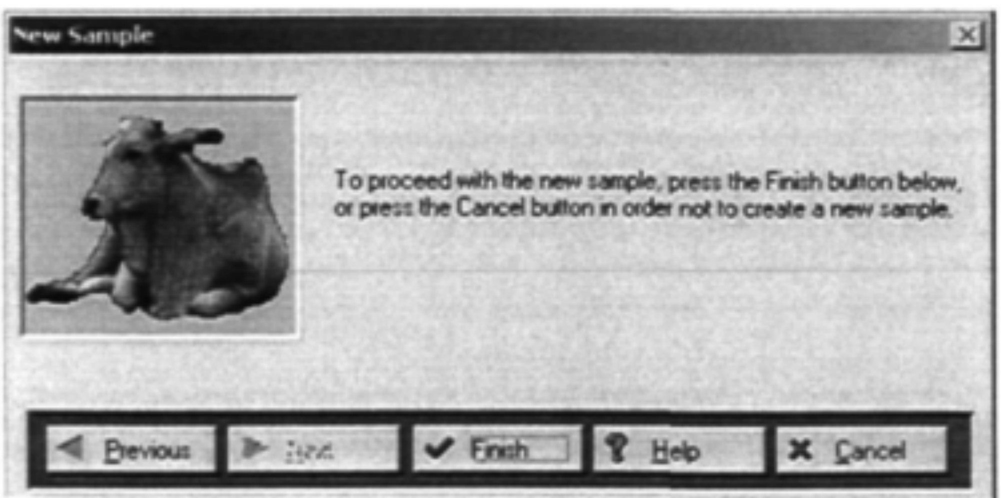
Feeding program, vaccines and medication administration, phase feeding and salt % in the diet – screen 12

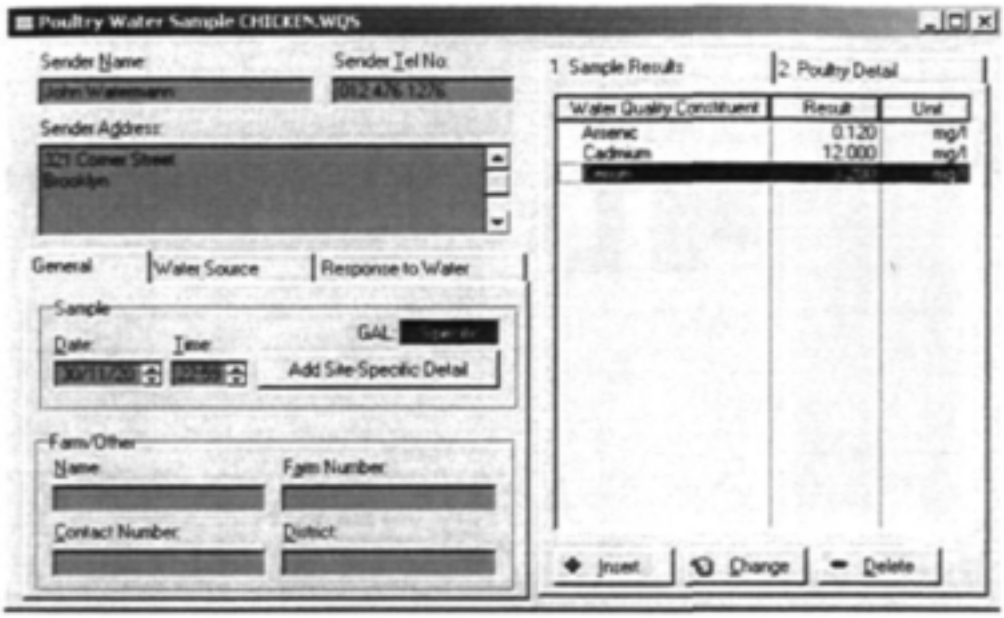
Watering programme – screen 13

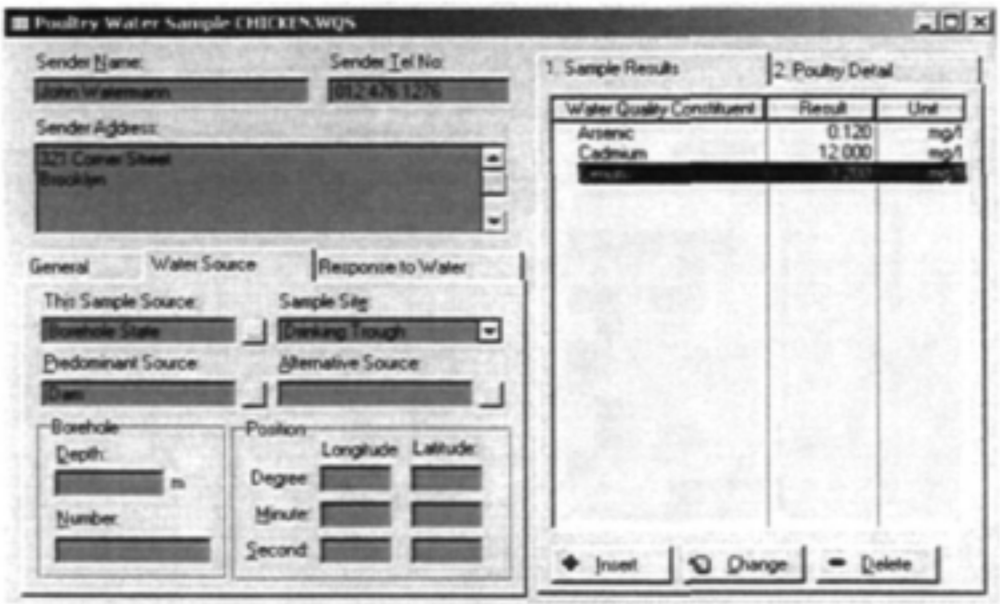
Examples of some these screens are provided next.

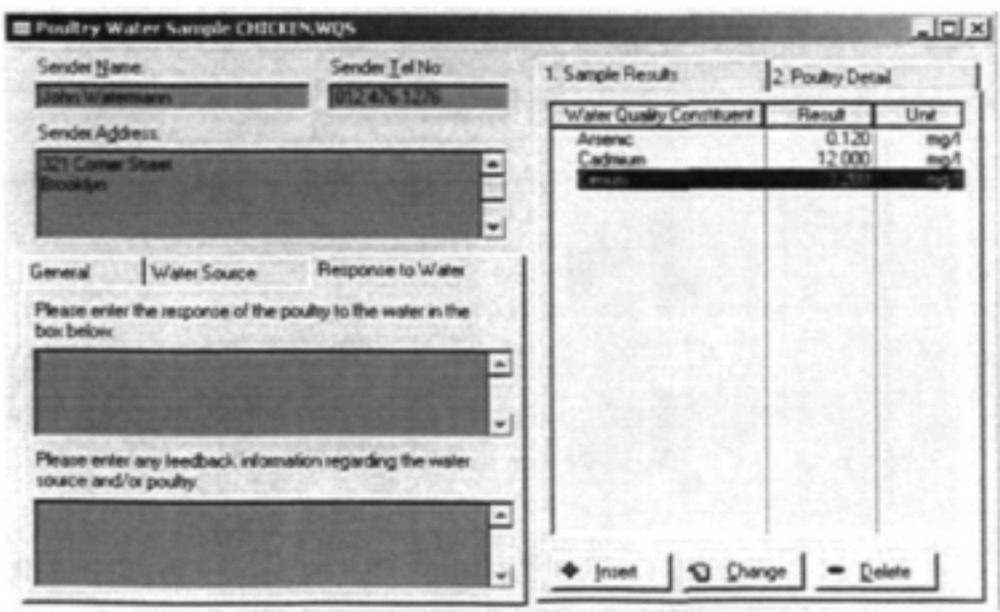

New Sample
The Specific-WQGIS is an advanced level of application using a modelling approach to formulate a risk assessment. It requires the user to provide animal, environmental and nutritional information. The Specific-WQGIS is the recommended GAL to
The WQGIS has two Guideline Application Levels (GAL), a Generic-WQGIS and a Specific-WQGIS.
Please select the Guideline Application Level for the new sample:
Generic
Specific
Next
Help
Cancel

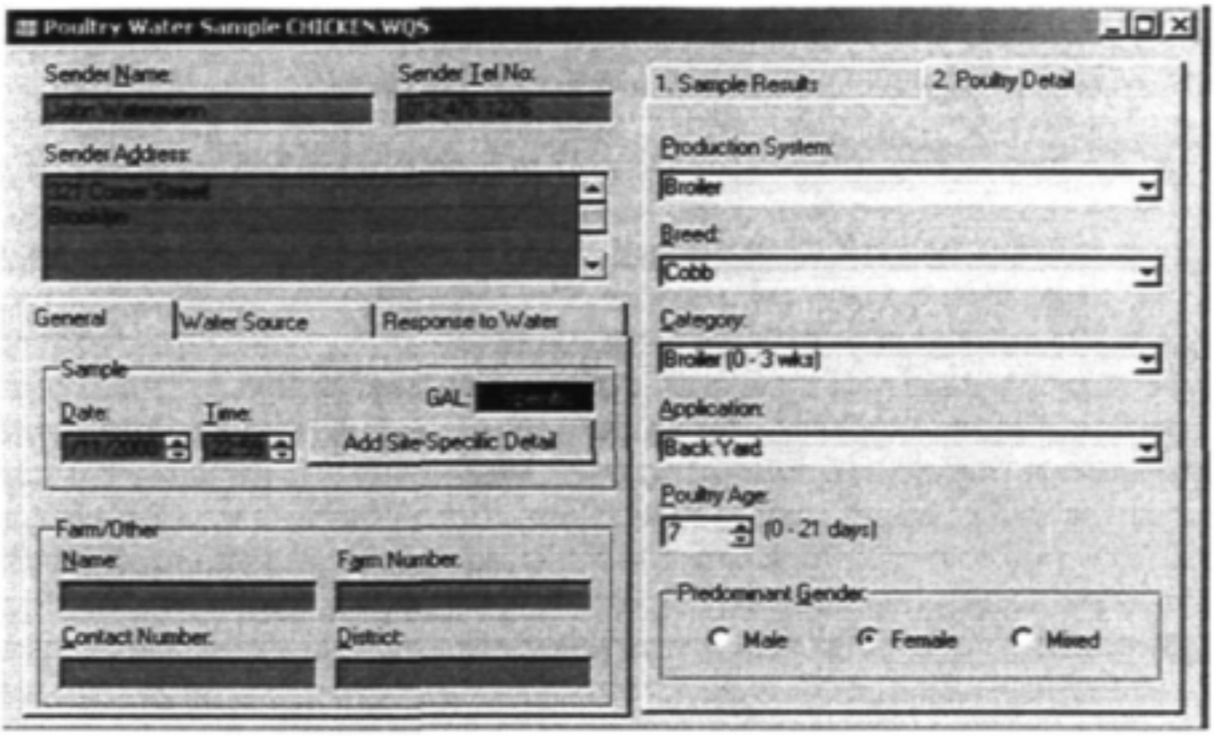

New Sample
Please select the Animal Production System to be evaluated:
Livestock
Wildlife
Poultry
Communal Production Systems
Livestock and Wildlife
Data Capturing Guides
Previous
Next
Help
Cancel

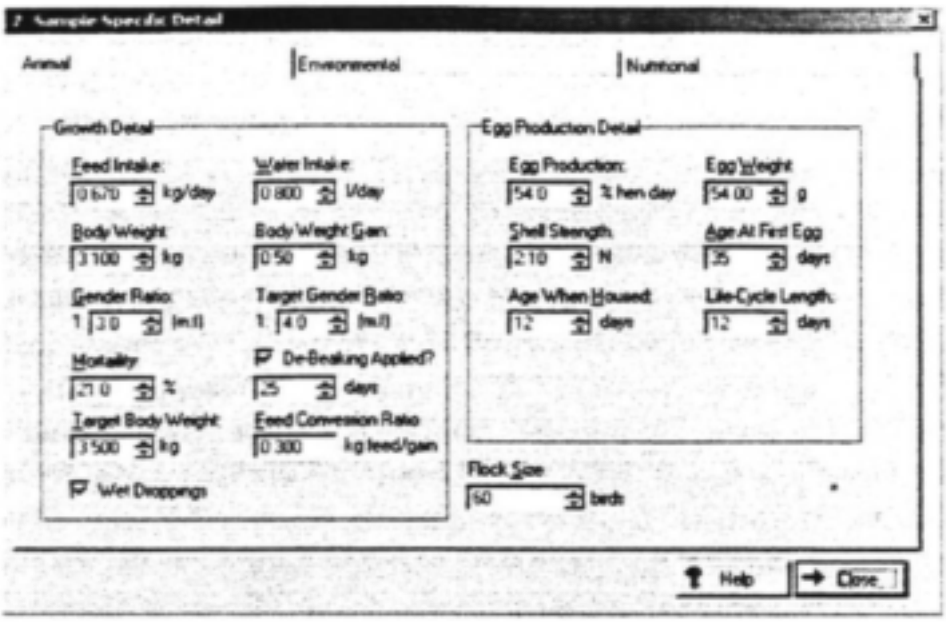

New Sample
To proceed with the new sample, press the Finish button below, or press the Cancel button in order not to create a new sample.
Previous
Finish
Help
Cancel

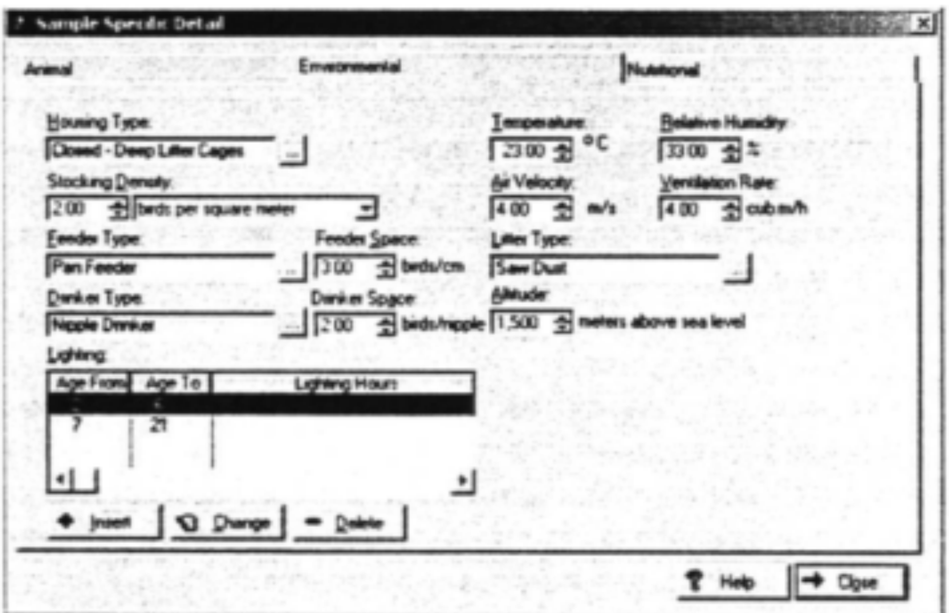

Poultry Water Sample CHICKEN.WQS
Sender Name:
Sender Tel No:
John Watermann
012 476 1276
Sender Address:
321 Corner Street
Brooklyn
General
Water Source
Response to Water
Sample
Date:
Time:
GAL:
Add Site-Specific Detail
Farm/Other
Name:
Farm Number:
Contact Number:
District:
1. Sample Results
2. Poultry Detail
Water Quality Constituent
Result
Unit
Arsenic
0.120
mg/l
Cadmium
12.000
mg/l
Insert
Change
Delete

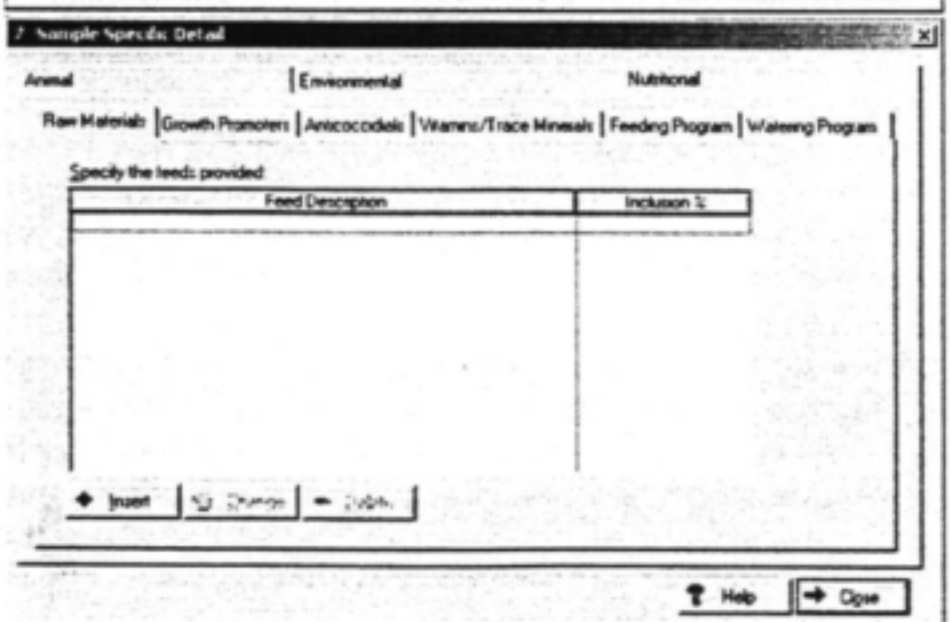

Poultry Water Sample CHICKEN.WQS
Sender Name:
Sender Tel No:
John Watermann
012 476 1276
Sender Address:
321 Corner Street
Brooklyn
General
Water Source
Response to Water
This Sample Source:
Sample Site:
Borehole State
Drinking Trough
Predominant Source:
Alternative Source:
Dam
Borehole
Depth:
m
Number:
Position
Longitude
Latitude
Degree:
Minute:
Second:
1. Sample Results
2. Poultry Detail
Water Quality Constituent
Result
Unit
Arsenic
0.120
mg/l
Cadmium
12.000
mg/l
Insert
Change
Delete


Poultry Water Sample CHICKEN.WQS
Sender Name:
Sender Tel No:
John Watermann
012 476 1276
Sender Address:
321 Corner Street
Brooklyn
General
Water Source
Response to Water
Please enter the response of the poultry to the water in the box below:
Please enter any feedback information regarding the water source and/or poultry:
1. Sample Results
2. Poultry Detail
Water Quality Constituent
Result
Unit
Arsenic
0.120
mg/l
Cadmium
12.000
mg/l
Insert
Change
Delete


Poultry Water Sample CHICKEN.WQS
Sender Name:
Sender Tel No:
Sender Address:
General
Water Source
Response to Water
Sample
Date:
Time:
GAL:
Add Site-Specific Detail
Farm/Other
Name:
Farm Number:
Contact Number:
District:
1. Sample Results
2. Poultry Detail
Production System:
Broiler
Breed:
Cobb
Category:
Broiler (0 - 3 wks)
Application:
Back Yard
Poultry Age:
7
(0 - 21 days)
Predominant Gender
Male
Female
Mixed


Sample Specific Detail
Animal
Environmental
Nutritional
Growth Detail
Feed Intake:
kg/day
Water Intake:
l/day
Body Weight:
kg
Body Weight Gain:
kg
Gender Ratio:
Target Gender Ratio:
Mortality
%
De-Beaking Applied?
days
Target Body Weight:
kg
Feed Conversion Ratio
kg feed/gain
Wet Droppings
Egg Production Detail
Egg Production:
% hen day
Egg Weight
g
Shell Strength
N
Age At First Egg
days
Age When Housed:
days
Life-Cycle Length:
days
Flock Size
birds
Help
Close


Sample Specific Detail
Animal
Environmental
Nutritional
Housing Type:
Closed - Deep Litter Cages
Stocking Density:
birds per square meter
Temperature:
°C
Relative Humidity:
%
Air Velocity:
m/s
Ventilation Rate:
cub m/h
Feeder Type:
Pan Feeder
Feeder Space:
birds/cm
Litter Type:
Saw Dust
Drinker Type:
Nipple Drinker
Drinker Space:
birds/nipple
Altitude:
meters above sea level
Lighting:
Age From
Age To
Lighting Hours
Insert
Change
Delete
Help
Close

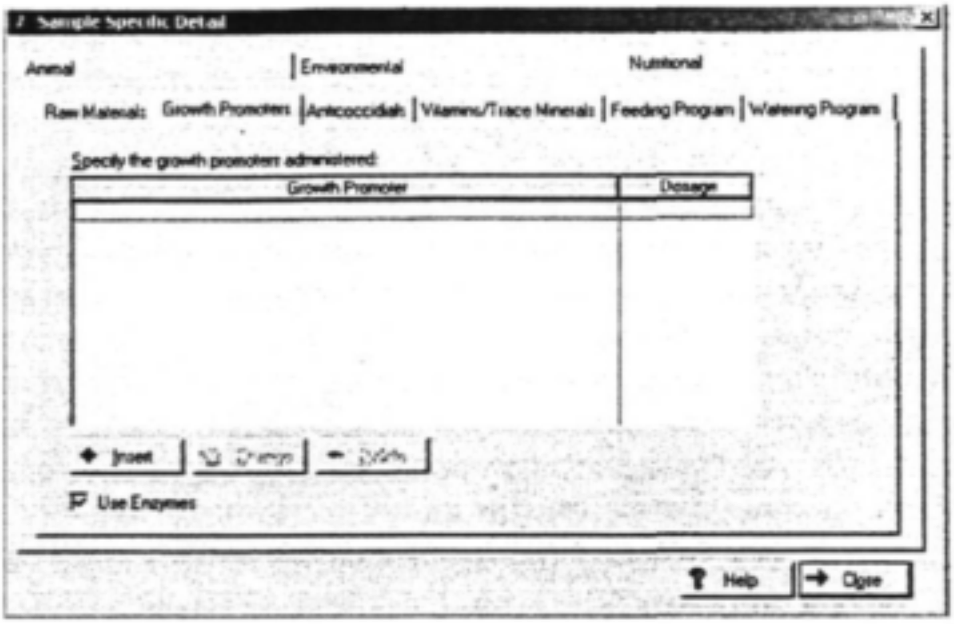

Sample Specific Detail
Animal
Environmental
Nutritional
Raw Materials
Growth Promoters
Anticoccidials
Vitamins/Trace Minerals
Feeding Program
Watering Program
Specify the feeds provided:
Feed Description
Inclusion %
Insert
Help
Close

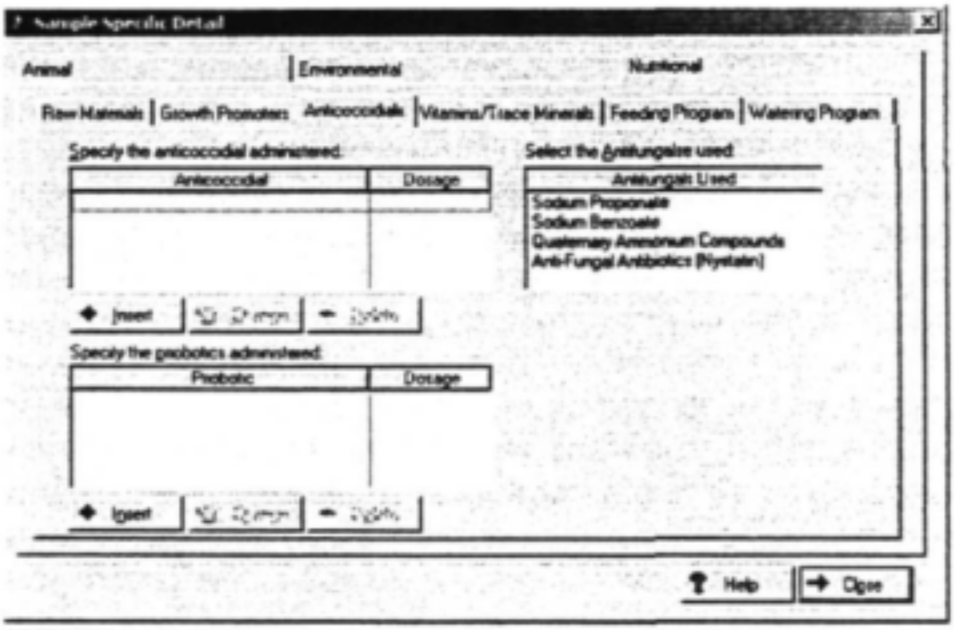

Select Housing Type
Housing Type
Closed (not environmentally controlled)
Closed - Cages
Closed - Floor
Closed - Litter and Slats
Closed - Slats
Convection (open sided)
Convection - Cages
Convection - Deep Litter Cages
Convection - Floor
Convection - Litter and Slats
Convection - Slats
Environmentally Controlled
Environmentally Controlled - Cages
Environmentally Controlled - Deep Litter Cages
Environmentally Controlled - Floor
Environmentally Controlled - Litter and Slats
Environmentally Controlled - Slats
Free Ranging
Outside Runs
Select
Close

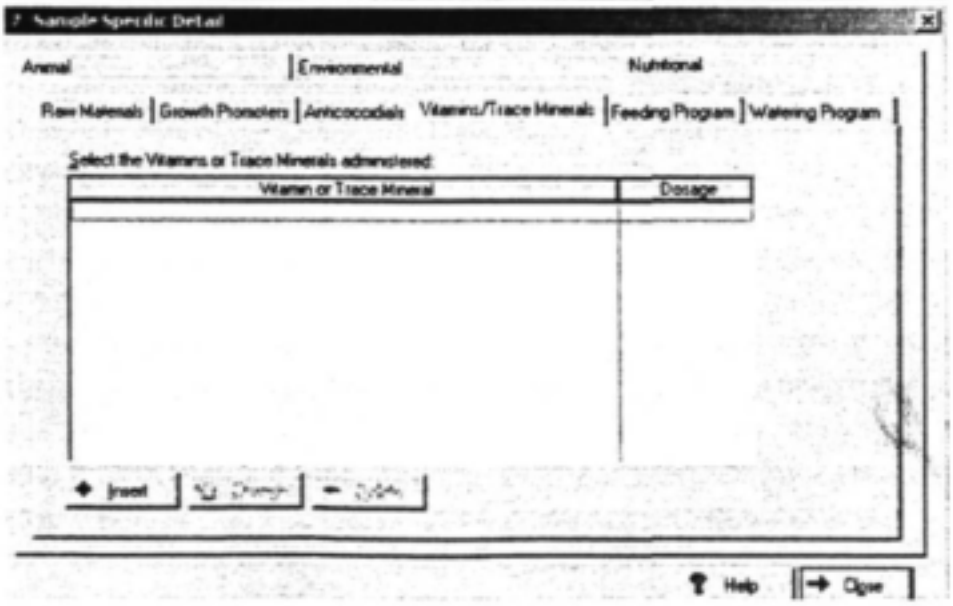

Select a Feeder Type
Feeder Type
Chain Feeder
Feeder Plates
Linear/Tube Feeder
Round Feeder
Trough Feeder
Select
Close

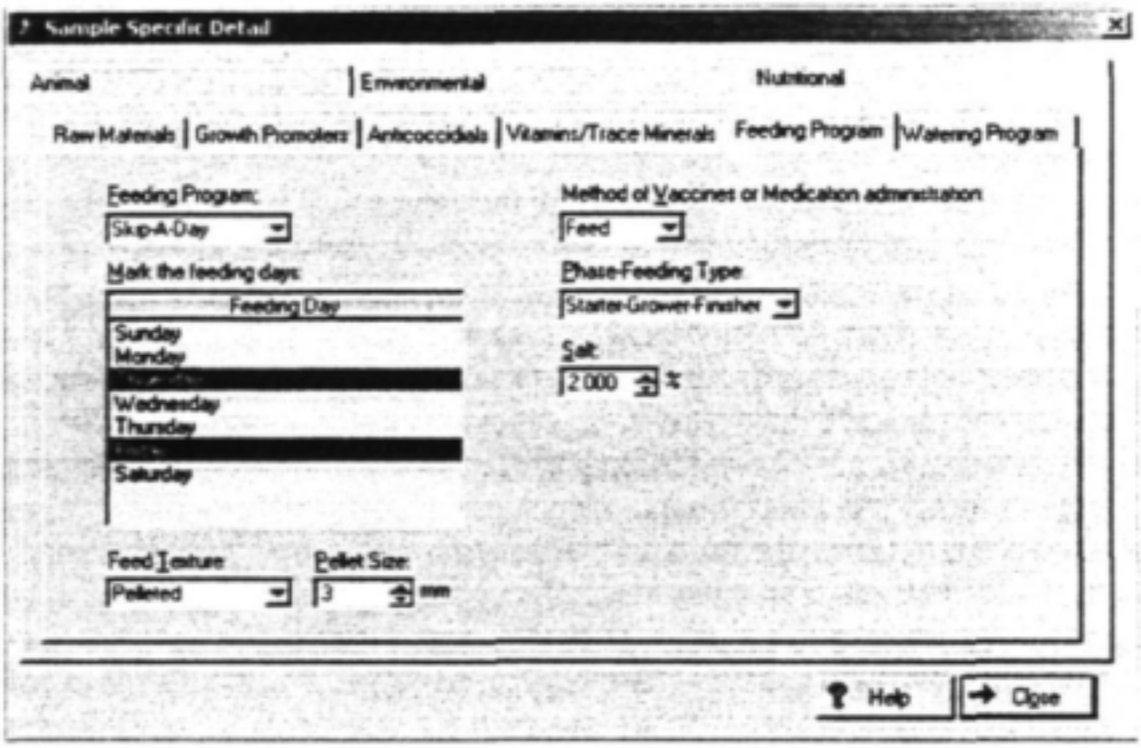

Select a Drinker Type
Drinker Type
Cup Drinker
Linear Drinker
Round Drinker
Select
Close

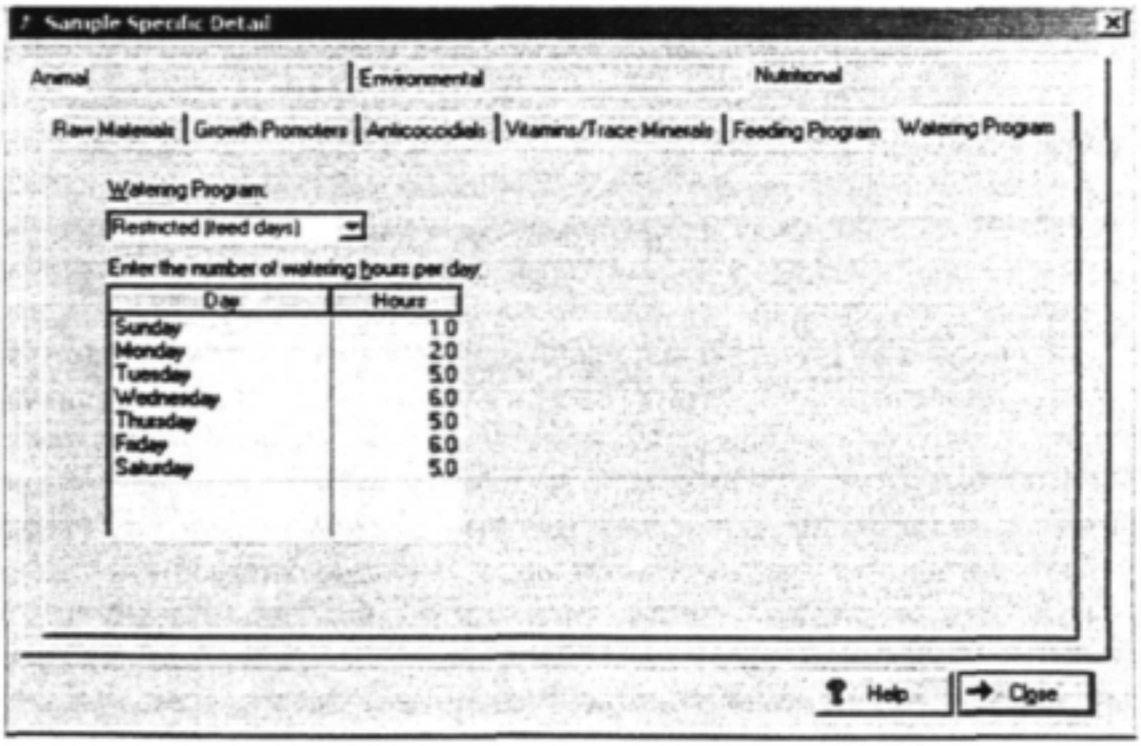

Select a Litter Type
Litter Type
Chaff and Hulls
Chopped Straw
Sand
Shredded Paper
White Wood Shavings
Select
Close


Sample Specific Detail
Animal
Environmental
Nutritional
Raw Materials
Growth Promoters
Anticoccidials
Vitamins/Trace Minerals
Feeding Program
Watering Program
Specify the growth promoters administered:
Growth Promoter
Dosage
Insert
Use Enzymes
Help
Close


Sample Specific Detail
Animal
Environmental
Nutritional
Raw Materials
Growth Promoters
Anticoccidials
Vitamins/Trace Minerals
Feeding Program
Watering Program
Specify the anticoccidial administered:
Anticoccidial
Dosage
Select the Antifungalse used:
Antifungals Used
Sodium Propionate
Sodium Benzoate
Quaternary Ammonium Compounds
Anti-Fungal Antibiotics (Nystatin)
Insert
Specify the probiotics administered:
Probiotic
Dosage
Insert
Help
Close


Sample Specific Detail
Animal
Environmental
Nutritional
Raw Materials
Growth Promoters
Anticoccidials
Vitamins/Trace Minerals
Feeding Program
Watering Program
Select the Vitamins or Trace Minerals administered:
Vitamin or Trace Mineral
Dosage
Insert
Help
Close


Sample Specific Detail
Animal
Environmental
Nutritional
Raw Materials
Growth Promoters
Anticoccidials
Vitamins/Trace Minerals
Feeding Program
Watering Program
Feeding Program:
Skip-A-Day
Mark the feeding days:
Feeding Day
Sunday
Monday
Wednesday
Thursday
Saturday
Method of Vaccines or Medication administration
Feed
Phase-Feeding Type
Starter-Grower-Finisher
Salt
2.000 %
Feed Texture
Pelleted
Pellet Size
3 mm
Help
Close


Sample Specific Detail
Animal
Environmental
Nutritional
Raw Materials
Growth Promoters
Anticoccidials
Vitamins/Trace Minerals
Feeding Program
Watering Program
Watering Program:
Restricted (feed days)
Enter the number of watering hours per day:
Day
Hours
Sunday 1.0
Monday 2.0
Tuesday 5.0
Wednesday 6.0
Thursday 5.0
Friday 6.0
Saturday 5.0
Help
Close

2.2.2.5 Supporting information for the site specific factors addressed

The following section presents the supporting information for the inclusion of those site-specific factors relevant to poultry production systems in terms of increasing or decreasing risk due to the presence of PHCs in the water source. These factors are based upon the literature cited and research conducted. Each of the above mentioned factors are incorporated into the model since they all affect water intake, and hence the dose ingestion of a PHC. The method of inclusion in the model is presented in section 2.2.2.6.

2.2.2.5.1 Animal detail

1. **Feed intake**

$$DFU = -17.7 + 3.45D + 8.11 \times 10^{-2}D^2 - 1.54 \times 10^{-3}D^3$$

$$(14 < D < 56)$$

Where DFU = daily feed use, kilograms per 1000 birds and D = days of age (Xin and Berry, 1994).

2. **Water intake:**

Broilers: $$DWU = -2.78 + 4.70D + 0.128D^2 - 2.17 \times 10^{-3}D^3$$

$$(1 \leq D \leq 56)$$

Where DWU = daily water use, liters per 1000 birds (Xin and Berry, 1994).

Layers: $$WI = -0.057\ BW^2 + 0.031\ BW - 0.000002\ EP^2 + 0.0005\ EP - 0.181$$

Where WI = Water intake; BW = Body weight; EP = Egg production

The layer equation was developed from local research (WRC Report No. 644/1/98). Table 2.5 shows the water intake of different type of poultry at different ages and at moderate and hot temperatures.

Table.2.5 Daily ad-lib water consumption of poultry (liters per 1000 birds) (Leeson & Summers, 1997).

Poultry type		20 °C	32 °C
Leghorn Pullet	4 wk	50	75
	12 wk	115	180
	18wk	140	200
Laying hen	50%	150	250
	90%	180	300
Non-laying hen		120	200
Broiler breeder pullet	4wk	75	120
	12wk	140	220
	18wk	180	300
Broiler breeder hen	50%	180	300
	80%	210	260
Broiler chicken	1wk	24	40
	3wk	100	190
	6wk	240	500
	9wk	300	600
Turkey	1wk	24	50
	4wk	110	200
	12wk	320	600

	18wk	450	850
Turkey breeder hen		500	900
Turkey breeder tom		500	1100
Duck	1wk 4wk 8wk	28 120 300	50 230 600
Duck breeder		240	500
Goose	1wk 4wk 12wk	28 250 350	50 450 600
Goose breeder		350	600

3. Body weight

Xin and Berry (1994) developed the following regression equations for 2 age groups.

$$LBW = 48 + 3.64D + 0.636D^2 + 9.63 \times 10^{-3}D^3$$
$$(1 < D < 28)$$

$$LBW = -1004 + 65.8D$$
$$(28 < D < 56)$$

4. Mortalities

$$CM = 4.02 \times 10^{-2} - 0.105D + 8.58 \times 10^{-2}D^2 - 5.11 \times 10^{-3}D^{-3}$$
$$(1 \leq D \leq 10)$$

$$CM = 1.26 + 0.174D - 5.56 \times 10^{-3}D^2 + 7.53 \times 10^{-5}D^3$$
$$(11 \leq D \leq 56)$$

CM = cumulative mortalities as a percentage of those placed (Xin & Berry, 1994).

5. Body weight gain and feed conversion:

$$G = -31.797 + 1.2071T + 0.21457BW - 8.852 \times 10^{-5}BW^2 + 1.51 \times 10^{-8}BW^3 - 2.0772 \times 10^{-3}TBW$$

Where G = gain per day, grams per day; T = environmental temperature, Celsius and BW = body weight, grams.

$$FC = 2.0512 - 2.007 \times 10^{-2}T - 7.226 \times 10^{-4}BW + 1.7361 \times 10^{-7}BW^2 + 2.5564 \times 10^{-5}TBW$$

Where FC = feed:gain in grams of feed consumed per grams of BW gain; T = environmental temperature, Celsius and BW = body weight, grams (May *et al.*, 1998).

6. Egg production

During the period when an egg is formed, a marked increase in water intake is observed. The overall increase in fluid intake is associated with a fall in plasma osmolarity of up to 14% and an increase in urine minute volume, this can be explained as a simple osmotic adjustment.

Plasma osmolarity changes follow alterations in ingestive activity with a phase lag of less than 0.5 h, indicating rapid assimilation of ingested water, but changes in renal output are much slower (1.5 h later) and are quantitatively insufficient to account for the increased fluid intake which occurs at that time.

Only 8g more urine is produced on a laying than on a non-laying day, and the water content of an egg is approximately 32g, though the extra water ingested amounted to 140g, the accountable fluid loss on a lying day is only 40g (Howard, 1975). Food intake is greater on days on which ovulation occurred than on days during which there was neither ovulation nor oviposition. Water intake is greater on days during which ovulation occurred than on days with oviposition but no ovulation. On a laying day, food intake is greater than on days without ovulation and oviposition (resting day). Both food and water intakes are depressed for 1 to 2 hours before oviposition, but ingestion increase during the hour of laying and remain high for 1 to 2 hours (Wood-gush & Horne, 1970). Approximate water requirements at varying percentages of egg production is shown in the table below (North & Bell, 1990).

Table.2.6 Egg production and water consumption of layers.

Hen-day Egg production (%)	Water consumption per 1000 birds (l)
10	151
30	159
50	174
70	201
90	239

7. Gender ratio

Too many males in the breeding pen reduce fertility, as do too few. The correct ratio of males to females depends on the type and size of the birds involved and is defined on the basis of the number of cockerels per 100 pullets. Allow a few extra males for early culling and mortalities and provide more males on slats and slats and litter than on all litter floors. The male to female ratio does not affect the frequency of male mating (North & Bell, 1990).

Table 2.7 Recommended male: female ratios.

Male of mating	Female of mating	Mating Producers	Males per 100 females	
			On Litter	On Slats and litter
Mini-Leghorn	Standard Leghorn	Commercial Mini Leghorn Pullet	8	9
Standard Leghorn	Standard Leghorn	Commercial Standard Leghorn Pullet	8	9
Medium size	Medium size	Commercial medium-size pullet (brown eggs)	9	10
Standard Meat-type	Mini-meat-type	Commercial broiler	9	10
Standard Meat-type	Standard meat-type	Commercial broiler	10	11

8. Beak trimming

Beak trimming in adult hens caused a temporary fall in food intake which was not followed by a compensatory hyperphagia, and body weight was reduced for at least 6 weeks. Removal of half the beak had more effect than removing one-third and the consequences were greater when the hens were fed pellets rather than mash. Beak trimming reduced feeding efficiency (number of pecks per gram of pellets ingested) to only 20% of its pre-operative value. Pecking rate rose sharply after beak trimming, then declined to the pre-operative value after 3 weeks, indicating o decline in feeding motivation (Gentle *et al*, 1982).

Table.2.8 Feed consumption and body weights of pullets on various debeaking treatments.

Debeaking	Feed consumed to 20 weeks of age (g)	Body weight (g) at	
		20 weeks	35 weeks
1 day, precision	6244.3	1285.9	1557.4
6 day, precision	6407.0	1340.6	1619.6
6 week, inside slant	64616	1335.8	1612.6
8 week, non-precision	6384.6	1324.5	1625.7
12 week, non-precision	6115.2	1264.0	1565.3
16 week, non-precision	6752.1	1353.7	1552.8
Non-debeaked	6719.4	1401.6	1695.2

Table.2.9 Effects of age at final beak trimming on age at 50% production, mortality, feed consumption, egg mass and egg production from 140 to 441 days.

Measurement	Beak trimming treatment		
	63 days	84 days	105 days
Age at 50% production (days)	157.5	155.9	155.6
Mortality (%)	5.4	7.6	9.2
Feed consumption (g/hen/day)	106	109	108
Egg mass (g/hen day)	43.0	43.6	43.4
Egg production (hen day %)	77.0	78.4	78.1

Table.2.10 Effects of beak treatment and age on body weight, weight gain, feed intake and the feed to gain ratio of pullets from 4 to 7 weeks of age.

Comparison	Body weight (g)	Weight gain (g)	Feed usage (g/day)	Feed:gain ratio (g/g)
Trimmed	355	83.3	37.1	3.14
Intact	376	92.6	42.4	3.19
Age				
4 weeks	329			
5 weeks	313	73.8	30.6	2.96
6 weeks	407	93.9	41.2	3.07
7 weeks	503	96.3	47.5	3.47

Broilers

After beak trimming, roasters fed firm pellets with essentially no fines experienced feed consumption and weight gain depressions from 50 to 70 days of age, compared with corresponding values for control. When birds were changed from mash to pellet diets at 42 days of age, a significant initial increase in feed intake and body weight gain occurred for broilers receiving the pelleted diet when compared with broilers receiving the mash diet.

Table.2.11 Effect of beak trimming on body weight gain and feed consumption of roasters fed feed in mash and pelleted form

Beak trimming	50 day Beginning weight	50 – 56 days		56 – 70 days	
		Weight gain	Feed consumption	Weight gain	Feed consumption
		(g)			
All mash diet					
None	2.457	443	1.110	898	2.813
1/3 Top	2.484	402	1.010	863	2.704
½ Top	2.487	380	960	845	2.693
½ Block	2.475	287	825	911	2.657
Pelleted diet					
None	2.602	431	1.118	850	2.633
1/3 Top	2.606	215	766	699	2.173
½ Top	2.593	-91	428	484	1.643
½ Block	2.598	-48	462	460	1.605

2.2.2.5.2 Environmental detail

1. Housing

Housing types:

1. Convection (open-sided)
   - Floor with litter
   - Slats
   - Cages
   - Litter and slats
2. Environmentally controlled
   - Floor with litter
   - Slats
   - Cages
   - Litter and slats
3. Closed house (not environmentally controlled)
   - Floor with litter
   - Slats
   - Cages
   - Litter and slats
4. Outside runs
5. Free ranging

2. Ventilation rate

More cooling equals more humidity. Reducing the temperature of the incoming air by 10° will cause humidity to go up 20 percent. Reducing incoming air temperature 20° will result in the relative humidity of the incoming air increasing 40 percent. In a study by Lacy and Czarick (1992), daily temperatures averaged 36 °C. Typically, house temperatures were reduced to 1 - 2 °C in the conventional house, and 4 - 7 °C in the tunnel-ventilated house. Body weights at 55 days averaged 2.42 kg in the tunnel-ventilated house and 2.33 kg in the conventional house. Feed conversion was 2.03 and 2.05 in the tunnel ventilated and conventional houses, respectively. Livability was essentially the same in both houses. Electricity costs over the entire grow-out in the tunnel-ventilated house were nearly double those of the conventional house, however, these costs were only 20 - 30 % higher on hot days.

3. Air velocity

Air speed around each bird greatly influences the comfort of the bird. During marginally-cool temperatures, the birds, especially young birds, can be easily and quickly chilled by air movements. During hot weather, birds are kept comfortable, even at high measured temperatures by the movement of air across their bodies (Krevinghaus, 1997). Male broilers were grown in environmental chambers from 21 to 49 days of age and weighed weekly. The chambers were maintained at 27 C and broilers were exposed to still air (< 15 m/min) or air velocity of 120 m/min. Water usage was calculated as percent of body weight per day. Daily water usage for still air ranged from 23 percent of body weight at 22 d to 12 percent of body weight at 48 d, and was 17 percent of body weight at 34 d. Air velocities tested had no effect before 30 d and at 34 d usage was 15.7 percent at 120 m/min. The average usage from 35 to 49 d was 14.3 percent in still air and 12.4 percent at 120 m/min. These results show the effect one may expect from age and tunnel ventilation (May & Lott, 2000).

Wind chill is the term used to describe the rate of heat loss on the body resulting from the combined effect of low temperature and wind. As air velocity increases, heat is carried away from the body at a faster rate, driving down both the skin temperature and eventually the internal body temperature. An equation is used to determine the Wind Chill Index (K) for poultry. This equation is however only applicable at air velocities higher than 1.79 m/s. Air velocity is measured in m/s and temperature in degrees Celsius.

$$K = 41 - ((10.45 + 10 * (\sqrt{\text{Air velocity}}) - \text{Air velocity}) * (41 - \text{Temperature})/22.04$$

Where 41 = the body temperature of a chicken.

4. Lighting

The duration of adaptation period to continuous light is an important factor in determining feeding behavior. Two important features must be adhered to when choosing a lighting program for growing and laying pullets (North & Bell, 1990).

1. The length of the light day should never increase for growing pullets.
2. The length of the light day should never decrease for laying pullets.

Table.2.12 Influence of lighting treatment on sexual maturity, laying house mortality and egg production.

Light treatment		Days to reach 10% Egg prod.	Days to reach 50% Egg prod.	Laying house Mortality %	Egg prod. during 47 weeks of lay
Growing period	**Laying period**				
Gradually decreased from 22hr to 16 hr	Gradually increased from 16 hr to 22 hr	156	172	3.3	225
Gradually decreased from 22hr to 9 hr	Gradually increased from 9 hr to 22 hr	172	186	3.3	220
Gradually decreased from 16hr to 9 hr	Gradually increased from 9 hr to 16 hr	171	191	3.8	220
Gradually decreased from 16hr to 9 hr	Gradually increased from 9 hr to 16 hr	163	176	5.0	230
Started on constant 16 hr then suddenly decreased to constant 9 hr	Suddenly increased from 9 hr to 16 hr	165	176	4.6	227
Constant 16 hr	Constant 16 hr	156	171	5.0	224

It is accepted that when pullets are delayed in the onset of egg production, the first eggs are larger (North & Bell, 1990).

Table.2.13 Age at lighting and egg size.

Trait	Age at lighting (wk)		
	18	20	22
Average egg weight (g/egg)	57.7	58.8	59.4
Percent large and above	65.8	74.2	79.5

Age at sexual maturity and age at light stimulation are correlated (Leeson & Summers, 1997).

$$Y = 92.6 + 0.44X$$

Where Y = Age at first egg

X = Age at light stimulation.

Broiler lighting:

Although the exact reasons for better growth on intermittent light programs are not known, it is thought that by giving chickens a meal (short feeding period), followed by a longer period of time for digesting the meal (no feed available), the efficiency of feed utilization is improved.

Table 2.14 Improvements with various lighting programs (North & Bell, 1990).

Light program	Hours light and dark	Relative growth efficiency
Continuous light in open sided house	23 hrs light, 1 hour darkness	100 (base)
Continuous light in light tight house	23 hrs light, 1 hour darkness	104-106 %
Intermittent light in light tight house	1 hr light, 3 hrs darkness, then repeat.	106%

Table 2.15 Effect of short daylength on male broiler performance (Leeson & Summers, 1997).

Light schedule	Body weight (g)				0-48d mortality (%)
	7d	21d	35d	48d	
23L:1D	138	738	1852	2924	9.0
16L:8D	126	684	1798	2912	3.0
14L:10D	121	641	1727	2850	3.5
Step down-step up.	115	614	1713	2884	3.5

5. Stocking density

The health implications for higher density broiler production are significant and must be taken into account. With increased density, feed and water will become more difficult for each bird to access. This will lead to reduced performance on each normal bird. Furthermore, birds, which may only have a marginal disability, will become less able to compete as the stocking density rises.

Poorer litter conditions associated with higher moisture content occur with higher stocking densities. By increasing the stocking density, the demand for vital oxygen will be increasing. Increasing the demand for oxygen will add more pressure to the bird's pulmonary and cardiovascular systems. Increasing stocking density will increase the likelihood of a bird being scratched. This coupled with an increase in litter moisture will set up the possibility for an increase in the incidence of type II cellulitis.

The ability to vaccinate birds via the drinking water will be compromised by increasing the stocking density. Poorly vaccinated flocks are more prone to vaccine "rolling" reactions and are more prone to disease. Increased stocking densities will increase stress. Increased stress will manifest itself in many ways, most commonly as a reduction in overall performance. Increased stress will result in an increased susceptibility to the common broiler diseases in a given geographical area and may open the door for new and re-emerging diseases (Ritchie, 1999).

Table 2.16 Stocking density for Broilers.

Live weight (kg)	**Birds/m^2**
1.0	34.2
1.2	28.5
1.25	27.2
1.4	24.4
1.50	22.7
1.6	21.4
1.75	19.4
1.8	19.0
2.0	17.1
2.2	15.6
2.25	15.1
2.4	14.3
2.50	13.6
2.6	13.2
2.75	12.4
2.8	12.2
3.0	11.4
3.2	10.7
3.4	10.0
3.50	9.7
3.6	9.5

Broilers:

Open side houses:	25 kg/m^2
Environmentally controlled houses:	30-35 kg/m^2

Breeders:	**week 1 – 7**	**week 8 – 20**	**week 21 - 65**
Female birds/m^2	10 - 12	5 – 7	4 - 6
Male birds/m^2	10 – 12	3 – 4	-

Layers:	**Week 0 – 5**	**Week 5 – 18**	**Week18 - 72**
Cage system	200 cm^2/bird	300 cm^2/bird	450 cm^2
Floor System	25 – 30 birds/m^2	12 birds/m^2	

6. Feeder space/type

Production per hen day and food intake were higher, but return on estimated capital outlay was lower, with 102 mm than with 76 mm feeding space/bird when colony size and floor area/bird were constant (Robinson, 1979). The following space requirements are advised.

Feeder Type	**Feeder Space**
Manually filled:	
Feeder plates	1 plate/70 – 100 chicks
Metal pen troughs (2cm)	4 cm space/chicken
Round suspended feeders (tube feeders 38cm)	1 tube/70 birds
Automatically filled:	
Chain feeders (troughs) single chain	2.5 cm/bird
Overhead tube feeders	1 tube/70 birds
Pan feeders (33 cm)	1 pan for 50 – 100 birds

Broilers:

Troughs	2.5 cm/bird
Pan or tube feeders	2 – 3/100 birds

Broiler breeders:

Hand-Fed Trough	20 cm/bird
Mechanical chain	15 - 20 cm/bird
Hanging 45 cm diameter tube	12 birds/tube (80 feeders/1000 birds)
Automatic centerless auger	10 - 12 birds per pan on restricted and controlled feed

Layer brooders:

Cage: feeder space	2.5 cm/bird (0 - 5 weeks)
	5 cm/bird (5 - 18 weeks)
Floor: feeder space	2.5 cm/bird (0 - 5 weeks)
	2 tubes /100 birds (0 - 5 weeks)
	8 cm/bird (5 - 18 weeks) or 1 pan/20 birds
	3 tubes /100 birds (5 - 18 weeks)

Layers:

Cage: feeder space	5 cm/bird
Floor: feeder space	7.5 cm/bird
Trough	4 cm/bird (18 - 72 weeks)
Round	4 per 100 birds (18 - 72 weeks)

7. Drinker space/type

In a study by Gernat and Adams (1992), hens/nipple had no effect on age at sexual maturity, egg production, mortality and egg weight, but efficiency of feed usage for egg production decreased with the 3.5:1 and 7:1 hens per nipple. Body weight and water intake was significantly influenced by the amount of nipples per hens. Body weight decreased with increased hens per nipple and water intake increased with decreased hens per nipple. When hens per nipple were increased from 2:1 to 14:1, water consumption and feed consumption decreased, but feed efficiency increased, so performance of all strains was not adversely affected. A decrease in hens per nipple would increase equipment cost and could increase feed cost.

Waterer Type			**Waterer Space**
Bell drinkers	-	hot climate	1 drinker/65 birds
Bell drinkers	-	cool climates	1 drinker/100 birds)
Nipples			12 – 15 birds/nipple
Cup drinkers			30 – 35 birds per cup
Broilers:			
Auto drinkers	-	400mm while brooding	1.6/100 birds
Auto drinkers	-	400mm	1/100 birds
Broiler breeders:			
Plastic cone type			2/200 birds
8-foot trough waterers			1/200 birds (80 birds/m)
Nipple			1/15 pullets
Layer brooders:			
Cage: waterer space			1 cup or nipple per 16 birds (0 - 8 weeks)
			1 cup or nipple per 8 birds (8 - 18 weeks)
Floor: waterer space			2 cm/bird (0 - 8 weeks)
			4 cm/bird (8 - 18 weeks)
			(average 3 cm over growing period)
Trough: waterer space			2 cm/bird (0 - 8 weeks)
			4 cm/bird (8 - 18 weeks)
			(average 3 cm over growing period)

Layers:

Cage: drinker space	8 birds per nipple
	12 hens per cup
	2.5 cm of space per bird
Floor: drinker space	2.5 cm of space per bird
	50 hens per fountain drinker
Nipples	4 - 6 birds/nipple (18 - 72 weeks)
Linear	2 cm/bird (18 - 72 weeks)
Round	1/125 birds (18 - 72 weeks)

Note: 2.5 cm of edge space of a round feeder or waterer is equivalent to 3.17 cm of straight trough. For trough waterers and feeders, count total usable edge space exposed to the birds.

8. Relative humidity

The higher the temperature, the lower the RH and the lower the outside temperature, the higher the RH. The reason for this inverse relationship between temperature and RH is that as air temperature rises its ability to hold moisture is increased. In fact for every 20 degree rise in temperature the moisture holding ability of air doubles. The hotter the day the drier the air (Lacy, 1995).

The relative humidity is presented by the line XM/PM on the figure below (Monteith, 1973).

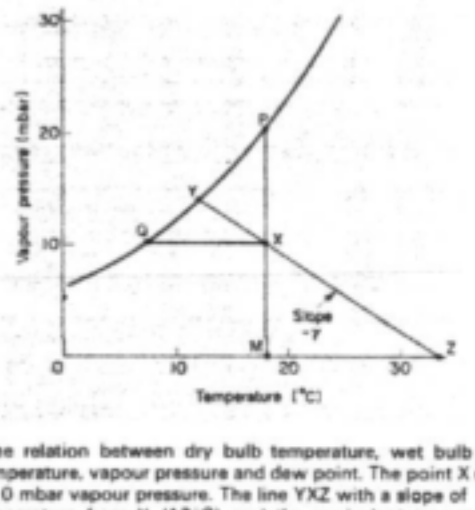


Fig. 11.1 The relation between dry bulb temperature, wet bulb temperature, equivalent temperature, vapour pressure and dew point. The point X represents air at 18°C and 10 mbar vapour pressure. The line YXZ with a slope of $-\gamma$ gives the wet bulb temperature from Y (12°C) and the equivalent temperature from Z (33·3°C). The line QX gives the dew point temperature from Q (7·1°C). The line XP gives the saturation vapour pressure from P (20·6 mbar).

The heat index (HI) gives a measure of how hot it actually feels due to the combined effect of the air temperature and the relative humidity. Hot, humid air actually feels hotter than hot, dry air.

The table below gives the optimum temperature and relative humidity for broilers.

Table 2.17 Relation between temperature (°C) and relative humidity (Avian Farms Broiler Manual).

Age in days	Relative Humidity				
	80%	70%	60%	50%	40%
1	33	33	33	33	35
2	32	32	32	32	34
3	31	31	31	31	33
4	30	30	30	30	32
5	30	30	30	30	32
6	29	29	29	29	31
7	29	29	29	29	31
8	28	29	29	29	31
9-12	27	28	28	29	31
13-16	26	27	27	29	31
17-20	25	26	26	28	30
21-24	24	25	26	27	29
25-30	23	24	25	27	29
31-35	22	23	25	26	28
>35	21	22	24	25	27

- The areas in bold numbers are considered ideal conditions for the chicks and birds.
- With a relative humidity (80%) the temperature should drop rapidly after 16 days of age in order not to affect the growth rate of the birds.
- With low relative humidity (40%) the temperatures can stay higher without affecting the growth rate and feed conversion.

9. Temperature

May *et al.* (1998) reported on the effect of high environmental temperatures on the growth and feed:gain in broilers. The body weight at the maximum rate of gain was inversely related to temperature. Feed:gain increased as body weight increased. Feed:gain was directly related to temperature at weights above 800g and the effect of temperature increased as body weight increased.
The following regression equations were developed in this study.

G = -31.797+ 1.2071T + 0.21457BW - 8.852 X 10 -5 BW2 + 1.51 X 10 -8 BW3 - 2.0772 X 10 -3 TBW
FC = 2.0512 - 2.007 X 10 -2T - 7.226 X 10 -4BW + 1.7361 X 10-7BW2 + 2.5564 X 10 -5 TBW

At moderate temperatures animals will consume twice as much water by weight, as they eat as food. Environmental temperature is perhaps the major factor influencing fluctuation in water intake. For every increase in environmental temperature of 1°C, there usually is an appropriate 7-9% increase in water consumption (Spesfeed, 1999).

Table. 2.18 % Increase in feed consumption between two temperatures as temperatures increase.

From °C	To °C					
	10.0	15.6	21.1	26.7	32.2	37.8
4.4	3	8	16	27	42	60
10.0		6	14	25	40	59
15.6			9	21	37	56
21.1				13	31	52
26.7					20	45
32.2						31

Table.2.19 % Increase in feed consumption between two temperatures as temperatures decrease.

From °C	To °C					
	32.2	26.7	21.1	15.6	10.0	4.4
37.8	46	82	110	130	143	151
32.2		25	44	58	67	72
26.7			10	26	34	38
21.1				10	16	20
15.6					6	9
10.0						3

10. Floor type

Poor litter conditions, reduces access to feed and water, and an increased demand for fresh air may result in an increase incidence of pulmonary/cardiovascular disease.

Table 2.20 Effect of floor type on feed consumption.

Floor type	Average body weight (g)	Average feed consumption/bird (g)	Feed:gain
Litter floor	1.663	6.922	4.26
Wire floor	1.746	7.584	4.44

2.2.2.5.3 Nutritional detail

1. Feeding program

Types:

- ***Ad libitum***
- Skip a day feeding
- 4 – 3 feeding
- 3 – 1 – 2 – 1 feeding

Significantly higher water intakes were measured in chick selected for high body weights, when fed a restricted diet (Marks, 1980).

Table 2.21 Water intake (g/bird/day) of broilers by line to 49 days of age.

Period (day)	Selected	Non-selected	Selected –feed restricted
2	16.0	3.1	12.8
3-4	21.5	12.9	17.4
5-6	37.0	20.6	29.7
7-8	46.3	25.0	36.9
9-10	58.0	29.0	46.6
11-12	70.3	31.6	56.7
13-14	78.8	36.0	56.6
15-16	87.3	39.0	57.6
17-18	95.5	43.1	64.8
19-20	113.4	48.2	74.8
21-22	157.5	57.5	102.9
23-34	178.1	62.8	119.4
25-26	166.0	58.0	112.2
27-28	203.1	68.0	127.9
29-36	362.1	110.6	233.5
37-42	297.6	97.7	225.2
43-49	396.0	128.9	273.1

2. Watering programme

Table 2.22 Effects of a 6-week period with water supply restricted to 90% of *ad libitum* intake in hens.

21d with *ad lib.* food and water supply, before restriction, Mean ambient temperature = 16.6°C				42 d with each bird's daily water supply restricted to 90% of *ad lib.* intake, Mean ambient temperature = 18.1°C					21d with *ad lib.* Food and water supply, after restriction. Mean temperature = 20.9 °C		
Daily food intake (g)	Daily water intake (g)	Egg prod. (egg/hen day)	R between food intake and water intake	Predicted daily food intake (g)	Actual daily food intake (g)	Daily water intake (ml)	Egg prod. (egg/hen/d)	Change in body weight (g)	Daily food intake (g)	Daily water intake (ml)	Egg prod. (egg/hen d)
157.2	339.8	0.62	0.22	152.6	136.3	292.7	0.52	-66	156.8	328.6	0.62
113.0	234.7	0.48	0.61	103.3	98.8	208.2	0.40	-30	92.0	217.1	0.29
101.1	246.4	0.14	0.16	98.0	134.5	217.6	0.38	+92	149.8	275.1	0.43
101.8	178.1	0.52	0.08	102.7	104.9	158.2	0.55	-7	107.8	239.9	0.57
119.6	201.5	0.38	0.69	109.5	80.1	165.7	0.45	-99	96.5	159.8	0.19
120.4	207.6	0.62	0.46	113.5	124.7	184.8	0.40	+106	103.8	279.2	0.29
112.1	229.8	0.48	0.37	106.7	107.8	201.6	0.38	+92	87.6	230.9	0.43
126.4	211.5	0.43	0.44	123.9	115.8	187.9	0.45	+86	118.3	197.6	0.52
96.2	213.0	0.48	0.78	85.0	103.0	188.9	0.57	+58	112.1	208.5	0.43
126.2	293.1	0.24	0.23	123.1	105.2	260.6	0.21	+89	105.4	244.5	0.43
Mean 117.4	235.6	0.44	0.40	111.8	111.1	206.6	0.43	+32.1	113.0	238.1	0.42

Table. 2.23 Effect of water restriction on weekly feed consumption of broilers (Leeson & Summers, 1997).

	Water restricted each day	Water restricted only on feed days	Ad-lib water
Water consumed on a feed day	175 ml	182 ml	270 ml
Water consumed on off-feed day	108 ml	109 ml	36 ml
Average	141 ml	145 ml	153 ml

3. Feed texture/Pellet size

The form of the feedstuffs also plays a role in the consumption of water. Although is it more due to the relationship between feed and water than the actual physical form of the feed.

Table 2.24 Mean body weights, feed intake and water intake by dietary treatment and age.

Age (days)	Body weight (g)			Age (days)	Feed intake (g/bird/day)			Water intake (g/bird/day)		
	Mash	Crumbles	Ratio C/M		Mash	Crumbles	Ratio C/M	Mash	Crumbles	Ratio C/M
0	42.8	43.1								
2	57.5	63.2	110	0-2	7.29	9.53	131	14.49	19.08	132
4	77.4	89.2	115	2-4	14.90	15.36	103	22.77	27.23	120
5	104.2	125.1	120	4-6	20.01	26.92	135	33.72	40.93	122
8	135.0	167.9	124	6-8	22.88	31.08	136	37.70	49.13	131
10	169.8	214.1	126	8-10	27.24	34.66	128	42.51	53.07	125
12	226.0	286.2	127	10-12	40.01	50.59	127	63.43	82.75	131
14	287.7	358.1	125	12-14	44.70	54.52	122	71.63	89.42	125
16	352.3	436.6	124	14-16	51.98	62.98	122	75.98	94.86	125
18	426.3	522.2	123	16-18	60.77	72.54	120	93.62	117.77	126
20	504.1	619.8	123	18-20	66.91	82.16	123	109.77	140.22	128

4. Phase feeding

Different levels of daily nutrient intake are usually employed in different phases of feeding, the water intake will therefore be affected, because the protein or ME inclusions of the diet varies (See section on protein and ME).

5. Additives

Feed additives affect water and feed intake in the following way:

Growth and production promoters

A. Antibiotics — 1% increase in feed intake

- Penicillin
- Chlortetracycline
- Oxytetracycline
- Bacitracin
- Streptomycin

B. Arsenic compounds — <5% decrease in feed intake

- Arsanilic acid (para – amino – hydroxyphenylarsonic acid)
- Sodium arsanilate
- 3 – nitro – 4 – hydroxyphenylarsonic

C. Hormonal preparations

1. Thyro – active — No effect on feed intake
   a) Iodinated casein
   b) Desiccated thyroid glands
   c) Thyroxine

2. Estrogenic — 2% increase in feed intake
   a) Diethylstilbestrol (DES)
   b) Dienestrol diacetate

Enzyme preparations

No effect on feed intake.

Pellet binders

No effect on feed intake.

1. Sodium Bentonite
2. Paper and pulp by-products (hemicelluloses and lignins)
3. Guar meal

Anticocidials

5% decrease in feed intake.

1. Coccidiostats
2. Coccidiocides
    a) Ionophores - Monensin

Antifungals

1% increase in feed intake.

1. Sodium propionate
2. Sodium benzoate
3. Quaternary ammonium compounds
4. Anti-fungal antibiotics (Nystatin)

Antioxidants

No effect on feed intake.

1. Butylated hydroxy – anisode (BHA)
2. Diphenylparaphenylediamine (DPPD)
3. Ethoxyquin
4. Butylated hydroxytoluene (BHT)
5. Tocopherols (Vit E)
6. Phospholipids

Pigmentation compounds

No effect on feed intake.

Insecticides (to kill flies)

No effect on feed intake.

Deworming drugs (Anthelminicts)

No effect on feed intake.

1. Hygromycin – round worm
2. Niclosmide – tape worm

Probiotics

0.5 – 1% increase in feed intake.

1. *Lactobacilli*

6. Vitamin and trace mineral premixes

The recommended vitamin and trace mineral levels are relevant to water quality as they not only influence the Total dose ingestion that determines the response in the bird, but also the probability of inducing deficiencies and imbalances.

Table 2.25 Recommended Vitamin and Trace Mineral levels for poultry

		Layer	Breeder Layer	Broiler Starter	Broiler Grower	Chick Starter	Chick Grower
Vit A	IU	8000	13000	12000	10000	10000	7500
Vit D_3	IU	2000	2500	2500	2000	2000	2000
Vit E	mg	10	40-80	40-80	30	20	10
Vit K	mg	3	4	4	2	2	2
Vit B_1	mg	0.5	3	2	2	2	2
Vit B_2	mg	3	8	6	5	5	5
Vit B_6	mg	2	4	4	3	3	3
Vit B_{12}	mg	0.02	0.02	0.02	0.01	0.015	0.01
Folic Acid	mg	0.5	2	2.5	2	0.8	0.5
Niacin	mg	20	40	40	30	20	20
Pantothenic	mg	4	12	15	12	10	10
Chlorine Cl	mg	200	600	300	300	200	200
Biotin	mg	0.05	0.25	0.075	0.05	0.05	0.05
Vit C	mg	0	100	0	0	0	0
Mn	mg	120	120	100	100	100	100
Zu	mg	100	100	100	100	100	100
Cu	mg	8	8	8	8	8	6
Fe	mg	70	70	70	70	70	70
I	mg	1	1	1	1	1	1
Se	mg	0.25	0.35	0.35	0.25	0.25	0.25
Co	mg	0.5	0.5	0.5	0.5	0.5	0.5

7. Interrealtionships

Numerous feeding trials conducted with chickens during the past eighty years have resulted in a wealth of information on their nutrient requirements. At least forty-one specific nutrients are recognised as essential in the nutrition of chickens. It is said that more is known about the nutrition of chickens than about any other species including man. Precise requirements for various amino acids, vitamins, minerals, energy and fatty acids have been worked out. Generally, the methodology followed for the determination of the requirement of a specific nutrient has been by adding graded amounts of the nutrient (under study) to a purified diet (a diet where all the constituents are chemically defined and the precise levels known) containing the rest of the nutrients required by the chickens except for the one where the requirement was to be measured. The minimum amount of the nutrient adequate to produce the maximum of the desired animal function, ie. growth, development, egg production or feed efficiency in a normal healthy flock, was recognised as the requirement for the nutrient, for the given function. Although it was imperative to determine the specific contribution of individual nutrients in maintaining the health and production of chickens, this led to an obviously mistaken idea of their independent and somewhat isolated function and requirement. Only during the last thirty years the concept of interdependence and interrelationships of various nutrients has been recognised and given due emphasis in the nutrition of chicken.

The following interrelationships well known and alter the nutrient requirements of chickens under practical conditions.

1. The energy-protein interrelationship.
2. The interrelationship between calcium, phosphorus and vitamin D_3.
3. Nicotinic acid and tryptophan.
4. Choline, methionine, folic acid and vitamin B_{12}.
5. Vitamin E, selenium and cystine.
6. Copper and zinc, zinc and cadmium, molybdenum and tungsten, selenium and arsenic.
7. Interrelationships between arginine and lysine, between leucine, isoleucine and valine.

ME:P

This interrelationship is the only one of the above-mentioned, which may affect water intake.

Table 2.26 ME/P ratios for varying caloric and protein content of the diet.

ME Kcal per0.45 kg	Protein %													
	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1200	100	92	86	80	75	71	67	63	60	57	55	52	50	48
1250	104	96	89	83	78	74	69	66	63	60	57	54	52	50
1300	108	100	93	87	81	76	72	68	65	62	59	56	54	52
1350	113	104	96	90	84	79	75	71	68	64	61	59	56	54
1400	117	108	100	93	88	82	78	74	70	67	64	61	58	56
1450	121	112	104	97	91	85	81	76	73	69	66	63	60	58
1500	125	115	107	100	94	88	83	79	75	71	68	65	63	60
1550	129	119	111	103	97	91	86	82	78	74	71	67	65	62
1600	133	123	114	107	100	94	89	84	80	76	73	69	67	64

8. NaCl

The addition of increasing amounts of salt to the ration causes a progressive increase in water intake per gram of feed consumed.

High levels of salt in the diet will lead to increased water intake and wet litter.

Table.2.27 Diet salt and litter moisture (Leeson & Summers, 1995).

Dietary salt (%)	Nipple drinker		Bell drinker	
	Litter moisture (%)			
	21 days	49 days	21 days	49 days
0.25	16	18	17	21
0.50	17	20	21	33
0.75	22	23	28	49

Table 2.28 Mean feed and water intake and water/feed ratios from 0 to 16 days of age by dietary treatments.

Line	Days	Feed intake (g/bird/day)			Water intake (g/bird/day)			Water/Feed ratio		
		0.4% NaCl	0.8% NaCl	1.6% NaCl	0.4% NaCl	0.8% NaCl	1.6% NaCl	0.4% NaCl	0.8% NaCl	1.6% NaCl
1	0 – 2	9.9	10.0	9.7	26.5	30.1	31.4	2.69	3.02	3.24
	2 – 4	16.0	16.7	16.1	38.9	42.5	48.4	2.43	2.55	3.01
	4 – 8	24.9	25.9	26.1	54.0	61.3	74.8	2.16	2.37	2.87
	8 – 12	35.0	37.6	37.7	73.3	84.7	107.5	2.09	2.26	2.85
	12 – 16	48.3	49.4	50.8	100.8	110.5	144.0	2.09	2.24	2.83
2	0 - 2	8.1	9.0	8.1	17.6	22.1	21.2	2.17	2.46	2.63
	2 – 4	14.2	15.1	14.3	30.7	36.8	40.3	2.15	2.44	2.83
	4 – 8	24.9	25.3	24.2	48.9	57.6	69.1	1.96	2.28	2.85
	8 – 12	36.0	36.7	36.8	68.3	78.4	103.0	1.89	2.14	2.80
	12 – 16	49.7	50.8	49.8	94.6	110.4	137.9	1.90	2.17	2.77

8. Protein

Protein sources such as soybean and meat/bone meal tend to increase water consumption compared to other protein sources. Certain fishmeals contain higher sodium concentrations depending on the age and type of fish used, as well as the time of the year processed, which will tend to increase water consumption. Any nutrient that increases mineral excretion by the kidney will influence water intake.

A comparison of the amount of oxidative water produced with the amount of water lost through evaporation and other routes allows an estimate of the general importance of metabolic water in avian physiology. The maximum and minimum amounts of oxidative water which a bird of a given size will produce at rest can be calculated if the following assumptions are made.

1. The relation of body weight to basal metabolism is expressed by Brody's (1945) formula: kcal/day = 89(wt. in kg) to the power of 0.64
2. The oxidation of 1g of fat yields 1.07g of water and 9.2 kcal.
3. The oxidation of 1g of carbohydrate yields 0.56 g of water and 4.10 kcal
4. The oxidation of 1g of protein yields 0.40g of water and 4.10 kcal.
   (Bartholomew & Cade, 1963)

Table 2.29 Growth, feed and water consumption of birds on different levels of soybean oil meal (44%) in the diet over 8 weeks (Glista & Scott, 1949).

Average/chick	% Inclusion of soybean oil meal			
	0	7.5	15	30
Water consumption (ml)	3646	3781	3898	4604
Feed consumption (g)	1868	1901	1939	2053
Ml water: g feed	1.95	1.99	2.01	2.24
8 week weight (g)	868	861	863	828
8 week feed efficiency	0.403	0.414	0.399	0.378

9. Energy

High-energy diets tend to decrease water consumption compared to low energy diets.

Table 2.30 Performance of broilers fed diets of variable energy content (Leeson & Summers, 1997).

Diet ME (kcal/kg)	Body weight (g)		Feed intake (g/bird)		
	25 days	49 days	0 – 25 days	25 – 49 days	0 – 49 days
3300	1025	2812	1468	3003	4471
3100	1039	2780	1481	3620	5101
2900	977	2740	1497	3709	5206
2700	989	2752	1658	3927	5586

Table 2.31 Effect of energy dilution of finisher diet on growth of broilers (Leeson & Summers, 1997).

Diet energy ME (kcal/kg)	Body weight (g)		Feed intake (g/bird)		Energy intake (Mcal)
	42d	49d	35 – 42d	42 - 29d	35 – 49d
3200	2370	2982	1250	1373	8.43
2950	2395	2998	1301	1401	8.00
2700	2371	2970	1377	1456	7.66
2450	2331	2913	1371	1585	7.24
2200	2323	3022	1444	1677	6.85
1950	2277	2946	1482	1946	6.65

2.2.2.6 Procedure for site-specific factor inclusion

This section presents the modelling procedures used to incorporate different values for the site-specific information entered into the data capturing screens by the user.

2.2.2.6.1 Animal factors

1. Water intake:

If the water intake is not known, then the following equations are used to predict the water intake. This is then used to establish the WIR in the RefDoc.

Broilers:

$$DWU = -2.78 + 4.70D + 0.128D^2 - 2.17 \times 10^{-3}D^3$$

$$(1 \leq D \leq 56)$$

Where DWU = daily water use, liters per 1000 birds (Xin & Berry, 1994).

Layers:

$$WI = -0.057\ BW^2 + 0.031\ BW - 0.000002\ EP^2 + 0.0005\ EP - 0.181$$

Where WI = Water intake; BW = Body weight; EP = Egg production

2. Egg production

The following factors apply for layers.

If hen-day egg production (%) is the following and water intake exceeds the reference value, then apply the factor 1.025

Hen-day Egg production (%)	Water consumption per 1000 birds (l)
10	151
30	159
50	174
70	201
90	239

3. Gender ratio

If the recommendations for gender ratio are not adhered to (section 2.2.2.5), the following rule applies:

Gender ratio > recommendation, then apply factor 0.9

Gender ratio < recommendation, then apply factor 1.1

Beak trimming

Layers:

If the following beak trimming methods are used, then the following factors apply.

Debeaking	Factor applied
1 day, precision	0.9
6 day, precision	0.95
6 week, inside slant	0.95
8 week, non-precision	0.95
12 week, non-precision	0.9
16 week, non-precision	1.1
Non-debeaked	1

Broilers

If the following beak trimming methods are used, then the following factors apply.

Beak trimming	50 day Beginning weight
All mash diet	
none	1.1
1/3 top	1
½ top	9.5
½ block	8
Pelleted diet	
none	1.1
1/3 top	7.5
½ top	4.5
½ block	4.5

2.2.2.6.2 Environmental factors

1. Housing factors

The following housing water turnover rate factors apply:

Housing type	Broilers	Layers	Breeders	Dual purpose
Convection (open-sided) with floor with litter	0.9	0.9	1	1
Convection (open-sided) with Slats	0.9	1	0.9	1
Convection (open-sided) with cages	0.9	1	0.9	1
Environmentally controlled house with floor with litter	1	0.9	1	1.1
Environmentally controlled house with slats	1	0.9	1	1.1
Environmentally controlled house with cages	0.9	1	0.9	1.1
Closed house (not environ.controlled) with floor with litter	0.9	0.9	0.9	1
Closed house (not environmentally controlled) with slats	0.9	1	1	1
Closed house (not environmentally controlled) with cages	0.9	0.9	0.9	1
Outside runs	0.8	0.9	0.9	1
Free ranging	0.7	0.8	0.8	1

2. Air velocity

If the air velocity is > 1.79 m/s, then the following equation determines the wind chill index. *Air velocity is measured in m/s and temperature in degrees Celsius.*

$$K = 41 - ((10.45 + 10 *(\sqrt{\text{Air velocity}}) - \text{Air velocity})*(41 - \text{Temperature})/22.04$$

Where 41 = the body temperature of a chicken.

Air velocity	Temperature	K
2	12	11.47392
4	12	7.798094
6	12	5.420924
8	12	3.715985
10	12	2.440639
12	12	1.470447
14	12	0.731486
16	12	0.17559
18	12	-0.2307
20	12	-0.51173

3. Lighting

Layers: If the following lighting regimens are not adhered to a factor 1.025 applies:

Light treatment	
Growing period	**Laying period**
Gradually decreased from 22hr to 16 hr	Gradually increased from 16 hr to 22 hr
Gradually decreased from 22hr to 9 hr	Gradually increased from 9 hr to 22 hr
Gradually decreased from 16hr to 9 hr	Gradually increased from 9 hr to 16 hr
Gradually decreased from 16hr to 9 hr	Gradually increased from 9 hr to 16 hr
Started on constant 16 hr then suddenly decreased to constant 9 hr	Suddenly increased from 9 hr to 16 hr
Constant 16 hr	Constant 16 hr

4. Broiler lighting: The following factors apply if the corresponding recommendations are not met.

Light program	Hours light and dark	Factor
Continuous light in open sided house	23 hours light, 1 hour darkness	1
Continuous light in light tight house	23 hours light, 1 hour darkness	1.5
Intermittent light in light tight house	1 hour light, 3 hours darkness, then repeat.	1.6

5. Stocking density: If stocking densities are exceeded, apply the factor 0.9:

Broilers:

Liveweight (kg)	Birds/m^2
1.0	34.2
1.2	28.5
1.25	27.2
1.4	24.4
1.50	22.7
1.6	21.4
1.75	19.4
1.8	19.0
2.0	17.1
2.2	15.6
2.25	15.1
2.4	14.3
2.50	13.6
2.6	13.2
2.75	12.4
2.8	12.2
3.0	11.4
3.2	10.7
3.4	10.0
3.50	9.7
3.6	9.5

Broilers:

Open side houses:	25 kg/m^2
Environmentally controlled houses:	30-35 kg/m^2

Breeders:	**week 1 – 7**	**week 8 – 20**	**week 21 - 65**
Female birds/m^2	10 - 12	5 – 7	4 - 6
Male birds/m^2	10 – 12	3 – 4	-

Layers:	**Week 0 – 5**	**Week 5 – 18**	**Week18 - 72**
Cage system	200 cm^2/bird	300 cm^2/bird	450 cm^2
Floor System	25 – 30 birds/m^2	12 birds/m^2	

6. Feeder space/type

If feeder space is smaller than prescribed, apply the factor 0.9

Feeder Type	**Feeder Space**
Manually filled:	
Feeder plates	1 plate/70 – 100 chicks
Metal pen troughs (2cm)	4 cm space/chicken
Round suspended feeders (tube feeders 38cm)	1 tube/70 birds
Automatically filled:	
Chain feeders (troughs) single chain	2.5 cm/bird
Overhead tube feeders	1 tube/70 birds
Pan feeders (33 cm)	1 pan for 50 – 100 birds
Broilers:	
Troughs	2.5 cm/bird
Pan or tube feeders	2 – 3/100 birds
Broiler breeders:	
Hand-Fed Trough	20 cm/bird
Mechanical chain	15 - 20 cm/bird
Hanging 45 cm diameter tube	12 birds/tube (80 feeders/1000 birds)
Automatic centerless auger	10 - 12 birds per pan on restricted & controlled feed

Layer brooders:

Cage: feeder space	2.5 cm/bird (0 - 5 weeks)	
	5 cm/bird (5 - 18 weeks)	
Floor: feeder space	2.5 cm/bird (0 - 5 weeks)	
	2 tubes /100 birds (0 - 5 weeks)	
	8 cm/bird (5 - 18 weeks) or 1	pan/20 birds
	3 tubes /100 birds (5 - 18 weeks)	

Layers:

Cage: feeder space	5 cm/bird
Floor: feeder space	7.5 cm/bird
Trough	4 cm/bird (18 - 72 weeks)
Round	4 per 100 birds (18 - 72 weeks)

7. Drinker space/type

If drinker space is smaller than prescribed, apply the factor 0.9:

Waterer Type			**Waterer Space**
Bell drinkers	-	hot climate	1 drinker/65 birds
Bell drinkers	-	cool climates	1 drinker/100 birds)
Nipples			12 – 15 birds/nipple
Cup drinkers			30 – 35 birds per cup

Broilers:

Auto drinkers	-	400mm while brooding	1.6/100 birds
Auto drinkers	-	400mm	1/100 birds

Broiler breeders:

Plastic cone type	2/200 birds
8-foot trough waterers	1/200 birds (80 birds/m)
Nipple	1/15 pullets

Layer brooders:

Cage: waterer space	1 cup or nipple per 16 birds (0 - 8 weeks)
	1 cup or nipple per 8 birds (8 - 18 weeks)
Floor: waterer space	2 cm/bird (0 - 8 weeks)
	4 cm/bird (8 – 18weeks)(ave 3 cm growing period)
Trough: waterer space	2 cm/bird (0 - 8 weeks)
	4 cm/bird (8 - 18weeks)(ave 3 cm growing period)

Layers:

Cage: drinker space	8 birds per nipple
	12 hens per cup
	2.5 cm of space per bird
Floor: drinker space	2.5 cm of space per bird
	50 hens per fountain drinker
Nipples	4 - 6 birds/nipple (18 - 72 weeks)
Linear	2 cm/bird (18 - 72 weeks)
Round	1/125 birds (18 - 72 weeks)

Note: 2.5 cm of edge space of a round feeder or waterer is equivalent to 3.17 cm of straight trough. For trough waterers and feeders, count total usable edge space exposed to the birds.

8. Relative humidity

If the RH exceeds the standards provided in section 2.2.2.5, then apply factor 1.1.

If the RH is less than the standards in section 2.2.2.5, then apply factor 0.8.

9. Temperature

The following regression equations are used to determine the effect of temperature on gain and feed conversion.

$$G = -31.797 + 1.2071T + 0.21457BW - 8.852 \times 10^{-5} BW^2 + 1.51 \times 10^{-8} BW^3 - 2.0772 \times 10^{-3} TBW$$

$$FC = 2.0512 - 2.007 \times 10^{-2} T - 7.226 \times 10^{-4} BW + 1.7361 \times 10^{-7} BW^2 + 2.5564 \times 10^{-5} TBW$$

10. Floor type

Apply the following factors:

Floor type	Factor
Litter floor	1.1
Wire floor	1

2.2.2.6.3 Nutritional factors

1. Feeding program

Apply the following water intakes (g/bird/day) if feed is restricted, or *ad libitum*.

Period (day)	Selected	Non-selected	Selected –feed restricted
2	16.0	3.1	12.8
3-4	21.5	12.9	17.4
5-6	37.0	20.6	29.7
7-8	46.3	25.0	36.9
9-10	58.0	29.0	46.6
11-12	70.3	31.6	56.7
13-14	78.8	36.0	56.6
15-16	87.3	39.0	57.6
17-18	95.5	43.1	64.8
19-20	113.4	48.2	74.8
21-22	157.5	57.5	102.9
23-34	178.1	62.8	119.4
25-26	166.0	58.0	112.2
27-28	203.1	68.0	127.9
29-36	362.1	110.6	233.5
37-42	297.6	97.7	225.2
43-49	396.0	128.9	273.1

2. Watering programme

The water intakes are adjusted as indicated by the watering programme detail provided in section 2.2.2.5.

3. Feed texture/Pellet size

Water intake (g/bird/day)

Mash	Crumbles	Ratio C/M
14.49	19.08	132
22.77	27.23	120
33.72	40.93	122
37.70	49.13	131
42.51	53.07	125
63.43	82.75	131
71.63	89.42	125
75.98	94.86	125
93.62	117.77	126
109.77	140.22	128

4. **Additives**

If the following additives are present in the diet, apply the following factors.

Growth and production promoters

A. Antibiotics — Factor 1.001

Penicillin

Chlortetracycline

Oxytetracycline

Bacitracin

Streptomycin

B. Arsenic compounds — Factor 9.995

Arsanilic acid (para – amino – hydroxyphenylarsonic acid)

Sodium arsanilate

3 – nitro – 4 – hydroxyphenylarsonic

C. Hormonal preparations

Thyro – active — Factor 1

Iodinated casein

a) Desiccated thyroid glands

b) Thyroxine

D. Estrogenic — Factor 1.002

a) Diethylstilbestrol (DES)

a) Dienestrol diacetate

Enzyme preparations — Factor 1

Pellet binders — Factor 1

Sodium Bentonite

Paper and pulp by – products (hemicelluloses and lignins)

Guar meal

Anticoccidials — Factor 9.995

Coccidiostats

Coccidiocides

Ionophores – Monensin

Antifungals Factor 1.001

Sodium propionate

Sodium benzoate

Quaternary ammonium compounds

Anti-fungal antibiotics (Nystatin)

Antioxidants Factor 1

Butylated hydroxy - anisode (BHA)

Diphenylparaphenylediamine (DPPD)

Ethoxyquin

Butylated hydroxytoluene (BHT)

Tocopherols (Vit E)

Phospholipids

Pigmentation compounds **Factor 1**

Insecticides (to kill flies) **Factor 1**

Deworming drugs (Anthelminicts) **Factor 1**

Hygromycin – round worm

Niclosmide – tape worm

Probiotics **Factor 1.0005**

Lactobacilli

5. Vitamin and trace mineral premixes

The recommended allowances are compared with the user input data and used to assess total trace mineral intake.

6. ME:P

User defined ME/P ratios for varying caloric and protein content of the diet are compared to the reference material provided in section 2.2.2.5.

7. NaCl

Salt in the diet affects water intake as follows:

Line	Days	Water intake (g/bird/day)			Water/Feed ratio		
		0.4% NaCl	0.8% NaCl	1.6% NaCl	0.4% NaCl	0.8% NaCl	1.6% NaCl
1	0 – 2	26.5	30.1	31.4	2.69	3.02	3.24
	2 – 4	38.9	42.5	48.4	2.43	2.55	3.01
	4 – 8	54.0	61.3	74.8	2.16	2.37	2.87
	8 – 12	73.3	84.7	107.5	2.09	2.26	2.85
	12 – 16	100.8	110.5	144.0	2.09	2.24	2.83
2	0 – 2	17.6	22.1	21.2	2.17	2.46	2.63
	2 – 4	30.7	36.8	40.3	2.15	2.44	2.83
	4 – 8	48.9	57.6	69.1	1.96	2.28	2.85
	8 – 12	68.3	78.4	103.0	1.89	2.14	2.80
	12 – 16	94.6	110.4	137.9	1.90	2.17	2.77

8. Protein

Apply the following values if the protein levels are 0, 7.5, 15 or 30%

Average/chick	0	7.5	15	30
Water consumption (ml)	3646	3781	3898	4604
Feed consumption (g)	1868	1901	1939	2053
Ml water: g feed	1.95	1.99	2.01	2.24
8 week weight (g)	868	861	863	828
8 week feed efficiency	0.403	0.414	0.399	0.378

9. Energy

Apply the following factors for water intake if the ME values are:

Diet energy ME (kcal/kg)	Factor	
	42d	49d
3200	1.25	1.373
2950	1.301	1.401
2700	1.377	1.456
2450	1.371	1.585
2200	1.444	1.677
1950	1.482	1.946

2.3 Conclusion

As described in the introduction water quality constituents may impact on several norms, ranging from poultry health to equipment failure, all of which have an effect on the profitability of a poultry enterprise. Apart from the obvious disadvantages to production from WQCs that have an adverse effect on poultry health due to mineral imbalances, pathogens and parasites, knowledge of water quality is also required for managerial and nutritional purposes. For large intensive commercial production systems a WQC that has a negative influence on nutrient bioavailability, feed intake, or one that may increase nutrient requirements for specific production defined parameters, can have a significant effect on the cost of production. For those production systems operating on large volumes and narrow margins between feed costs and profitability, the contribution that the chemical composition of the water source makes towards mineral requirements, and significant dietary and drug interactions, must be taken into account if feed formulation is to be accurate and representative of the true requirements.

As reported previously (Casey *et al.*, 1996; 1998; Coetzee *et al.*, 1997; 2000), many water sources used for poultry production purposes in South Africa contain WQC concentrations that exceed local and international guidelines by large margins. Predicting the likely outcome of events, and relevant cause and effect relationships due to the use of such water sources has been the focus of this chapter. One of the primary reasons for striving to develop a system that can incorporate those site-specific factors that influence the adverse effects that may occur, due to the presence of WQCs at potentially hazardous concentrations, is to allow for increased measurement and observations relating to these factors. It is hoped that this will not only allow for more efficient usage of water, but also prevent the incorrect classification of water sources that pose a "potential" hazard based on rudimentary guidelines, and encourage water users to acknowledge water with a high mineral content as not simply water with poor quality, but rather as a potentially valuable source of minerals.

CHAPTER 3

THE EFFECT OF WATER QUALITY ON MINERAL CONCENTRATIONS IN OSTRICHES

3.1 Introduction

Ostriches are bred commercially and reared in South Africa, primarily for the production of leather. Ostrich meat and feathers also provide a source of income. Edible offal includes the liver, gizzard, heart, and carcass and bone meal. Birds are mature at 104 kg (Mellet, 1993), although may be slaughtered at 14 months (ca 73 kg) when the optimum leather yield may be obtained. Most of the production systems included in this study are similar to the natural habitats where ostriches occur such as savanna, desert and grassland. The natural diet includes green annual grasses, berries, seeds, succulent plants, small reptiles and insects (which may however be due to incidental ingestion). The specific nutrient requirements for the various categories within the production systems are still being established.

This chapter addresses the possible effects of water quality on the mineral content of various biological tissues in ostriches. Research regarding water quality for ostrich production systems in the Oudtshoorn District was initiated by the State Veterinary Inspector at the Oudtshoorn Abattoir due to observations of carcass defects that appeared to be more prevalent in birds originating from certain areas within the district. Defects included breaks at the proximal portion of the *Os humerus* and distal portion of the radius and ulna during attachment to jigs, and femur, tibia and fibula fractures en route to stunning procedure. Exostoses were more prevalent in certain batches. Several producers had also noted significant seasonal fluctuations in growth rates that appeared to be linked to water quality. Other research regarding water quality for poultry in the Western Cape also raised concern (Coetzee *et al*., 2000).

3.2 Methods

3.2.1 Water quality investigation

Farms which had produced ostriches from which carcass abnormalities had been observed, or farms which had reported a perceived water quality problem, were identified by the State Veterinarian at the Oudtshoorn Abattoir and the Agricultural Extension Officer, in conjunction with the Klein Karoo Kooperasie. Due to the results from a previous sampling phase, in particular those of mercury, selected farms were re-sampled. This second phase was conducted without the use of the preservation techniques used in the first sampling phase that had not permitted mercury determination in some samples. Sample location was determined using a Garmin GPS system, but due to sensitive nature of the results obtained, only general references will be made to districts and farm codes.

Water samples were collected in 250 ml sterilised plastic containers obtained from the Institute for Soil Climate and Water (Pretoria, ARC), according to techniques prescribed by the ISCW (1998). The ISCW also conducted the laboratory analyses of all the samples, and also prepared the sample containers where necessary (for example, sample preservation with $HgCl_2$ for NO_3 determination). Samples were preferably taken from the point of use, for example the drinking trough. In some cases samples were collected from the borehole and reservoir, dependent on the nature of the available water sources to the users involved, and the watering techniques. Long reservoir residence times and multiple watering points were sampled. The reader is referred to Volume 1 of the WRC Final Report K5/644 (Casey et al., 1998) for more information.

3.2.1.1 Guidelines and acronyms used for water quality assessment

Generic risk assessments for poultry were formulated using the software program CIRRA, Version 1.03. The guidelines used are presented in section 2.2 of this Volume. Although the guidelines are generally accepted as representative of avian species, differences in production environment (extensive versus controlled intensive) and differences in water turnover rates, did not permit the use of the Specific risk assessment models. Furthermore, due to the cumulative nature of many of the PHCs recorded, a longer productive life-cycle of breeding ostriches (compared to broiler production), and the harsh environment factors (low moisture from ration, high ambient temperatures), in many cases the same trigger levels and target water quality ranges as proposed in section 2.2 were used. Due to the harsh environmental factors prevalent in the areas sampled, and in the interests of erring on the conservative side, in cases where more than one guideline is reported for a particular constituent, the lower guideline reported was used. This is in accordance with the recommendations of how to apply developed guidelines under local conditions (WHO, 1993). Concentrations recorded that exceeded TWQR as proposed in section 2.2, were reported as potentially hazardous constituents (PHC). Constituents that recorded values within 10% of a guideline limit were reported as constituents of concern (COC). Definitions of these terms appear below.

- PHC: indicates that the WQC in question is likely to result in adverse effects
- COC: indicates that the WQC in question could conceivably become a PHC due to concentration variations, such as seasonal fluctuation in the water source or evaporative effects, and should therefore be monitored.

<u>Acronyms used:</u>

Cat C/D/E	Category level (Quality of Domestic Water Supplies, 1998)
TWQR	Target Water Quality Range (DWA&F 1996)
MPL	Maximum Permissible Level ((Kempster *et al.*, 1981; Smith 1988)
AV	Antagonistic variable (Underwood & Suttle, 1999)

<u>Antagonistic Variable</u>

An antagonistic variable (AV) is a constituent with unsubstantiated toxicity, but which may indirectly lead to trace mineral imbalances due to interference with the absorption of other trace minerals (Underwood & Suttle, 1999). With regard to fluoride toxicity, molybdenum is an AV. Due to the possible antagonistic effects of Sr on Ca, 0.1 mg/L was taken as a trigger for COC classification for Sr. Zinc is as an additional example of a constituent that, at a certain concentration (0.1 mg/L), may not have any direct adverse effects, but possibly interfere with the absorption of essential trace elements.

3.2.2 Tissue collection and assay

Samples were collected at the Oudtshoorn Abattoir from ostriches originating from previously identified farms yielding birds with carcass problems. Not all the farmers involved in the water quality study produced ostriches for slaughter, or were able to provide sufficient numbers of birds in the time frame of this study. As a result the data set used for the models tested for mineral levels does not involve all the farmers presented in the water quality section. A total of 20 farmers were included in the tissue collections from the abattoir, with birds selected at random from the slaughter batches.

Duplicate liver, kidney and humerus samples were taken at the Oudsthoorn Abattoir during the normal slaughter process, packed in ice and sent by courier to the Department of Animal and Wildlife Science, University of Pretoria. Kidney and liver samples were sectioned, dried (at 60 degrees C), processed by the Wet-ash method, diluted with standards also being prepared. Bone samples had fat, muscle and connective tissue removed, broken into small fragments with a wooden mallet prior to fat extraction (16 hours) performed. Samples were then ground to fine particles, processed by the Wet-ash method and diluted with the appropriate standard being prepared. All duplicates wee tested for normality before being accepted as reliable data points after being read by Atomic Absorption Spectrophotometry. Tissues were assayed for magnesium, calcium, sodium, potassium, manganese and copper (Heckman, 1967; 1968; 1971).

3.2.3 Statistical procedure

Replicate samples were tested for normal distribution fit, with those indicating significant variance between duplicates eliminated from the data set. Models were tested on a total of 360 observations for each mineral, using the SAS Software System (SAS, 1994). Differences between tissues within minerals, and between treatments (subgroups = geographical location; water chemistry; tissue levels) for both tissue (indexed) and mineral observations, were tested for using Fisher's Test, at the $P < 0.05$ level of significance for Type III Sums of Squares with the model tested, and $P < 0.01$ level for Least Squares Means.

3.3 Results

3.3.1 Water quality investigation

1A Earth Dam – Source (Van Wyksdorp – 21:20-33:45)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.066	0.004 – MCL	Br	2.338	3 – TWQR
Ca	78	75 – TWQR	Sr	1.355	0.1 – AV
Cl	1150	500 – Cat D			
F	7.39	2 – TWQR			
Na	848	250 – Cat D			
SO_4	411	250 – Cat D			
TDS	2923	3000 – Cat D			
Hg	0.002	0.001 – TWQR			
Se	0.026	0.01– TWQR			
Ti	0.467	0.2 – MPL			

1B Small Drinking Trough (Van Wyksdorp – 21:20-33:45)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	3.05	3 – TWQR	Sr	1.701	0.1 – AV
Be	0.12	0.004 – MCL			
Ca	104	75 – TWQR			
Cl	1302	500 – Cat D			
F	6	2 – TWQR			
Mg	135	125 - TWQR			
Na	929	250 – Cat D			
SO_4	347	250 – Cat D			
TDS	3151	3000 – Cat D			
Hg	0.002	0.001 – TWQR			
Ti	0.616	0.2 – MPL			

2A Borehole – Source (Van Wyksdorp – 21:20-33:40)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	3.71	3 – TWQR	Sr	2.686	0.1 – AV
Be	0.113	0.004 – MCL			
Ca	365	75 – TWQR			
Cl	2347	500 – Cat D			
Mn	0.811	0.6 – TWQR			
Mg	203	125 - TWQR			
Hg	0.003	0.001 – TWQR			
Se	0.013	0.01– TWQR			
Na	1250	250 – Cat D			
SO_4	572	250 – Cat D			
TDS	4992	3000 – Cat D			
Ti	1.516	0.2 – MPL			

2B Small Drinking Trough (Van Wyksdorp – 21:20-33:40)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	4.27	3 – TWQR	Sr	2.66	0.1 – AV
Be	0.108	0.004 – MCL			
Ca	332	75 – TWQR			
Cl	2171	500 – Cat D			
Mg	194	125 - TWQR			
Se	0.016	0.01– TWQR			
Na	1110	250 – Cat D			
SO_4	511	250 – Cat D			
TDS	4559	3000 – Cat D			
Ti	1.439	0.2 – MPL			

* Hg not detected due to sample preservation technique

3 Olifants River and Fountain (De Rust 22:54-33:28)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.173	0.05 - TWQR	Sr	0.664	0.1 – AV
Br	3.02	3 – TWQR			
Be	0.024	0.004 – MCL			
Cu	0.56	0.6 – Cat D			
Se	0.707	0.05– Cat D			
Te	0.028	0.005 - TWQR			
Ti	2.911	0.2 – MPL			

* Hg not detected due to sample preservation technique

4 Fountain – Kamanassie Range (De Rust 22:58-33:32)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.098	0.05 – TWQR	Sr	0.749	0.1 – AV
Cl	1997	500 – Cat D			
Se	0.413	0.01– TWQR			
Ti	1.933	0.2 – MPL			
Zn	3.439	1.5 – TWQR			

*** Hg not detected due to sample preservation technique**

6 Fountain Swartberg Range (De Rust 22:40-33:29)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.009	0.004 – TWQR			
Se	0.275	0.05– Cat D			
Ti	1.225	0.2 – MPL			
Zn	2.552	1.5 – TWQR			

* Hg not detected due to sample preservation technique

7(10) Fountain Swartberg Range (De Rust 22:41-33:30)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.006	0.004 – MCL	As	0.022	0.05 – TWQR
Se	0.198	0.05 – Cat D			
Ti	1.065	0.2 – MPL			
Zn	1.788	1.5 – TWQR			

* Hg not detected due to sample preservation technique

7(2) Fountain Swartberg Range (De Rust 22:41-33:30)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Hg	0.014	0.002 – Cat D	Sr	0.219	0.1 – AV

8(10) Fountain Kamanassie Range (Oudtshoorn 22:32-33:32)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Ca	83	75 – TWQR	Sr	0.77	0.1 – AV
Cl	396	200 – TWQR	As	0.011	0.05 - TWQR
F	2.66	2 – TWQR			
Na	249	250 – Cat D			
SO_4	160	125 – TWQR			
TDS	1052	1000 – TWQR			
Ti	0.389	0.2 – MPL			

* Hg not detected due to sample preservation techniques

8(2) Fountain Kamanassie Range (Oudtshoorn 22:32-33:32)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Hg	0.025	0.001 – TWQR	Sr	0.522	0.1 – AV
Se	0.01	0.01– TWQR			
Ti	0.29	0.2 – MPL			

9 Olifants River via earth dam (Oudtshoorn 22:26-33:28)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.034	0.05 – TWQR	Zn	1.4	1.5 – TWQR
Se	0.221	0.05– Cat D			
Ti	0.811	0.2 – MPL			

* Hg not detected due to sample preservation techniques

10 Borehole Kamanassie Range (Oudtshoorn 22:33-33:40)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.03	0.05 – TWQR	Zn	1.174	1.5 – TWQR
Se	0.175	0.05– Cat D			
Te	0.013	0.005 – MPL			
Ti	0.767	0.2 – MPL			

11 Borehole (Oudtshoorn 22:17-33:38)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.04	0.05 – TWQR	Sr	0.844	0.1 – AV
Be	0.014	0.004 – MCL			
Ca	122	75 – TWQR			
Cl	301	500 – Cat D			
Se	0.02	0.01– TWQR			
Na	453	250 – Cat D			
SO_4	210	125 – TWQR			
TDS	1633	1000 – TWQR			
Ti	0.522	0.2 – MPL			

11A Reservoir in Olifants River (Oudtshoorn 22:17-33:38)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.048	0.004 – MCL	Sr	1.238	0.1 – AV
Ca	183	75 – TWQR			
Cl	1112	500 – Cat D			
Se	0.015	0.01– TWQR			
Na	794	250 – Cat D			
SO_4	529	250 – Cat D			
TDS	2913	1000 – TWQR			
Ti	0.826	0.2 – MPL			

* Hg not detected due to sample preservation technique

11B Rural water (Oudtshoorn 22:17-33:38)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.004	0.004 – MCL	Sr	0.157	0.1 – AV
Se	0.087	0.05– Cat D			
Ti	0.821	0.2 – MPL			

11C Drinking Trough (Oudtshoorn 22:17-33:38)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.065	0.004 – MCL	Sr	1.371	0.1 – AV
Ca	190	75 – TWQR	As	0.02	0.05 – TWQR
Cl	1251	500 – Cat D	Br	2.898	3 – TWQR
Mg	440	250 – Cat D			
Se	0.022	0.01– TWQR			
Na	864	250 – Cat D			
SO_4	535	250 – Cat D			
TDS	3196	3000 – Cat D			
Ti	0.895	0.2 – MPL			

* Hg not detected due to sample preservation technique

11D Drinking Trough (Oudtshoorn 22:17-33:38)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.006	0.004 – MCL	Sr	1.893	0.1 – AV
Ca	107	75 – TWQR	V	0.055	0.1 – TWQR
Cl	1054	500 – Cat D			
Se	0.197	0.01– TWQR			
Na	774	250 – Cat D			
SO_4	513	250 – Cat D			
TDS	2690	1000 – TWQR			
Ti	1.284	0.2 – MPL			

* Hg not detected due to sample preservation technique

11G Drinking Trough (Oudtshoorn 22:17-33:38)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.048	0.004 – MCL	Sr	1.146	0.1 – AV
Ca	149	75 – TWQR	As	0.012	0.05 – TWQR
Cl	1176	500 – Cat D	Br	2.428	3 – TWQR
Se	0.023	0.01– TWQR			
Na	837	250 – Cat D			
SO_4	540	250 – Cat D			
TDS	2947	3000 – Cat D			
Ti	0.271	0.2 – MPL			

* Hg not detected due to sample preservation technique

13A Borehole in Olifants River (Oudtshoorn 22:20-33:38)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Cl	237	200 – TWQR	Sr	0.499	0.1 – AV
Na	192	50 – TWQR			
Ti	0.297	0.2 – MPL			

13B Drinking Trough (Oudtshoorn 22:20-33:38)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.004	0.004 – MCL	Sr	4.532	0.1 – AV
Cl	481	200 – TWQR			
Se	0.11	0.02 – Cat D			
Na	288	50 – TWQR			
TDS	1135	1000 – TWQR			
Te	0.016	0.005 - MPL			
Ti	0.825	0.2 – MPL			

*Hg not detected due to sample preservation technique

14 Trough BPlaas (Oudtshoorn 22:20-33:38)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Cd	2.186	0.01 – Cat D	Sr	0.43	0.1 – AV
Mn	42.9	0.6 – TWQR	F	1.01	2 – TWQR
Ti	0.215	0.2 – MPL	As	0.035	0.05 – TWQR
			Mo	2.631	10 – TWQR

15 Trough (George 22:19-33:47)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Mn	0.705	0.6 – TWQR	Sr	0.209	0.1 – AV
			F	1.47	2 – TWQR

16(11) Borehole (Oudtshoorn 22:19-33:41)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	3.185	3 – TWQR	As	0.01	0.05 – TWQR
Ca	378	75 – TWQR	Sr	2.11	0.1 – AV
Cl	1564	500 – Cat D			
Mg	211	125 – TWQR			
Se	0.021	0.01– TWQR			
Na	937	250 – Cat D			
SO_4	1043	250 – Cat D			
TDS	4434	3000 – Cat D			
Ti	1.486	0.2 – MPL			

16(2) Borehole (Oudtshoorn 22:19-33:41)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	6.6	3 – TWQR	As	0.03	0.05 – TWQR
Ca	385	75 – TWQR	Sr	3.72	0.1 – AV
Cl	2018	500 – Cat D			
Mg	240	125 – TWQR			
Hg	0.01	0.002 – Cat D			
Se	0.011	0.01– TWQR			
Na	945	250 – Cat D			
SO_4	1320	250 – Cat D			
TDS	5119	3000 – Cat D			
Ti	1.744	0.2 – MPL			

17 Trough from fountain (George 22:19-33:47)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Cl	668	500 – Cat D	As	0.022	0.05 – TWQR
Na	474	250 – Cat D	Sr	0.521	0.1 – AV
TDS	1375	1000 – TWQR			

*Hg not detected due to sample preservation technique

18 Borehole Kalkrug (George 22:31-33:46)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Cl	372	200 – TWQR	Sr	0.695	0.1 – AV
Se	0.104	0.01– TWQR	F	1.76	2 - TWQR
Na	208	50 – TWQR	V	0.041	0.1 - TWQR
SO_4	182	125 – TWQR	Cd	0.004	0.005 - TWQR
TDS	1001	1000 – TWQR			
Ti	0.793	0.2 – MPL			

19(11) Borehole (Calitzdorp 21:59-33:34)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	2.967	3 – TWQR	Sr	0.94	0.1 – AV
Be	0.089	0.004 – MCL			
Ca	109	75 – TWQR			
Cl	1498	500 – Cat D			
Na	1270	250 – Cat D			
SO_4	679	250 – Cat D			
TDS	3722	3000 – Cat D			
Ti	0.685	0.2 – MPL			

19(2) Trough (Calitzdorp 21:59-33:34)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	6.44	3 – TWQR	Sr	1.132	0.1 – AV
Ca	96	75 – TWQR			
Cl	1597	500 – Cat D			
Hg	0.008	0.002 – Cat D			
Na	1160	250 – Cat D			
SO_4	624	250 – Cat D			
TDS	6323	3000 – Cat D			
Ti	0.558	0.2 – MPL			

20 Borehole Rooiberg (Calitzdorp 21:48-33:40)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Ca	88	75 – TWQR	As	0.017	0.05 – TWQR
Cl	424	500 – Cat D	Sr	0.515	0.1 – AV
F	2.8	2 – TWQR			
Se	0.011	0.01– TWQR			
Na	240	250 – Cat D			
SO_4	189	125 – TWQR			
TDS	1214	1000 - TWQR			
Ti	0.423	0.2 – MPL			

21A Grobbelaars River (Oudtshoorn 21:47-33:37)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Ti	0.208	0.2 – MPL	Sr	0.241	0.1 – AV

21B Borehole Kango series (Oudtshoorn 21:47-33:37)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.066	0.05 – TWQR	Sr	1.567	0.1 – AV
Se	0.016	0.01– TWQR			
Ti	0.824	0.2 – MPL			

22(2-1) River Kango (Oudtshoorn 22:20-33:30)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Hg	0.006	0.002 – Cat D	Sr	0.107	0.1 – AV

22(2-3) River Kango (Oudtshoorn 22:20-33:30)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
As	0.014	0.05 – TWQR			
Hg	0.001	0.001 – TWQR			
Pb	0.102	0.015– TWQR			

23 Fountain Swartberg Range (De Rust 22:28-33:22)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.024	0.004 – TWQR			
Br	3.79	3 – TWQR			
Pb	0.043	0.015 – TWQR			
Se	0.054	0.05 – Cat D			
Ti	1.09	0.2 – TWQR			

24 Fountain (Prins Albert 22:01-33:16)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Be	0.016	0.004 – TWQR	As	0.013	0.05 – TWQR
Br	5.74	3 – TWQR	Sr	1.67	0.1 – AV
Pb	0.01	0.015 – TWQR	Mo	1.279	10 – TWQR
Na	177	50 – TWQR			
Ti	0.898	0.2 – MPL			

25 Fountain Northern aspect Swartberg (Prins Albert 22:08-33:15)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	3.75	3 – TWQR			

26(2 -1) (Oudtshoorn 22:11-33:28)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Hg	0.004	0.002 – Cat D	Sr	0.253	0.1 – AV
Se	0.015	0.001 – TWQR			
Ti	0.183	0.2 – MPL			

26(2 -5) (Oudtshoorn 22:11-33:28)

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	3.47	3 – TWQR	As	0.013	0.05 – TWQR
Ca	100	75 – TWQR	Sr	1.063	0.1 – AV
Cl	824	500 – Cat D			
Hg	0.008	0.002 – Cat D			
Na	583	250 – Cat D			
SO_4	539	250 – Cat D			
TDS	2146	1000 – TWQR			
Ti	0.542	0.2 – MPL			

Hotsprings

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	3.92	3 – TWQR	As	0.041	0.05 - TWQR
Mn	1.151	0.6 – Cat D			

Olifants - Stomprif

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	**WQC**	Measured (mg/l)	Relevant Guideline (mg/l)
Br	3.10	3 – TWQR	As	0.028	0.05 – TWQR
Cl	341	500 – Cat D	Sr	0.733	0.1 – AV
F	2.56	2 – TWQR			
Se	0.026	0.01– TWQR			
Na	242	250 – Cat D			
SO_4	129	125 – TWQR			
Ti	0.432	0.2 – MPL			

Olifants - Volmoed

PHC			COC		
WQC	Measured (mg/l)	Relevant Guideline (mg/l)	WQC	Measured (mg/l)	Relevant Guideline (mg/l)
Br	8.42	3 – TWQR	As	0.063	0.05 – TWQR
Be	0.193	0.004 – MCL	Sr	2.548	0.1 – AV
Ca	471	75 – TWQR	B	3.81	5 – TWQR
Cl	3897	500 – Cat D			
Mg	321	125 – TWQR			
Se	0.108	0.01– TWQR			
Na	2660	250 – Cat D			
SO_4	1731	250 – Cat D			
TDS	9262	3000 – Cat D			
Ti	1.979	0.2 – MPL			

Table 3.1 Summary statistics for the main PHCs and COCs identified from 44 water samples.

WQC	PHC	COC	Average (mg/L)	SD (mg/L)	Median (mg/L)	Range (mg/L)	
(n) / WP	259	63				Minimum	Maximum
	5.88	1.43					
As	7	14	0.02	0.031	0.01	0	0.173
Be	18	0	0.027	0.046	0.004	0	0.193
Br	15	3	2.248	1.94	1.95	0	8.423
Cl	23	0	678	856	289	0	3897
Ca	17	0	95	115	57.8	1.7	471
F	5	3	0.63	1.54	0	0	7.39
Hg	11	0	*	*	*	0	0.025
Mg	7	0	64.8	94.2	32	1	440
Mn	4	0	1.116	6.45	0.061	0	42.9
Na	23	0	415	538	184	1	2660
SO_4	19	0	258	380	70.5	0	1731
Se	26	0	0.067	0.133	0.014	0	0.707
Ti	34	0	0.743	0.62	0.651	0.04	2.911
TDS	20	0	1642	2061	632.5	30	9262
Sr	0	35	0.961	1.029	0.68	0.014	4.532
Zn	3	2	0.319	0.729	0	0	3.439

*not calculated due to sample preservation techniques

3.3.2 Mineral concentrations of selected tissues

Table 3.2 presents Proc GLM results for differences in mineral values obtained within tissues, between treatments, whilst Tables 3.3 to 3.5 provide the least squares means results. Treatments are defined as pooled farmer subgroups sharing similar characteristics, either tissue values (TT), geographical proximity (GT) or water chemistry (WT). The treatments tested were as follows:

TT:
- TT1 = Water samples 4, 5, 16
- TT2 = Water samples 8, 10, 11
- TT3 = Water samples 1, 9, 24
- TT4 = Water samples 7, 17, 13,14,15
- TT5 = Water samples 2, 20, 18, 19
- TT6 = Water samples 6, 21, 23, 25

GT:
- GT1 = Water samples 1, 10, 16,25
- GT2 = Water samples 2, 9, 11, 13, 14, 15 18, 20, 21,
- GT3 = Water samples 4, 5, 8, 23, 24
- GT4 = Water samples 6, 7, 17, 19

WT: WT1 = Water samples 1, 2, 11, 16, 19

WT2 = Water samples 8, 17, 18, 20

WT3 = Water samples 13, 14, 15, 21, 24, 25

WT4 = Water samples 4, 5, 7, 9, 10

Table 3.2. Differences ($P<0.05$) between minerals within three tissue types for 6 tissue treatments (TT) in ostriches.

Dependent Variable	Tissue	R-square (%)	Type III SS (P<0.05)
Mg	Liver	6.6	0.1706
Ca	Liver	17.5	0.0006
Na	Liver	23.7	0.0001
K	Liver	10.2	0.0306
Cu	Liver	12.9	0.0068
Mn	Liver	27.3	0.0001
Mg	Bone	6.2	0.226
Ca	Bone	31.2	0.001
Na	Bone	9.3	0.0599
K	Bone	17.9	0.0007
Cu	Bone	5.9	0.254
Mn	Bone	14.2	0.0055
Mg	Kidney	33.3	0.0001
Ca	Kidney	46.5	0.0001
Na	Kidney	61.6	0.0001
K	Kidney	54.9	0.0001
Cu	Kidney	16.5	0.0014
Mn	Kidney	17.9	0.0006

Table 3.3 Significant ($P<0.01$) LSMeans interactions for minerals determined in liver between tissue treatments (TT).

LSMeans for Liver (mg/kg DM)					
Mg	**Ca**	**Na**	**K**	**Mn**	**Cu***
none	TT1 & TT6 (222.78 & 172.30)	TT1 & TT3 (3459.0 & 2925.3)	TT4 & TT5 (9081.6 & 9964.0)	TT1 & TT2 (6.432 & 5.09)	TT4 & TT6 (0.395 & 0.493)
	TT2 & TT6 (216.68 & 172.30)	TT1 & TT5 (3459.0 & 2515.9)	TT5 & TT6 (9964.0 & 9322.1)	TT1 & TT3 (6.432 & 5.15)	TT5 & TT6 (0.372 & 0.493)
	TT4 & TT6 (210.06 & 172.30)	TT1 & TT6 (3459.0 & 2791.7)		TT1 & TT5 (6.432 & 5.65)	
		TT2 & TT5 (3031.0 & 2515.9)		TT2 & TT4 (5.09 & 6.18)	
		TT3 & TT5 (2925.3 & 2515.9)		TT2 & TT6 (5.09 & 6.17)	
		TT4 & TT5 (2982.8 & 2515.9)		TT3 & TT4 (5.15 & 6.18)	
				TT3 & TT6 (5.15 & 6.17)	

* mg Cu/kg = (reported value) x 49

Table 3.4 Significant ($P<0.01$) LSMeans interactions for minerals determined in bone between tissue treatments (TT).

LSMeans for Bone (mg/kg DM)					
Mg	**Ca**	**Na**	**K**	**Mn**	**Cu**
none	TT1 & TT4 (18.63 & 19.68)	TT5 & TT6 (3981 & 3880)	TT1 & TT3 (782.87 & 1019.0)	TT2 & TT3 (5.34 & 5.99)	none
	TT1 & TT5 (18.63 & 19.56)		TT1 & TT4 (782.87 & 1005.0)	TT2 & TT5 (5.34 & 5.94)	
	TT1 & TT6 (18.63 & 20.48)		TT3 & TT5 (1019.0 & 815.37)		
	TT2 & TT6 (19.44 & 20.48)		TT3 & TT6 (1019.0 & 765.5)		
	TT3 & TT4 (18.80 & 19.68)		TT4 & TT6 (1005.0 & 765.5)		
	TT3 & TT5 (18.80 & 19.56)				
	TT3 & TT6 (18.80 & 20.48)				
	TT4 & TT6 (19.68 & 20.48)				
	TT5 & TT6 (19.56 & 20.48)				

Table 3.5 Significant ($P<0.01$) LSMeans interactions for minerals determined in kidney between tissue treatments (TT).

LSMeans for Kidney (mg/kg DM)					
Mg	**Ca**	**Na**	**K**	**Mn**	**Cu**
TT1 & TT2 (886.04 & 780.32)	TT1 & TT4 (292.58 & 387.37)	TT1 & TT2 (6180.81 & 8009.57)	TT1 & TT2 (10284.8 & 8306.8)	TT2 & TT3 (7.87 & 7.10)	TT1 & TT2 (13.04 & 12.25)
TT1 & TT3 (886.04 & 780.95)	TT2 & TT4 (264.01& 387.37)	TT3 & TT2 (5754.90& 8009.57)	TT1 & TT3 (10284.8 & 8241.0)	TT6 & TT3 (8.26 & 7.10)	TT1 & TT3 (13.04 & 11.93)
TT1 & TT4 (886.04 & 839.54)	TT3 & TT4 (268.21& 387.37)	TT4 & TT2 (5877.52& 8009.57)	TT1 & TT4 (10284.8 & 9567.0)	TT6 & TT4 (8.26 & 7.35)	TT1 & TT4 (13.04 & 12.34)
TT1 & TT5 (886.04 & 796.50)	TT5 & TT4 (298.39& 387.37)	TT5 & TT2 (6376.56& 8009.57)	TT1 & TT5 (10284.8 & 9470.9)	TT6 & TT5 (8.26 & 7.60)	TT1 & TT6 (13.04 & 12.31)
TT1 & TT6 (886.04 & 813.79)	TT6 & TT4 (269.55& 387.37)	TT6 & TT2 (5965.76& 8009.57)	TT1 & TT6 (10284.8 & 9591.7)		TT3 & TT5 (11.93 & 12.55)
TT2 & TT4 (780.32 & 839.54)		TT3 & TT5 (5754.90 & 6376.56)	TT2 & TT4 (8306.8 & 9567.0)		
TT3 & TT4 (780.95 & 839.54)		TT4 & TT5 (5877.82 & 6386.56)	TT2 & TT5 (8306.8 & 9470.0)		
TT4 & TT5 (839.54 & 796.50)			TT2 & TT6 (8306.8 & 9591.7)		
			TT3 & TT4 (8241.0 & 9567.0)		
			TT3 & TT5 (8241.0 & 9470.0)		
			TT3 & TT6 (8241.0 & 9591.7)		

Table 3.6. Differences (P<0.05) between minerals within three tissue types for 6 water chemistry treatments (WT) in ostriches.

Dependent Variable	Tissue	R-square (%)	Type III SS (P<0.05)
Mg	Liver	5.4	0.1269
Ca	Liver	23.9	0.0001
Na	Liver	24.1	0.0001
K	Liver	10.01	0.0128
Cu	Liver	4.3	0.1954
Mn	Liver	12.6	0.0031
Mg	Bone	6.9	0.0598
Ca	Bone	9.4	0.0168
Na	Bone	3.4	0.3136
K	Bone	18.3	0.0001
Cu	Bone	7.0	0.0585
Mn	Bone	12.1	0.0040
Mg	Kidney	10.5	0.0089
Ca	Kidney	13.0	0.0022
Na	Kidney	13.3	0.0016
K	Kidney	11.6	0.0047
Cu	Kidney	16.3	0.0003
Mn	Kidney	11.0	0.0068

Table 3.7 Significant (P<0.01) LSMeans interactions for minerals (indexed) determined in liver between water chemistry treatments (WT).

LSMeans for Liver (index value)					
Mg	**Ca**	**Na**	**K**	**Mn**	**Cu**
none	WT1 & WT2 (109.31 & 90.55)	WT1 & WT4 (96.05 & 116.0)	WT3 & WT4 (95.70 & 103.82)	(WT1 & WT3) (89.95 & 102.4)	none
	WT1 & WT3 (109.31 & 90.47)	WT2 & WT4 (93.93 & 116.0)		WT1 & WT4 (89.95 & 104.43)	
	WT2 & WT4 (90.55 & 1114.4)	WT3 & WT4 (91.73 & 116.0)			
	WT3 & WT4 (90.47 & 114.4)				

Table 3.8 Significant (P<0.01) LSMeans interactions for minerals (indexed) determined in bone between water chemistry treatments (WT).

LSMeans for Bone (indexed values)					
Mg	**Ca**	**Na**	**K**	**Mn**	**Cu**
none	WT 1 & WT4 (100.73 & 96.66)	none	WT1 & WT3 (103.8 & 80.41)	WT1 & WT2 (103.1 & 94.0)	none
			WT2 & WT3 (10.6 & 80.41)	WT3 & WT4 (98.15 & 103.2)	
			WT4 & WT3 (113.0 & 80.41)		

Table 3.9 Significant (P<0.01) LSMeans interactions for minerals (indexed) determined in kidney between water chemistry treatments (WT).

LSMeans for Kidney (indexed values)					
Mg	**Ca**	**Na**	**K**	**Mn**	**Cu**
WT1 & WT4 (97.99 & 103.8)	WT1 & WT2 (98.33 & 113.0)	WT1 & WT3 (103.85 & 92.26)	WT1 & WT4 (97.0 & 104.3)	WT1 & WT4 102.4 & 92.60)	WT1 & WT3 (103.0 & 96.10)
	WT2 & WT3 (113.0 & 92.58)	WT2 & WT3 (106.3 & 92.26)	WT2 & WT4 (95.33 & 104.3)	WT2 & WT4 (101.0 & 92.60)	WT3 & WT4 (96.10 & 100.8)
				WT3 & WT4 (100.98 & 92.60)	

Table 3.10 Differences (P<0.05) between minerals within three tissue types for 6 geographical location treatments (GT) in ostriches.

Dependent Variable	**Tissue**	**R-square (%)**	**Type III SS (P<0.05)**
Mg	Liver	16.1	0.0002
Ca	Liver	0.7	0.8331
Na	Liver	6.0	0.0675
K	Liver	11.0	0.0039
Cu	Liver	14.3	0.0004
Mn	Liver	3.8	0.2151
Mg	Bone	5.3	0.1155
Ca	Bone	42.7	0.0001
Na	Bone	12.6	0.0022
K	Bone	10.8	0.0059
Cu	Bone	11.8	0.0033
Mn	Bone	5.1	0.1254
Mg	Kidney	4.0	0.2105
Ca	Kidney	21.2	0.0001
Na	Kidney	5.0	0.1259
K	Kidney	3.3	0.2844
Cu	Kidney	12.4	0.0021
Mn	Kidney	5.5	0.0975

Table 3.11 Significant (P<0.01) LSMeans interactions for minerals (indexed) determined in liver between geographical location treatments (GT).

LSMeans for Liver (indexed values)					
Mg	**Ca**	**Na**	**K**	**Mn**	**Cu**
GT2 & GT3 (106.27 & 93.92)	none	none	GT2 & GT3 (103.79 & 96.33)	none	GT2 & GT3 (87.63 & 111.66)
GT2 & GT4 (106.27 & 97.01)			GT2 & GT4 (103.79 & 97.54)		GT2 & GT4 (87.63 & 112.37)

Table 3.12 Significant (P<0.01) LSMeans interactions for minerals (indexed) determined in bone between geographical location treatments (GT).

LSMeans for Bone (indexed values)					
Mg	**Ca**	**Na**	**K**	**Mn**	**Cu**
none	GT1 & GT3 (101.74 & 95.36)	GT2 & GT4 (101.32 & 98.12)	GT2 & GT4 (96.90 & 117.13)	none	GT1 & GT3 (97.37 & 102.21)
	GT1 & GT4 (101.74 & 106.00)		GT3 & GT4 (90.27 & 117.13)		GT3 & GT4 (102.21 & 97.23)
	GT2 & GT3 (99.07 & 95.36)				
	GT2 & GT4 (99.07 & 106.00)				
	GT3 & GT4 (95.36 & 106.00)				

Table 3.13 Significant (P<0.01) LSMeans interactions for minerals (indexed) determined in kidney between geographical location treatments (GT).

LSMeans for Kidney (indexed values)					
Mg	**Ca**	**Na**	**K**	**Mn**	**Cu**
none	GT1 & GT4 (93.37 & 118.19)	none	none	none	GT1 & GT2 (102.29 & 97.41)
	GT2 & GT4 (98.19 & 118.19)				GT2 & GT4 (97.41 & 102.84)
	GT3 & GT4 (93.59 & 118.19)				

Table 3.14 provides an indication of the range concentrations found within tissues for all the minerals investigated. To correct for naturally occurring differences between mineral concentrations within tissues the observations were indexed. The results are provided for the three treatment types, TT, GT and WT.

Table 3.14 Summary of mineral ranges (indexed) occurring between tissue types.

Mineral	TT minimum & maximum index value (group)		
	Liver	**Bone**	**Kidney**
Mg	68.32 (G2) & 136.81(G2)	68.39 (G5) & 119.7 (G1)	62.25 (G6) & 114.5 (G1)
Ca	67.28 (G2) & 173.01 (G2)	84.41 (G1) & 112.0 (G6)	79.16 (G3) & 180.4 (G4)
Na	71.98 (G3) & 160.29 (G1)	93.66 (G2) & 106.4 (G2)	75.83 (G3) & 149.0 (G2)
K	82.30 (G4) & 122.13 (G2)	56.55 (G6) & 183.7 (G2)	76.35 (G3) & 124.2 (G1)
Cu	66.19 (G2) & 144.20 (G4)	91.49 (G5) & 125.9 (G1)	84.64 (G3) & 113.8 (G1)
Mn	67.43 (G2) & 142.11 (G1)	87 (all groups) & 131 (G4)	65.23 (G3) & 123.8 (G2)
	WT		
Mg	68.32 (G2) & 142.2 (G2)	68.39 (G2) & 119.7 (G1)	87.83 (G1) & 114.2 (G1)
Ca	67.28 (G2) & 173.0 (G1)	84.41 (G4) & 110.6 (G1)	79.16 (G3) & 180.47 (G2)
Na	64.69 (G1) & 160.2 (G4)	93.66 (G1) & 106.4 (G2)	75.83 (G3) & 149.0 (G2)
K	81.66 (G3) & 125.3 (G2)	56.55 (G3) & 183.7 (G1)	76.35 (G3) & 118.5 (G3)
Cu	66.19 (G1) & 234.0 (G3)	91.49 (G1) & 125.94 (G4)	84.49 (G4) & 113.8 (G4)
Mn	67.43 (G2) & 142.1 (G4)	87.06 (G2) & 131.1 (G3)	65.65 (G3) & 123.8 (G4)
	GT		
Mg	68.32 (G3) & 142.2 (G2)	68.39 (G2) & 119.7 (G4)	62.25 (G4) & 114.5 (G3)
Ca	67.28 (G3) & 173.0 (G2)	84.41 (G3) & 112.0 (G4)	79.16 (G2) & 180.1 (G4)
Na	64.69 (G4) & 160.2 (G3)	93.53 (G4) & 106.6 (G2)	75.83 (G3) & 149.0 (G3)
K	81.66 (G3) & 125.3 (G2)	56.66 (G2) & 183.7 (G4)	76.35 (G3) & 124.2 (G3)
Cu	66.19 (G2) & 234.0 (G3)	91.49 (G4) & 125.9 (G3)	84.49 (G1) & 113.8 (G3)
Mn	67.43 (G3) & 142.1 (G3)	87.06 (G2) & 131.1 (G2)	65.23 (G3) & 123.8 (G3)

Table 3.15 presents the mean for all observations for the various tissue types for the purposes of indicating differences in magnitude of occurrence in the different tissue types.

Table 3.15 Mean Concentrations (mg/kg DM) and standard deviations of minerals in ostrich humerus, liver, renal tissue.

Mineral	Liver (n = 360)		Bone (n = 360)		Kidney (n = 360)	
	mean	SD	mean	SD	mean	SD
Mg	605	17.44	2965.77	69.38	816.19	11.76
Ca	202.28	9.07	194438.83	2161.7	296.68	10.185
Na	2950.96	114.92	3924.16	29.75	6360.88	134.18
K	9572.49	206.51	890.37	53.6	9243.7	150.49
Mn	5.773	0.1882	5.705	0.083	7.629	0.169
Cu	20.47	1.388	7.438	0.13	12.407	0.194

3.4 Discussion

3.4.1 Water quality

The concentrations found present with two main areas of concern. Firstly, the fact that multiple PHCs occur within a water source at levels that exceed the recommended guidelines by large margins, is a source of concern for the health of species consuming the water. This must be seen in conjunction with the tissue results that suggest that water chemistry had a significant effect on mineral levels in liver, bone and renal tissue (for example, TT results for Ca in liver). Secondly, the presence of the PHCs, at very high levels, and over a large section of the area investigated, requires monitoring on a valley specific basis, as diverse profiles with regard to the types of PHCs occurring was observed.

The results suggest that the ostrich producing areas north of the Groot Swartberge utilise water for ostrich consumption that is more fit for use than those producers on the southern side of this mountain range. This would appear to be the case, specifically for those producers between this range and the Kamannassie Berg, with PHCs occurring to a lesser degree between the Kamannassie Berg and the Outeniekwa Berge. Several producers south and south-east of the Oudtshoorn were found to be utilising water with significant potential hazards. The samples obtained to the north and west of Oudtshoorn (valleys between the Langeberge, Rooiberge and Groot Swartberge) towards Calitzdorp were found to pose less of a risk to ostrich production.

The same risk as described previously (Casey *et al*., 1998) was found with respect to TDS and the occurrence of PHCs. This is attributed to the preference for water sources with a lower TDS to be used by both animals and domestic users due to the perception that it is safer, whilst, as the correlation coefficients indicate, an inverse relationship often exists.

3.4.2 Mineral values in tissue

For the tissue treatments kidney emerged as the best indicator of significantly different Mg, Ca, Na, K and Cu levels, whilst liver was the best for Mn. Calcium and Na values differed between the various farms for all tissue types, suggestive that site-specific factors influenced absorption and systemic handling of these minerals. The same pattern was observed for the water chemistry treatments. Geographical location treatments differed substantially however, with bone being the best indicator for Cu, K, Na and Ca, liver for Mg, and kidney for Mn.

The LSMeans values (TT) obtained accord with the water quality results from the farms from which the tissues were sourced for many minerals. For example, the farms comprising treatment group TT6 (which recorded significantly ($P<0.01$) lower liver Ca values than TT1, TT2, and TT4, all yielded water quality results with Ca values of less than 50 mg/L, and TDS values of less than 1000 mg/L (water samples 6, 21, 23 and 25). Similar results were obtained for GT3, which recorded significantly lower ($P<0.01$) liver Ca values and consisted of ostriches sourced from farms with very low water Ca concentrations (4, 5, 8, 23 and 24).

Although the role of water quality in influencing mineral levels in livestock is dealt with in detail in Volume 1 of this report, it is noteworthy to mention that the water chemistry may provide an indication of the potential exposure of the animal to the same mineral through other sources (geophagia and feed). In the liver samples collected low Ca values were found to occur in ostriches produced on farms with low Ca in the water, however, not all low water Ca concentrations yielded low liver Ca levels. This is most probably due to different site-specific geochemical factors occurring throughout the district, but may also be due to low water Ca concentrations precipitating a Ca deficiency, which can induce Ca resorption from bone causing elevated systemic levels of Ca, and hence high liver Ca values. This appeared to be the case for group GT4 which recorded the highest liver Ca values sourced from farms with very low Ca values (samples 6, 7, 17 an 19). Some farms with high water Ca values did yield TT groups with high liver Ca values, namely TT1 and TT2. Bone samples returned similar results, specifically on an individual farmer basis, with the majority of water Ca concentrations exceeding the TWQR associated with high bone values, whilst those with low Ca in water having low bone values (water samples 4, 9, 11, 19 and 24). Kidney tissue displayed an inverse relationship for most farms investigated with water Ca concentrations, with water samples exceeding the TWQR all having low kidney Ca values, and water samples with no Ca detected having high kidney samples (low water Ca - high kidney Ca = 21, 17; high water Ca – low kidney Ca = 19, 11, 11A, 11C. 11C. 11D. 11G).

Copper showed a linear relationship between water concentration and liver tissue values (water samples 6, 10, 18) for high water Cu concentrations, but results were less consistent for bone and renal tissue. Although most water samples did demonstrate a linear relationship (samples 21, 24 for kidney) the results were difficult to determine due to the variation in water chemistry between water points on the same farm. Water samples 7 and 19 provide examples of this, with both high and low water Cu concentrations being recorded. As reported in previous WRC Final Reports, the concentration for many WQCs can vary significantly between subterranean sources merely 30 m apart, and it is therefore recommended that farmers should sample all the watering points used in multiple water source situations.

For all the treatment groupings (tissue, water chemistry and geological location) K had the greatest variation in bone, Ca in renal tissue, whilst Cu tended to return the greatest variation for liver tissue (Table 3.14).

The water chemistry values for Mn for the geographical location treatment groups were observed to result in both highest and lowest values across tissues (Table 3.14), as both the two groups involved, GT3 and GT2, recorded the two highest average water concentrations for Mn. The averages for the farms included in the GT groups were 0.09 mg Mn/L for GT4, 0.125 mg Mn/L for GT1, 0.131 mg Mn/L for GT3, and 0.269 mg Mn/L for GT2. Only the higher groups GT2 and GT3 yielded lowest and highest values, with GT2 providing the highest value for bone, and GT3 the highest value for both liver and kidney tissue. The occurrence of low values in these groups are most probably attributed to the presence of farms in the groups with zero water Mn concentrations (water samples 18 and 21B for GT2). The lowest average obtained for the water chemistry treatments for Mn, namely WT2 (0.07 mg Mn/L) yielded both the lowest liver and bone values, with the highest liver and kidney values attributed to the group with the highest Mn average (GT4 = 0.179 mg Mn/L). For the tissue treatments bone Mn correlated well with the highest group Mn average, namely TT4 (0.187 mg Mn/L), whilst the low Mn averages either recorded low liver (TT2 = 0.062 mg Mn/L), low bone (TT2, TT3 = 0.084 mg Mn/L, TT5 = 0.031 mg Mn/L and TT6 = 0.041 mg Mn/L), or low kidney values (TT3).

Groups TT2 and TT4 returned both the highest and lowest values for liver tissue, with TT5 displaying greater central tendency with respect to all liver minerals. TT3 was similar in this respect for bone samples, but the lowest renal values for all minerals were attributed to TT3.

Of interest is the relationship apparent in the water chemistry treatments for the maximum and minimum tissue values for Cu (Table 3.12.), and water concentrations of Se. Although not significant for all tissues due to the farmers assigned to the respective groups (Cu was not a treatment factor), farmers comprising water treatment group 3 (WT3) were found to have ostriches with significantly higher liver Cu values than all the other farms. With the exception of one farmer in the group (water sample 13), none of the water collected on these farms had Cu concentrations exceeding 0.01 mg/L. Farmers from WT4 were found to have the highest water Cu concentrations (except water sample 5), but had very low liver Cu values. These seemingly conflicting liver results are understood when viewed in context of the accompanying Se values, with WT3 all returning very low (<0.01 mg/L) Se values (except water sample 13), whilst water samples from WT4 showed very high values, some greater than 0.1 mg/L. Many workers have reported the protective value of Se on Cu uptake (Underwood & Suttle, 1999) and the resultant effect on hepatic Cu values (Van Ryssen *et al.*, 1997), and the water chemistry and liver tissue results accord with these findings. This relationship between Se and Cu is supported further by WT4 recording the highest bone and kidney tissue results, whilst WT3 recorded the lowest kidney Cu values.

The pooled concentrations obtained for the tissues as presented in Table 3.15 suggest that little differences are found between some tissue types for certain minerals, whereas great differences exist for others. An example of the latter is Ca with both renal and liver tissue recording values in the 200 mg/kg DM range, whilst for bone the mean value obtained for all observations was 194 438.83 mg/kg DM. Manganese did not demonstrate any significant difference between liver and bone samples, nor did K for liver and renal samples. The tissues recording the highest values for each mineral were bone for Mg and Ca, kidney for Na, K and Mn, and liver for Cu.

3.5 Conclusion

These results, when interpreted in conjunction with the treatments (water chemistry, geographical location, mineral trends in tissues) indicate certain patterns with respect to significant differences in the tissues reviewed, dependent on all treatment factors. The occurrence of significant differences in mineral concentrations found, and the consistency with which these differences occurred within treatment groups, indicates the need to incorporate the role of water chemistry and geochemistry in formulating the dietary requirements on a farm-specific basis. Pre-scribing a ration or nutritional programme for a district runs the risk of under, and over-estimating the mineral requirements of ostriches. As a result, imbalances may precipitate deficiencies, with consequent loss of productivity, and as appears to be the case in at least several of the farms, may even result in skeletal-related slaughter-process problems.

The net effect of a WQC may thus alter from a generic to a specific assessment. Where initially a concentration viewed only in water will represent a portion of the dietary requirement, when additional sources of ingestion taken and inter-mineral effects (even only within a water source) are taken into account, the same constituent concentration may well increase the final risk that is posed.

Although the constituents Hg and Se were present in the vast majority of the samples collected, large differences in the concentrations recorded between areas (North versus south of the Groot Swartberge), and the lack of such differences within an area (South of Groot Swartberge and North of Kamannasie Berg), suggest that there is merit in formulating supplementary alleviator feeds that are area (or valley) specific.

The results seem to indicate that certain recommendations may be made regarding which tissue to use as an indicator of mineral status for specific elements, for example renal tissue for Mn, bone for K and liver for Cu. However, in order to place a high or low value in a tissue in perspective, for example bone values for Mg and Ca, levels for liver and kidney may also required.

As a precautionary measure, it is recommended that Ca and P intake be reduced in breeding males for those producers within the relevant tissue treatment groups, as levels satisfactory for eggshell formation in the female may reduce Mn, Zn and Fe absorption in the male (Cilliers, 1991; Du Preez, 1989), and given the Ca concentrations in water and several of the tissues investigated, excessive exposure is a definite risk. As far as growing birds destined for slaughter are concerned, a farm-specific risk assessment is required as the results indicate the in some cases bone resorption may be occurring, suggestive of a Ca-deficiency (Underwood & Suttle, 1999).

Furthermore, fast growing chicks may develop porosis of the stifle between two to eight months, and Mn supplementation to 200 ppm is recommended. Excessive Ca and P can increase the likelihood of this disorder, with the recommended dietary level for Ca for birds at 3 – 13 weeks 0.96% on a DM basis (Mellet, 1993). Given the low Mn values that accompanied many of the high Ca values observed, Mn supplementation ranges may have to be increased.

Further areas of research that require attention include the incorporation of additional farm-specific geochemistry data to ascertain the total exposure, seasonal variations in water quality, and detailed profiling of minerals in various tissues in ostriches that may pose problems during the slaughter procedure and potential product quality hazards. Tissues were collected for macroscopic histopathological examination, but results were not yet available for inclusion in this report.

CHAPTER 4

REFERENCES

Bartholomew, G.A. and Cade, T.J. (1963). *The water economy of land birds*, 505-539, The Auk, 80.

Benoff, F.H. and Buss, E.G. (1976). *Water consumption and urine volume in polydipsic and normal white leghorn chickens.*, 1140-1142, Poultry Science, 55.

Black , J.G., Davies, G.T. and Fleming G. J.F. (1993). Role of computer simulation in the application of knowledge to animal industries. Australian Journal of Agricultural esearch. 44: 541-555.

Brody, S. (1945). Bioenergetics and growth. Reinhold Publishing Corporation.

Carter, T.A., (1985). Drinking water quality for poultry production. *Poultry Digest*. February, 50.

Casey, NH and Meyer, JA (1996). Interim Water Quality Guidelines for Livestock Watering. Water Research Commission. ISBN 1 86845 225 5.

Casey, NH, Meyer, JA, Coetzee, CB and van Nierkerk, W.A. (1996). An investigation into the quality of water for livestock production. Report to the Water Research Commission. WRC Report No. 301/01/94.

Casey, NH, Meyer, JA and Coetzee, CB (1998a). An investigation into the quality of water for animal production livestock production with the emphasis on subterranean water and the development of a water quality guideline index system. Volume 1: Development and modelling. Report to the Water Research Commission. WRC Report No: 644/1/98. ISBN No: 1 86845 739 0

Casey, NH, Meyer, JA and Coetzee, CB (1998b). An investigation into the quality of water for animal production livestock production with the emphasis on subterranean water and the development of a water quality guideline index system. Volume 2: Research results. Report to the Water Research Commission. WRC Report No: 644/2/98. ISBN No: 1 86845 380 4.

Casey, NH, Meyer, JA and Coetzee, CB (1998c). An investigation into the quality of water for animal production livestock production with the emphasis on subterranean water and the development of a water quality guideline index system. Volume 3: Appendix. Report to the Water Research Commission. WRC Report No: 644/3/98. ISBN No: 1 86845 381 2.

Chapman, T.E. and Black, A.L. (1967). *WATER TURNOVER IN CHICKENS*, 761 - 765, Poultry Science, 46.

Cilliers, SC (1991). Voedingstandaarde vir volstruise. Department of Agricultural Development, Proc. Ostr. Sem. 30 –33.

Coetzee, C.B., Casey, N.H. and Meyer, J.A. (1997). Fluoride tolerance of laying hens. *British Poultry Science* 38: 597 – 602.

Coetzee, C.B., Casey, N.H. and Meyer, J.A. (2000). Quality of groundwater used for poultry production in the Western Cape. Water SA. Vol.26 (4). 563 – 567.

DWA&F (1993). Department of Water Affairs and Forestry: South African Water Quality Guidelines (second edition). Volume 4: Agricultural Use: Livestock Watering.

DWA&F (1996). Department of Water Affairs and Forestry: South African Water Quality Guidelines (second edition). Volume 4: Agricultural Use: Livestock Watering.

Du Preez, J.J. (1989). Accumulation of data useful in constructing models for applied nutrition and the husbandry of ostrich (Struthio camelus). Department of Agriculture and Water Supply, Proc, Ostr, Res, Sem., 6-26.

Ernst, R. (1989). Water quality guidelines. *Poultry International.* June. 40-42.

Gentle, M.J., Hughes, B.O. and Hubrecht, R.C. (1982). *The effect of beak trimming on food intake, feeding behavior and body weight in adult hens*, 147-159, Applied Animal Ethology, 8.

Gernat, A.G. and Adams, A.W. (1992). *Effect of number of nipples per nipple waterer on the performance of several strains of layers in cages*, 1292-1295, Poultry Science, 71.

Glista, W.A. and Scott, H.M. (1949). *Growth and feed efficiency studies with broilers. 2. Gross water consumption in relation to the level of soybean oil meal in the ration.*, 747-749, Poultry Science, 28.

Good, B. (1985). Water quality affects poultry production. *Poultry Digest.* March. 108-109.

Heckman, M. (1967). *J. Ass.Offic. Anal. Chem.*, 50, 45.

Heckman, M. (1968). *J. Ass.Offic. Anal. Chem.*, 51, 766.

Heckman, M. (1971). *J. Ass.Offic. Anal. Chem.*, 54, 666.

Howard, B.R. (1975). Water balance of the hen during egg formation. 1046-1053, *Poultry Science*, 54.

ISCW (1998). Institute for Soil Climate and Water. Agricultural Research Council. Water Analysis Division. Pretoria R.S.A.

Kechavarz, K. (1987). Proper water management for poultry. *Poultry Digest*. January: 12-22.

Kempster, P.L., Hattingh, W.H.J. and van Vliet, H.R. (1985). Summarised Water Quality Criteria. Dept of Agriculture and Water Affairs, Hydrological Research Institute. Technical Report TR 108.

Krevinghaus, B. (1997). *Environmental parameters and measuring equipment.* www.agric.gov.ab.ca/livestock/poultry/psiw/psiw9715.html, 9/1/99.

Lacy, M. (1995). *Handling summer.* 349-354, Poultry Bulletin, December.

Lacy, M.P. and Czarick, M. (1992). Tunnel ventilated broiler houses: broiler performance and operating costs., 104-109, *Journal of Applied Research*, 1.

Lacy, M.P. and Czarick, M. (1999). *Environmental control of poultry houses*, 1-19, http://www.ces.uga.edu/pubcd/b1085-w.html, 10/11/99, University of Georgia College of Agricultural and Environmental Sciences.

Lasiewski, R.C. and Dawson, W.R. (1967). A re-examination of the relation between standard metabolic rate and body weight in birds. *CONDOR* 69:13-23.

Lee, K.Y. and Craig, J.V. (1990). Beak trimming effects on the behavior and weight gain of floor reared, egg strain pullets from three genetic stocks during the rearing period. 568-575, *Poultry Science*, 69.

Leeson, S., Diaz, G and Summers, J.D. (1995). Poultry metabolic disorders and mycotoxins. University Books Ontario, Canada.

Leeson, S. and Summers, J.D. (1997). Commercial poultry nutrition. University Books Ontario, Canada.

Lifchitz, E., German, O., Favret, E.A. and Manso, F. (1967). Difference in water ingestion associated with sex in poultry. 1021-1023, *Poultry Science*, 46.

Mancl, M., Sauis, M. and Wagert, L. (1991). Private Drinking Water Supplies. NRAES-47, Cooperative Extension, Ithaca, NY 14853.

Marks, H.L. and Washburn, K.W. (1983). The relationship of altered water/feed intake ratios on growth and abdominal fat in commercial broilers. 263-272, *Poultry Science*, 62.

Marks, H.L. (1980). Water and feed intake of selected and non-selected broilers under *ad libitum* and restricted feeding regimes. 205-219, Growth, 44.

May, J.D. and Lott, B.D. (2000). Effect of air velocity and body weight on water usage by broilers. Southern Poultry Science Society - Atlanta.

May, J.D. and Lott, B.D. (1992). Feed and water consumption patterns of broilers at high environmental temperatures. 331-336, *Poultry Science*, 71.

May, J.D., Lott, B.D. and Simmons, J.D. (1998). The effect of environmental temperature and body weight on growth rate and feed:gain of male broilers. 499-501, *Poultry Science*, 77.

Medway, W. and Kare, M.R. (1957). Water metabolism of the domestic fowl from hatching to maturity. 139-141, *American Journal of Physiology*, 190.

Medway, W. and Kare, M.R. (1959). Water metabolism of the growing domestic fowl with special reference to water balance. 631-637, *Poultry Science*, 38.

Medway, W. (1958). Total body water in growing domestic fowl by antipyrine dilution technique. 733-736, Proceedings of the Society for Experimental Biology and Medicine. 99.

Mellet, FD (1993). Ostrich production and products. In: Livestock Production Systems. Ed: Maree, C & Casey, NH. Agri Development Foundation. 187 – 192,

Meyer, JA (1992). Potentially toxic variable in water for livestock and the physiological impact of fluoride and total dissolved solids on sheep, MSc thesis. Univ. of Pretoria. South Africa.

Meyer, JA (1998). Modelling for the Prediction of Water Quality Guidelines for Livestock in South Africa. Ph.D. Thesis Univ. of Pretoria. South Afrifca.

Meyer, J.A., Casey, N.H. and Coetzee, C.B. (1997). Water quality guidelines for livestock watering in Southern Africa. *Water SA*. Vol. 23 (1). 7-12.

Meyer, JA and Casey, NH (1999). Selenium and fluoride toxicology - water quality guidelines for Dohne Merino Sheep in southern Africa. Trace Elements in Man and Animals – 10 – Proceedings of the Tenth International Symposium. Plenum Publishers, Evian. Plenum Publishers (in press)

Monteith, J.L. (1973). Principles of environmental physics. Edward Arnold Publishers Limited. London.

Muirhead, S. (1995). Good, clean water is a critical component of poultry production. 12, *Feedstuffs*, Dec 4.

Mulkey, G.J. and Huston, T.M. (1967). The tolerance of different ages of domestic fowl to body water loss. 1564-1569, *Poultry Science*, 46.

North, M.O. and BellL, D.D. (1990). Commercial Chicken Production. 4th ed. Aci Publ. Co. Westport, CT.

Puls, R (1994). Mineral levels in animal health: Diagnostic Data. Serpa Int., Canada.

Quality of Domestic Water Supplies (1998). Volume 1. Assessment Guide. Second edition. Second Print. Published by Water Research Commission, The Department of Water Affairs and Forestry, and The Department of Health. 65-95.

Ritchie, S.J. (1999). Health implications for higher density broiler production, 1 - 2, http:www.agric.gov.ab.ca/livestock/poultry/psiw9607.html, 9/1/99.

Robinson, D. (1979). Effects of cage shape, colony size, floor area and cannibalism preventatives on lying performance. 345-356, *British Poultry Science*, 20.

SAS (1994) SAS/STAT User's Guide. Volume 2. Version 6. 4TH Edit. SAS Institute Inc. Cary, NC, USA.

Smith, R (1988). Water Quality Criteria for Livestock Watering and Human Consumption. CSIR: Division of Water Technology. Project No. 670 21 70 9.

Schwartz, D.L. (1994). Water Quality. VSE 81c. Penn.State U., in Proceedings AVMA Annual Conference, July, 1994.

Skadhauge, E. (1976). Water conservation in xerophilic birds, 732-739, *Israel Journal of Medical Sciences*, 12, 8.

Spesfeed. (1999) Commercial Poultry Nutrition in Southern Africa. Sixth Edition. Spesfeed, South Africa.

USEPA (1998). Environmental Protection Agency. Drinking water regulations and health advisories. Office of Water. October 1998. Washington DC. USA.

Underwood, EJ and Suttle, NF (1999). The Mineral Nutrition of Livestock. 3rd edition. CAB International. ISBN 0 85199 128 9.17 - 66.

Van Ryssen, J.B.J., van Malsen, P.S.M., and Hartman, F. (1997). The contribution of dietary sulphur to the interaction between selenium and copper in sheep. *J.Agric.Sci.*, (Camb.)

Vohra, P.N. (1980). Water quality for poultry use. *Feedstuffs*. 52:24-25.

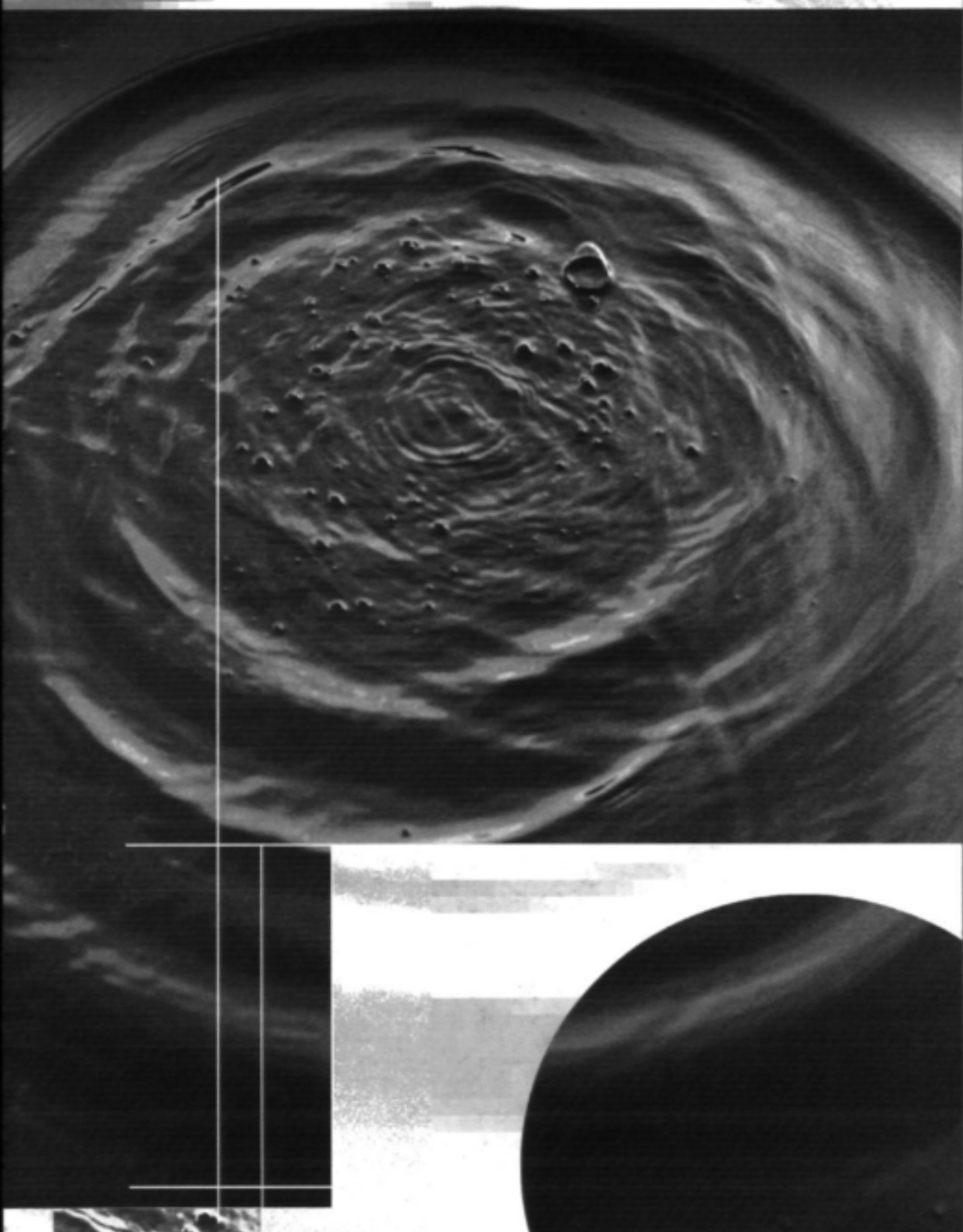
Waggoner, R. E. (1986). Tyson Foods, Inc. as quoted by Keshavarz, 1987.

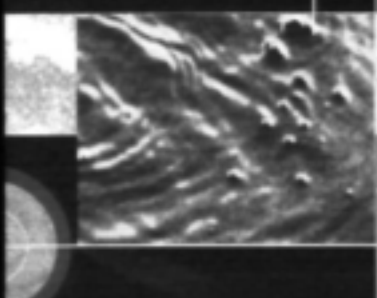
WHO (1993). World Health Organisation. Geneva. Guidelines for drinking-water. Volume 2. 55-77.

Wood-gush, D.G.M. and Horne, A.R. (1970). The effect of egg formation and laying on the food and water intake of brown leghorn hens. 459-466, *British Poultry Science*, 11.

Xin, H. and Berry, I.L. (1994). Feed and water consumption, growth and mortality of male broilers. 610-616, *Poultry Science*, 73.

Zimmerman, N.G. (1995). Relationship of drinking water quality and broiler performance. Proc. Delmarva Broiler Housing & Flock Supervisors Conf. University of DE & MD Cooperative Extension and DPI, Inc.





Water Research Commission

PO Box 824, Pretoria, 0001, South Africa

Tel: +27 12 330 0340, Fax: +27 12 331 2565

Web: http://www:wrc.org.za

1868457141