The development of water quality guidelines for poultry production in southern Africa

by

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SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF
PHILOSOPHEA DOCTORE: ANIMAL SCIENCE

DEARTMENT: Animal and Wildlife Sciences

in the

FACULTY OF NATURAL AND AGRICULTURAL SCIENCES
UNIVERSITY OF PRETORIA
PRETORIA

December 2005

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Abstract

The objective of this study was to develop water quality guidelines for poultry reared under South African conditions and production systems. This was achieved by a modeling approach that was based on a survey of water used by poultry producers throughout the country. Potentially hazardous constituents identified were – Sodium, Magnesium, Chloride, Sulphate, Nitrate, Calcium and Phosphorus. Three experiments were conducted to test these constituents' effects on poultry production. Experiment 1 examined the influence of different levels of magnesium, sodium, sulphate and chloride in the drinking water of layers and the effect thereof on their production. The study showed that 12 different combinations of Mg, Na, Cl and SO_4 had no significant effect on growth, food and water intake, and egg production or egg quality. Poultry producers in areas with naturally high levels of these minerals in their ground water can therefore continue to function successfully if the concentrations present are up to 250 mg/l of Mg, 500 mg/l of Cl, 500 mg/l of SO_4 and 250 mg/l of Na. Experiment 2 examined the effect of elevated levels of $NaNO_3$ in the drinking water of layers and broilers. No negative effects on broiler production and growth were observed. The only mineral ion to show a significant effect on performance was nitrate, with lower nitrate concentrations in well water being associated with better performance. Experiment 3 examined the effects of Ca and P in the drinking water on egg production, egg quality, bone integrity and shell strength. The results showed that water can be a valuable asset to increase eggshell integrity, but waterline maintenance may be increased because of the tendency of calcium to precipitate. Water should be seen as a dietary source of minerals (Ca + P) and should be taken into consideration when nutrient specifications are set for feed formulations to be used in the various poultry production systems. The preceding results served as basis for developing a modeling approach to water quality guidelines for poultry.

Acknowledgements

- Prof. Norman Casey for his mentorship and patience.
- The Water Research Commission for financial assistance throughout the duration of the project.
- Roelf Coertze for statistical analysis.
- Ollie Coetzee for burning the midnight oil with me.
- Daniel for being my inspiration.

For the LORD giveth wisdom: out of his mouth cometh knowledge and understanding. Proverbs 2:6

List of abbreviations	
°C	Degrees Celcius
BHA	Butylated hydroxy-anisode
BHT	Butylated hydroxytoluene
BW	Body Weight
Ca	Calcium
CIRRA	Constituent Ingestion Rate Risk Assessment
Cl	Chloride
CM	Cumulative Mortalities
COC	Constituent of Concern
CT	Calcitonin
DES	Diethylstilbestrol
DFU	Daily Food Use
DPPD	Diphenylparaphenylediamine
DWAF	Department of Water Affairs and Forestry
DWU	Daily Water Use
EDTA	Ethylenediaminetetraacetic acid
EP	Egg Production
EPA	Environmental Protection Agency
FC	Feed Conversion
FI	Feed Intakes
G	Gain
GAL	Guideline Application Level
GI	Gastro Intestinal
GLM	General Linear Model
HI	Heat Index
HPLC	High Performance Liquid Chromatography
IU	International Unit
K	Wind Chill Index
KOH	Potassium hydroxide
LBW	Live Body Weight
LS	Least Square
MCL	Maximum Contaminant Level
ME	Metabolzable Energy
Mg	Magnesium
MINRD	Mineral Reference Document
N	Newton
Na	Sodium
NO3	Nitrate
NRC	National Research Council

NTS	Nucleus Tractus Solitarius
O2	Oxide
P	Phosphorus
PCR	Peripheral calcium receptors
PHC	Potentially Hazardous Constituent
PTH	Parathyroid Hormone
RD	Reference Document
RH	Relative Humidity
RSA	Republic of South Africa
SD	Standard Deviation
SFO	Subfornical organ
SO4	Sulphate
T	Temperature
TDS	Total Dissolved Solids
TWI	Total Water Intake
TWQR	Target Water Quality Range
WI	Water Intake
WIR	Water Ingestion Rate
WIRRD	Water Ingestion Rate Reference Document
WQC	Water Quality Constituent
WQG	Water Quality Guideline
WQGIS	Water Quality Guideline Index System
WQI	Water Quality Index
WRC	Water Research Commission

Introduction

Water quality concerns have often been neglected because good quality water supplies were plentiful and readily available. This situation is changing in many areas. Sound planning is now required to ensure that water of the quality available is put to the best use.

The climate in South Africa varies from desert and semi-desert in the west, to sub-humid along the eastern coastal areas, with an average annual rainfall for the country of just over half of the average for the rest of the world. South Africa's water resources are limited and, in global terms, are considered sparse. The natural availability of water across the country is distributed unevenly, with more than 60% of the river flow arising from only 20% of the land area. In addition, as the country is mainly underlain by hard rock formations, it is poorly endowed with groundwater in some areas and does not have many groundwater springs (Millard, 1999).
Minister Ronnie Kasrils, the South African Minister for Water Affairs, started his address to parliament in commemoration of water week (19 March 2001) by saying the following:

"*This week is National Water Week, when South Africans are called upon to re-evaluate their attitude to the single most important asset South Africa has – WATER*."
(Pretoria News, March 2001)

To make optimal use of this valuable asset it is important to understand the dynamics involved in the use and quality of water in agriculture. The validity of existing water quality guidelines in their application to South Africa's unique circumstances require examination. Water quality refers to the characteristics of a water supply that will influence its suitability for a specific use. Each specific use has a different quality requirement and one water supply is considered more acceptable if it produces better results or causes fewer problems than an alternative water supply.

There have been a number of different water quality guidelines for livestock watering. Each has been useful but none has been entirely satisfactory because of the wide variability in findings and applications (Table 1.1).

Table 1.1 Maximum acceptable levels of water quality constituents found in literature.

CONSTITUENT	MAX ACCEPTABLE LEVEL	REFERENCE
Aluminium	0.25 mg/l	Kempster, et al., 1981
	0.2 mg/l	Zimmerman, 1995
	5 mg/l	Mancl et al., 1991.
Arsenic	0.2 mg/l	Carter, 1985, Keshavarz, 1987 & Mancl et al., 1991
	1 mg/l	Kempster, et al., 1981
	0.05 mg/l	Vohra, 1980 & Zimmerman, 1995
Bacteria	Total = 100/ ml	Schwartz, 1994 & Waggoner et al., 1994
	Coliform=50/ml	Schwartz, 1994 & Waggoner et al., 1994
Barium	1 mg/l	Vohra, 1980
	2 mg/l	Zimmerman, 1995
Bicarbonate	98 mg/l	Keshavarz, 1987
	500 mg/l	Keshavarz, 1987
Cadmium	50 mg/l	Kempster, et al., 1981
	0.01 mg/l	Vohra, 1980
	0.005 mg/l	Zimmerman, 1995
	0.05 mg/l	Mancl, et al., 1991
Calcium	402 mg/l	Kempster, et al., 1981
	600 mg/l	Carter, 1985 & Keshavarz, 1987
	200 mg/l	Vohra, 1980
Chloride	250 mg/l	Schwartz, 1994, Waggoner et al., 1994, Ernst, 1989 & Zimmerman, 1995
	1500 mg/l	Carter, 1985
	200 mg/l	Keshavarz, 1987
	600 mg/l	Vohra, 1980
Chromium	5 mg/l	Kempster, et al., 1981
	0.05 mg/l	Vohra, 1980
	0.1 mg/l	Zimmerman, 1995
	1 mg/l	Mancl et al., 1991
Copper	0.06 mg/l	Schwartz, 1994 & Waggoner et al., 1994
	2 mg/l	Schwartz, 1994 & Waggoner et al., 1994
	2.5 mg/l	Kempster, et al., 1981
	0.5 mg/l	Good, 1985
		Carter, 1985, Keshavarz, 1987 & Mancl et al., 1991
	1.5 mg/l	Vohra, 1980
	0.6 mg/l	Ernst, 1989
	1.3 mg/l	Zimmerman, 1995
Fluoride	2 mg/l	Carter, 1985, Keshavarz, 1987 & Mancl et al., 1991
	0.9-1.7 mg/l (air temp 10-12°C)	Vohra, 1980
	0.06-0.08 mg/l (air temp 26.2-32.6°C)	Vohra, 1980
	4 mg/l	Zimmerman, 1995
Iron	0.3 mg/l	Schwartz, 1994, Waggoner et al., 1994 & Ernst, 1989
	1.2 mg/l	Kempster, et al., 1981
	6 mg/l	Keshavarz, 1987
	0.1 mg/l	Vohra, 1980

Table 1.1 Maximum acceptable levels of water quality constituents found in literature (continued)

CONSTITUENT	MAX ACCEPTABLE LEVEL	REFERENCE
Lead	0.02 mg/l	Schwartz, 1994, Waggoner et al., 1994 & Ernst, 1989
	0.1 mg/l	Carter, 1985, Keshavarz, 1987 & Mancl et al., 1991
	0.5 mg/l	Kempster, et al., 1981
	0.05 mg/l	Vohra, 1980
	0.015 mg/l	Zimmerman, 1995
Magnesium	125 mg/l	Schwartz, 1994, Waggoner et al., 1994 & Ernst, 1989
	350 mg/l	Carter, 1985
	50 mg/l	Keshavarz, 1987
	150 mg/l (if 250 mg/l sulphate is present)	Vohra, 1980
Manganese	4.6 mg/l	Kempster, et al., 1981
	0.05 mg/l	Carter, 1985 & Vohra, 1980
	0.6 mg/l	Keshavarz, 1987
Mercury	10 mg/l	Kempster, et al., 1981
	0.002 mg/l	Vohra, 1980 & Zimmerman 1995
Nickel	0.001 mg/l	Zimmerman, 1995
	1 mg/l	Mancl et al., 1991
Nitrates	25 mg/l	Schwartz, 1994, Waggoner et al., 1994, Ernst, 1989 & Mancl et al., 1991
	200 mg/l	Kempster, et al., 1981
	20 mg/l	Good, 1985 and Keshavarz, 1987
	10 mg/l	Zimmerman, 1995; Waggoner et al., 1994.
Nitrites	4 mg/l	Schwartz, 1994, Waggoner et al., 1994 & Ernst, 1989
	1 mg/l	Zimmerman, 1995
	3 mg/l	Mancl et al., 1991
pH	> 6.0	Schwartz, 1994 & Waggoner et al., 1994
	10-Feb	Kempster, et al., 1981
	> 5.9	Good, 1985
Phosphate	5 mg/l	Kempster, et al., 1981
	0.7 mg/l	Carter, 1985
Selenium	0.05 mg/l	Kempster, et al., 1981, Zimmerman, 1995 & Mancl et al., 1991
	0.01 mg/l	Vohra, 1980
Sodium	200 mg/l	Ernst, 1989
	50 mg/l	Ernst, 1989
	75 mg/l	Keshavarz, 1987
Sulphate	250 mg/l	Schwartz, 1994, Waggoner et al., 1994 & Ernst, 1989
	60 mg/l	Keshavarz, 1987
	400 mg/l (if Na & Mg are present)	Vohra, 1980
	300 mg/l	Mancl et al., 1991
Zinc	1.5 mg/l	Schwartz, 1994, Waggoner et al., 1994 & Ernst, 1989
	2.5 mg/l	Carter, 1985 & Keshavarz, 1987
	15 mg/l	Vohra, 1980
	25 mg/l	Mancl et al., 1991

In evaluating the usability of any particular water, local conditions and availability of alternate water sources will play an important role. The following factors need to be taken into consideration:

- Species - Variation in tolerance to different water quality constituents is considerable between animal species and breeds within a species according to the production status.

- Ingestion rate - The concentration of a constituent in a water source alone is not indicative of its effect. The ingestion rate of specific constituent should be established.
- Exposure time - Short-term exposure to some constituents can be tolerated by some species.

Not all water quality constituents in animal drinking water are potentially hazardous. Some only cause management problems or are nuisances.

The effect of water quality on the growth and production of livestock and wildlife in South Africa has recently been re-evaluated at the instigation of the Water Research Commission of South Africa (WRC). A new approach to minimising the risk associated with water of varying quality was developed in a series of projects funded by the WRC (Casey, Meyer, and van Niekerk, 1993; Casey, Meyer, Coetzee and Van Niekerk, W.A. 1994 (a); Casey, Meyer, Coetzee and Van Niekerk, 1994 (b); Casey and Meyer, 1993; Casey and Meyer, 1996; Casey, and Meyer, 1996; Casey, Meyer and Coetzee, C.B., 1998 (a); Casey, Meyer and Coetzee, 1998 (b); Casey, Meyer and Coetzee, 1998 (c); Casey, Meyer and Coetzee, 2000 (a); Casey, Meyer and Coetzee, 2000 (b); Meyer, 1998 and Casey and Meyer 2000.)

The South African poultry industry comprises 617 million broilers and 17.8 million layers (Coetzee, 2005). These production systems are intensively operated and function within a small profit margin. Extensive economic losses can result from water quality constituents that are potentially hazardous.

Since Australia is on the same latitude as South Africa and the two countries have similar climatic conditions the Australian Water Quality Guidelines were used as a starting point. These water quality guidelines, however, address livestock watering as a whole and do not specify separate guidelines for poultry. The fact that poultry are less susceptible to high nitrate inclusions in the water than ruminants (Jennings and Sneed, 1996) is but one example where poultry's tolerance to a water quality constituent differs from other livestock. It amplifies the need for a specific set of water quality guidelines for poultry.

The few poultry specific guidelines available are all either outdated or list old guidelines in new publications (Keshavarz, 1987; Vohra, 1980; Carter 1985; Carter and Sneed, 1996). Some poultry water quality standards have been derived from large animal work. Still others are based on poultry mortality rather than effects on growth, reproduction or other production factors (Carter, 1985).
The objective, therefore, is to re-evaluate existing water quality standards for poultry reared under South African conditions and production systems.

A further motivation for this thesis is that South Africa's water quality needs may be different from other production regions in the world, because of the environment that ranges from humid sub-tropical to arid regions and from sea level up to 1800 metres above sea level. Water is scarce and the main water sources available on farms with intensive poultry production are boreholes (ground water). Often the quality of water in these boreholes does not conform to international water quality guidelines. Some guidelines define the already scarce commodity as unsuitable for poultry. Established water quality guidelines required re-evaluation and modification to a standard suitable for this unique environment.

The hypothesis in this thesis is that current water quality guidelines are inadequate and need re-assessment. A new approach to the development of water quality guidelines for poultry production is needed.

This hypothesis was challenged by reviewing existing international water quality guidelines, which currently serve as the basis for water quality assessment for poultry production in South Africa. This entailed a survey of the water used by poultry producers and analysing the results of a number of trials, which tested inclusion levels of Fluoride, Sodium, Magnesium, Chloride, Sulphate, Nitrates, Calcium and Phosphorus.

A modelling procedure was used to establish a Water Quality Guideline Index System (WQGIS) for commercial poultry farmers in the RSA. This tool will enable maximum utilisation of a water source, by incorporating exposure time, species tolerance and ingestion rates into the model.

Chapter 1

A national survey of the quality of groundwater used by poultry producers in South Africa.

Published in:

Casey, N.H., Meyer, J.A. & Coetzee C.B. 1998. An investigation into the quality of water for 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

Coetzee, C.B., Casey, N.H. and Meyer, J.A. 2000. Groundwater quality of poultry producers in the Western Cape. Water SA. Vol. 26:4 p 563-568

Introduction

Knowledge regarding water quality is important for poultry production as it provides the producer with managerial information to prevent the potential adverse consequences of specific concentrations of water constituents. These typically pertain to health and production parameters, the quality of the livestock product and the watering systems of intensive poultry production systems. Meyer, Casey and Coetzee (1998 e) reported that there was no national database on the water quality constituent profile of water sources used for livestock production. They suggested that a water quality monitoring system be formulated in which the relevant water constituents for the specific areas and production systems be identified. The system should be based primarily on the constituent's potential to cause adverse effects and their occurrence in the natural aquatic environment. Existing information lacked the analyses of critical constituents at specific sites, required to formulate a risk assessment. Analyses are often not standardised and information on constituents that may affect the usability of the water source may be left out.

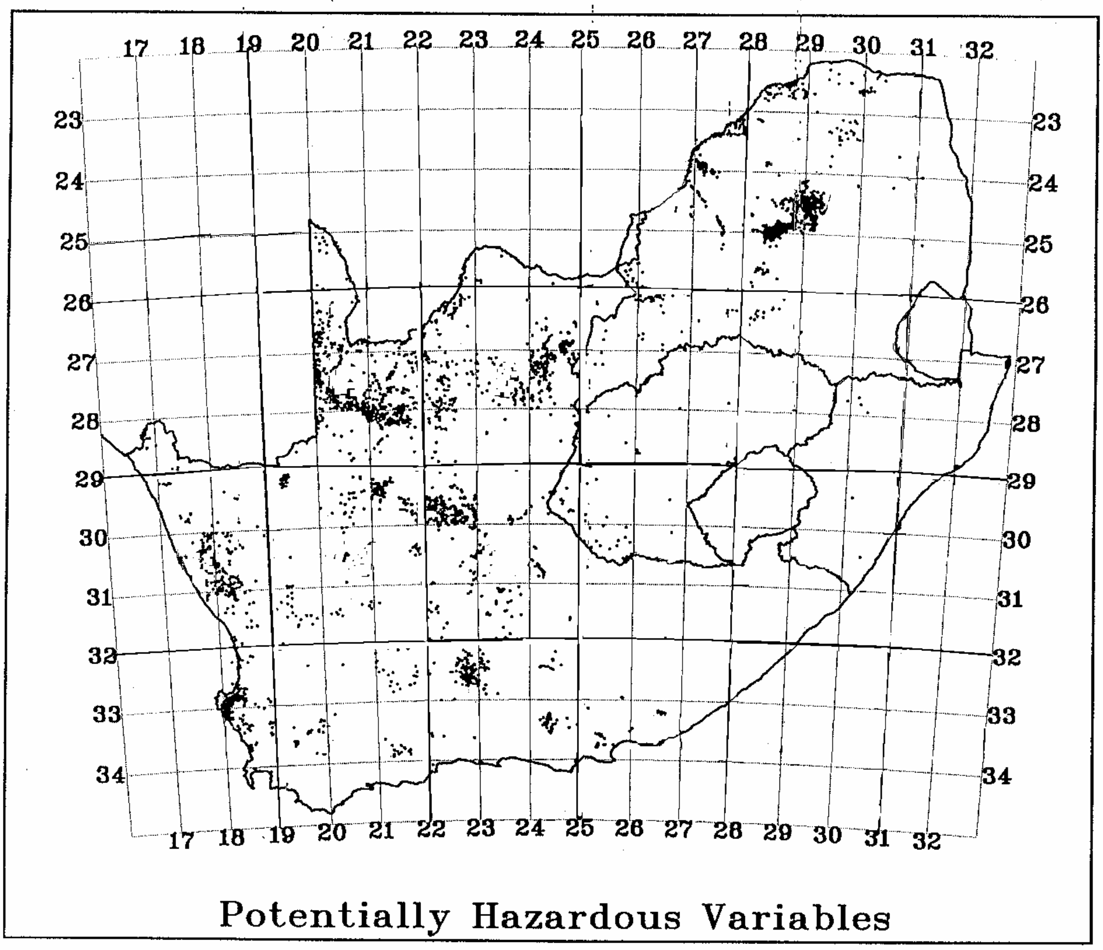
This chapter reports on the quality of water used by poultry producers in South Africa. It refers to and uses the PHC (Potentially Hazardous Constituent) and COC (Constituent of Concern) quantification system described by Meyer, 1998 and Meyer et al., 1997 but with specific reference to poultry. The objective was to identify PHCs (constituents in excess of the recommended guidelines) and COC (constituents within 10% of the recommended upper limit), to establish the validity of water quality guidelines currently in use for poultry, and to identify constituents at specific sites that require further investigation as potential hazards.

Materials and Methods

1. Borehole Selection:

A map (Map 1.1) was obtained from the Atomic Energy Corporation showing the occurrence of potentially hazardous constituent levels for livestock watering in southern Africa (Map 1.1). A large number of poultry producers in provinces with potentially hazardous water sources were contacted and those that use ground water were visited on site and the boreholes in use sampled. In the Western Cape 35 boreholes were sampled; in the North Western Province 9, in Gauteng 9, in the Freestate 17 and in the Eastern Cape, 3 boreholes.

Map 1.1: Potentially hazardous levels for livestock watering occurring in South African ground water.



Source: Atomic Energy Corporation 1997

2. Sample collection:

The sampling bottles were left in a solution of 1 ml concentrated nitric acid per litre of water for 24 hours. Bottles were rinsed with distilled water and dried. The borehole pump was allowed to run for at least 30 minutes. A tap near the borehole was located and allowed to run for at least 1 minute to purge the plumbing. More or less 1 litre of water was collected in a clean bucket from the running tap at 1 minute intervals for at least 5 minutes. This sample was stirred and 500 ml and 100 ml of water respectively was collected in acid treated plastic containers. The 500 ml sample was analysed for mineral content and the 100 ml sample for metal content. The 100 ml sample was acidified with nitric acid to a 0,001% solution, to keep the metals in suspension and the samples were kept at less than 5°C and returned to water quality laboratory within a week of the sampling time (Goan et al., 1992).

Laboratory Analyses:

The water samples were analysed for mineral content and a semi-quantitative metal scan was done by the Institute for Soil, Climate and Water at the ARC in Pretoria, making use of the United States Environmental Protection Agency's (EPA) Standard Operating Procedure for the determination of metals and minerals. See Tables 1.2 (mg/l) and 1.3 (µg/l) for lists of the constituents analysed.

Statistical evaluation:

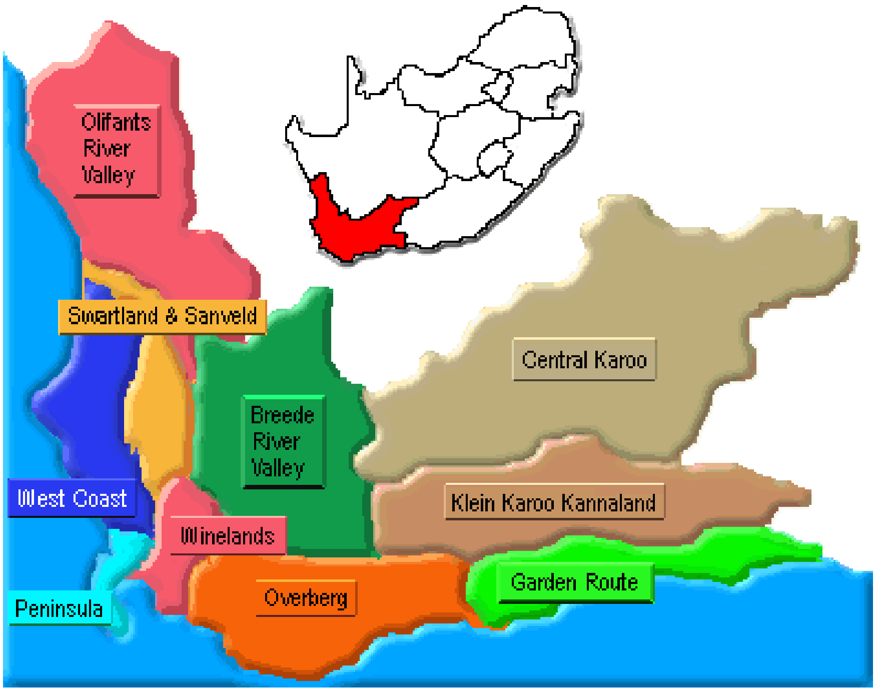
Means, standard deviations, minimum and maximum levels of constituents in water sources were determined using Proc Means (PC – SAS Version 6.08).

2. Results of water analysis:

Results of water analyses of boreholes are presented in Tables 1.2 – 1.16., with a summary in Tables 1.17 – 1.18. The results of the survey are presented with a list of probable or possible adverse effects linked to the relevant constituents. Note the huge differences between minimum and maximum levels of the different minerals and metals observed within the same province. This accentuated the need for a water quality index system.

The Western Cape:

Map 1.2. The Western Cape region where the water samples were taken



Source: http://www.places.co.za/html

The Western Cape region west of the Hottentot's Holland mountain range is highly urbanised and industrialised and is farmed intensively. The farms include some of the country's biggest poultry units, which collectively deliver 24.5% of the gross egg production and 27.1% of the gross broiler production (Liebenberg et al., 1996) of South Africa. The physiography is a dominance of fold mountains, which affect the spatial distribution of rainfall and results in a high runoff. The potentially precarious water supply and the high demand for water for the urban areas, industry and agriculture, has forced many producers to rely on or supplement water from subterranean sources. The characteristics of this water may vary substantially (Hem, 1979), due to the occurrence of fractured aquifers (Parsons and Tredoux, 1993).

No complete reference to all the constituents adverse to poultry was found in the literature. Many different sources were used to compile a complete list of constituents involved in poultry water quality and often these sources used different methods to indicate guidelines. Tables 1.2 and 1.3 show the means of constituents present in the samples analysed. Highest recorded levels of constituents are presented in Table 1.4. Bicarbonates, chlorides, fluoride, nitrates, phosphates, sodium, cadmium, iron, lanthanum, lead, mercury, titanium and zirconium were identified as potentially hazardous constituents (PHC) in some areas. The mean levels of chlorides, bicarbonates, sodium and lead, found in all the boreholes samples were higher than the maximum levels allowed by the authors mentioned in Table 1.4. The rest of the constituents identified as potentially hazardous were isolated cases of levels exceeding the allowed maximum levels (Table 1.2 and 1.3).

Table 1.2. Water Quality Constituents (mg/l), pH and electrical conductivity (mS/m) of borehole water from selected poultry farms in the Western Cape (n = 35).

Measured variable	Mean	SD	Minimum	Maximum	MAX PHC	COC	Adverse effects of excess #
Bicarbonate	108.249	43.208	18.3	216.6	98	88.2	Non-toxic.
Boron	0	0	0	0	5	4.5	Not a priority pollutant
Calcium	33.391	15.39	9.3	68.5	600	540	Non-toxic, clogs up pipes.
Carbonate	0	0	0	0	500	450	Lower egg production.
Chloride	326.937	182.132	82.7	703.5	250	225	May cause metabolic problems.
Fluoride	0.934	1.521	0	7.2	6	5.4	Lower feed intakes and growth rates.
Magnesium	24.471	12.398	6.7	53.7	125	112.5	Laxative effect.
Nitrate	8.271	8.886	0	48.5	10	9	Reduced growth, increased mortality rate.
Nitrite	0	0	0	0	1	0.9	Thyroid enlargement methaemoglobinaemia
Phosphate	0.5	2.233	0	5.2	5	4.5	Indicator of sewage contamination.
Potassium	5.129	3.696	1.6	20.7	2000	1800	Acts as a laxative
Sodium	153.543	87.555	42.4	357	50	45	Diuretic, reduced egg production and growth.
Sulphate	27.36	25.413	4.9	87	250	225	Laxative effect, reduced egg production.
TDS	634.629	296.569	201.4	1216	3000	2700	Indication of excessive mineral content.
Hardness	87.2	33.73	15	151	-	-	Blocks water systems, scale formation.
pH	7.602	0.389	6.8	8.22	6-9	6-9	Acid - corrosive to pipes, lower performance, lower egg production.
pHs	8.082	0.381	7.7	9.24	-	-	Stability pH
NAV	4.822	2.259	2.24	9.75	-	-	-
Electrical conductivity	109.171	49.666	37	208	1980	1782	Related to ions in water, no influence on poultry production.

#Kempster et al., (1981); Waggoner et al. (1994); Vohra (1980); Zimmerman (1995); Carter (1985); Phillips et al. (1935); Ralph (1989), Puls 1994 and Coetzee (1994)

Table 1.3. Water quality constituents (µg/l) of borehole water from selected poultry farms in the Western Cape (n = 35).

Measured variable	Mean	SD	Minimum	Maximum	MAX PHC	COC	Adverse effects of excess #
Antimony	0.42	0.707	0.108	4.223	6	5.4	Emetic and a cardio-toxin.
Arsenic	1.332	2.181	0	9.812	50	45	Toxic substance.
Barium	69.371	67.776	9.795	252.1	2000	1800	Cardio-toxin.
Bismuth	0.066	0.033	0.015	0.149	500	450	Neuro-toxin.
Bromine	56.442	30.594	20.103	123.33	3000	2700	Reduced growth rate.
Cadmium	1.371	2.604	0	12.694	5	4.5	Excess has severe health effects.
Caesium	4.517	8.849	0	32.918	50000	45000	Cyanosis and convulsions.
Chromium	35.69	4.108	25.484	47.17	100	90	May contribute to hardness of water, low toxicity, Essential nutrient; absence causes diabetes.
Cobalt	4.043	6.706	0.557	27.166	1000	900	Essential nutrient, toxic in excess.
Copper	25.609	35.602	5.082	194.99	1300	1170	Bitter, causes liver damage.
I odine	110.942	82.558	43.131	485.47	1000	900	Thyroid-related effects.
Iron	3.731	7.858	0	37.19	6	5.4	Causes odour, bad taste & precipitate.
Lead	40.288	36.9	112.432	202.8	20	18	Toxic element
Manganese	649.986	661.358	27.157	2204.7	4600	4140	May contribute to hardness and turbidity, deposits in pipes and bitterness of water.
Mercury	0.956	1.214	0	4.182	2	1.8	A toxic element with no beneficial physiological function.
Molybdenum	0.781	1.639	0	8.148	100	90	Reduced growth, highly toxic.
Nickel	41.755	21.399	19.342	109.96	1000	900	Reduced growth.
Platinum	0.236	0.154	0.005	0.568	-	-	Allergenic.
Rubidium	7.895	7.435	0.486	27.463	5000	4500	Non-toxic.
Selenium	0.076	0.447	0	2.645	50	45	Reduced growth.
Strontium	289.913	274.323	36.206	1328.4	10000	9000	May contribute to hardness of water.
Tin	0.565	0.677	0.07	3.281	200	180	Essential nutrient, low toxicity.
Titanium	173.348	108.758	26.457	430.68	100	90	Soluble salts potentially toxic.
Tungsten	0.546	0.597	0.046	2.072	500	450	Only soluble salts potentially toxic.
Uranium	26.924	96.931	0.014	423.42	4000	3600	Low Toxicity
Vanadium	0.454	1.293	0	6.131	100	90	Nutritionally essential.
Zinc	256.827	388.63	50.319	1661.8	1500	1350	Astringent taste, may contribute to hardness.
Zirconium	0.731	0.577	0.237	2.916	1	0.9	Low toxicity.

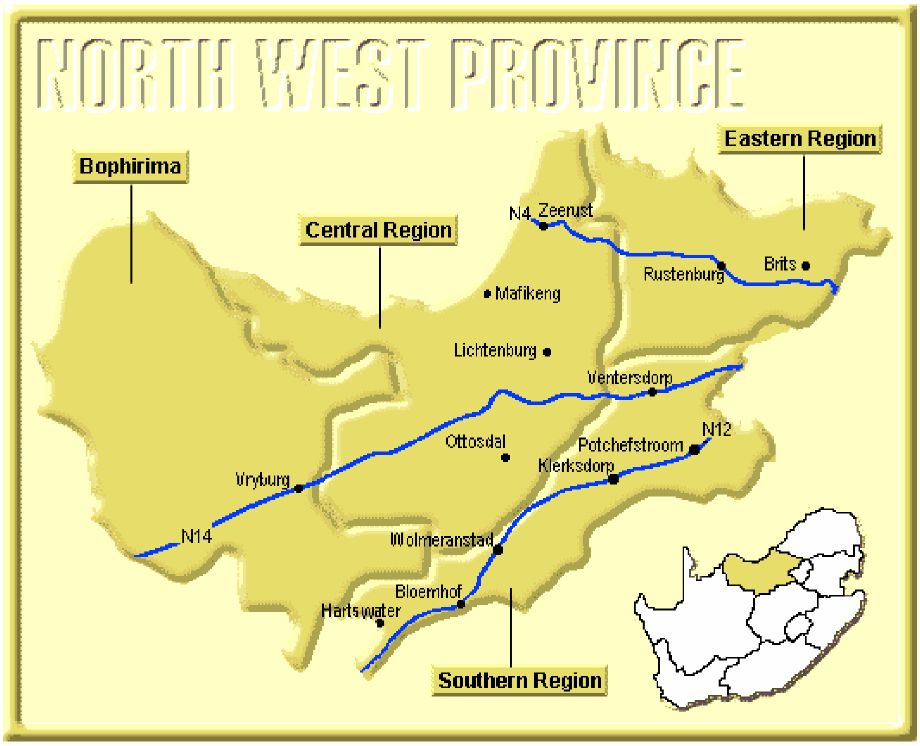
Kempster et al., (1981); Waggoner *et al.* (1994); Vohra (1980); Zimmerman (1995); Carter (1985); Phillips *et al*. (1935); Ralph (1989) and *Puls (1994)*

Table 1.4. Highest recorded levels of constituents in the Western Cape

Constituents	Highest recorded level	Recommended maximum levels	Source
Bicarbonates	216.6 mg/l	98.0 mg/l	Kempster *et al.*, 1981
Chlorides	703.5 mg/l	250.0 mg/l	Waggoner *et al.*, 1994
Fluoride	7.2 mg/l	2.0 mg/l	Kempster *et al.*, 1981
Nitrates	48.5 mg/l	10.0 mg/l	Waggoner *et al.*, 1994
Phosphates	5.2 mg/l	5.0 mg/l	Kempster *et al.*, 1981
Sodium	357.0 mg/l	50.0 mg/l	Waggoner *et al.*, 1994
Cadmium	12.694	5.0 µg/l	Zimmerman, 1995
Iron	37.190 mg/l	6.0 mg/l	Keshavarz, 1987
Lanthanum	2.304 µg/l	1.0 µg/l	Vohra, 1980
Lead	202.8 µg/l	20 µg/l	Schwarz, 1994
Mercury	4.182 µg/l	2.0 µg/l	Zimmerman, 1995
Titanium	430.68 µg/l	100.0 µg/l	Kempster *et al.*, 1981
Zirconium	2.916 µg/l	1.0 µg/l	Vohra, 1980

The North West Province

Map 1.3. The North West Province where the water samples were taken.



Source: http://www.places.co.za/html

Much of the province consists of flat areas of scattered trees and grassland (Map 1.3). The Magaliesberg mountain range in the northeast extends about 130 km (about 80 miles) from Pretoria to Rustenburg. The Vaal River flows along the southern border of the province. Temperatures range from 17° to 31° C (62° to 88° F) in the summer and from 3° to 21° C (37° to 70° F) in the winter. Annual rainfall totals about 360 mm (about 14 inches), with almost all of it falling during the summer months, between October and April.

Tables 1.5 and 1.6 show the means of constituents present in the samples analysed. The PHCs observed in the North Western Province were, bicarbonates, nitrates, sodium, lanthanum and titanium. The highest recorded levels of these constituents are shown in Table 1.7. No COCs were observed.

Table 1.5. Water quality constituents (mg/l), pH and electrical conductivity (mS/m) of borehole water from selected poultry farms in the North West Province (n = 9).

Measured variable	Mean	SD	Minimum	Maximum	MAX PHC	COC	Adverse effects of excess #
Bicarbonate	311.789	118.162	91.5	515.5	98	88.2	Non-toxic.
Boron	0	0	0	0	5	4.5	Not a priority pollutant
Calcium	46.233	26.189	19.9	93.8	600	540	Non-toxic, clogs up pipes.
Carbonate	3.5	3.824	0	10.5	500	450	Lower egg production.
Chloride	30.456	23.055	4	79	250	225	May cause metabolic problems.
Fluoride	0.018	0.038	0	0.11	6	5.4	Lower feed intakes and growth rates.
Magnesium	34.122	11.345	16.5	54.6	125	112.5	Laxative effect.
Nitrate	66.167	37.897	10.1	133.5	10	9	Reduced growth, increased mortality rate.
Nitrite	0	0	0	0	1	0.9	Thyroid enlargement methaemoglobinaemia
Phosphate	0	0	0	0	5	4.5	Indicator of sewage contamination.
Potassium	2.289	2.599	0.1	7.9	2000	1800	Acts as a laxative
Sodium	33.244	31.428	2.6	104.3	50	45	Diuretic, reduced egg production and growth.
Sulphate	14.233	6.788	1.3	24.7	250	225	Laxative effect, reduced egg production.
TDS	386.189	135.857	235.9	632.7	3000	2700	Indication of excessive mineral content.
Hardness	241.222	80.298	75	331	-	-	Blocks water systems, scale formation.
pH	8.356	0.314	7.87	8.74	6-9	6-9	Acid - corrosive to pipes, lower performance, lower egg production.
PHs	7.463	0.419	6.96	8.19	-	-	Stability pH
NAV	0.899	0.79	0.07	2.51	-	-	-
Electrical conductivity	55.333	17.081	35	87	1980	1782	Related to ions in water, no influence on poultry production.

#Kempster et al., (1981); Waggoner et al. (1994); Vohra (1980); Zimmerman (1995); Carter (1985); Phillips et al. (1935); Ralph (1989), Puls 1994 and Coetzee (1994)

Table 1.6. Water quality constituents (µg/l) of borehole water from selected poultry farms in the North West Province (n = 9).

Measured variable	Mean	SD	Minimum	Maximum	MAX PHC	COC	Adverse effects of excess #
Antimony	0.018	0.029	0	0.081	6	5.4	Emetic and a cardio-toxin.
Arsenic	0.006	0.018	0	0.055	50	45	Toxic substance.
Barium	77.113	67.297	8.958	202.98	2000	1800	Cardio-toxin.
Bismuth	0.028	0.056	0	0.166	500	450	Neuro-toxin.
Bromine	0	0	0	0	3000	2700	Reduced growth rate
Cadmium	0.021	0.061	0	0.183	5	4.5	Excess has severe health effects.
Caesium	0.008	0.022	0	0.066	50000	45000	Cyanosis and convulsions.
Chromium	46.428	3.688	39.237	50.432	100	90	May contribute to hardness of water, low toxicity. Essential nutrient; absence causes diabetes.
Cobalt	0.02	0.059	0	0.176	1000	900	Nutritionally essential, toxic in excess.
Iron	0	0	0	0	6	5.4	Causes odour, bad taste & precipitate.
Lanthanum	5.077	9.827	0.021	27.429	1	0.9	Low to moderate acute toxicity rating.
Lead	0.786	0.465	0.167	1.417	20	18	Toxic element
Manganese	0	0	0	0	4600	4140	May contribute to hardness and turbidity, deposits in pipes and bitterness of water.
Mercury	0	0	0	0	2	1.8	A toxic element with no beneficial physiological function.
Molybdenum	0	0	0	0	100	90	Reduced growth, highly toxic.
Nickel	30.177	4.127	24.33	35.965	1000	900	Reduced growth.
Platinum	0.074	0.107	0	0.285	-	-	Allergenic.
Rubidium	0	0	0	0	5000	4500	Non-toxic.
Selenium	7.123	7.788	0	19.624	50	45	Reduced growth.
Strontium	269.467	145.397	30.846	416.09	10000	9000	May contribute to hardness of water.
Tin	0	0	0	0	200	180	Essential nutrient; low toxicity.
Titanium	377.359	216.745	145.1	773.68	100	90	Soluble salts potentially toxic.
Tungsten	0.031	0.037	0	0.144	500	450	Only soluble salts potentially toxic.
Uranium	0.36	0.226	0.005	0.777	4000	3600	Low Toxicity
Vanadium	14.894	11.747	2.313	38.802	100	90	Essential nutrient.
Zinc	319.309	418.698	0	1207	1500	1530	Astringent taste, may contribute to hardness.
Zirconium	0	0	0	0	1	0.9	Low toxicity.

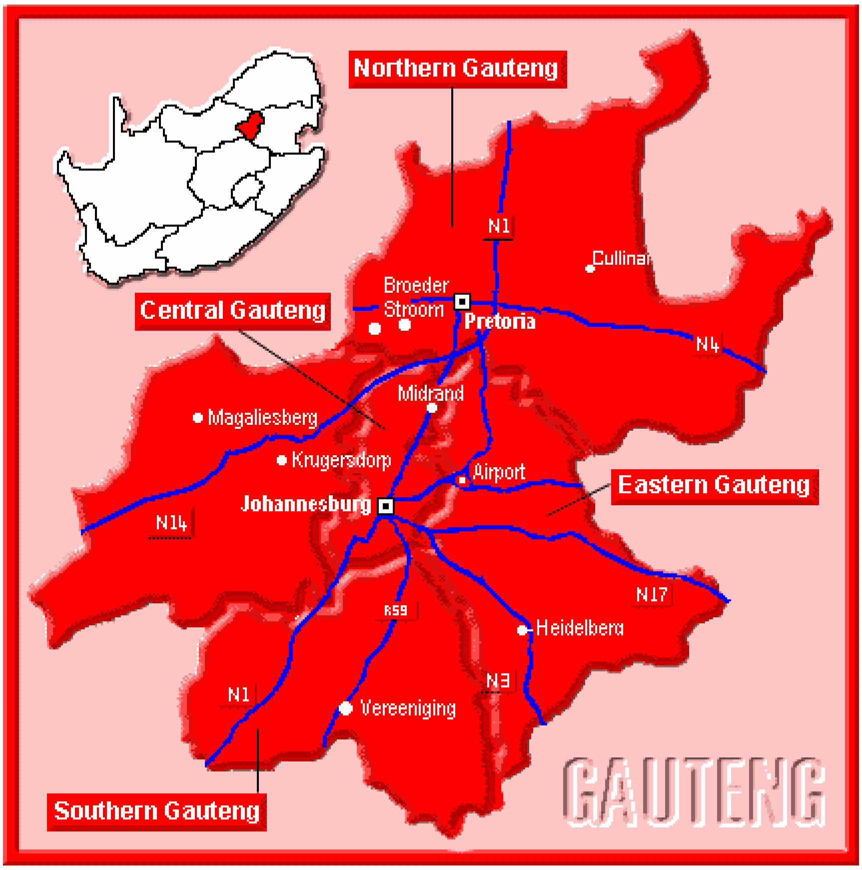
Kempster et al., (1981); Waggoner *et al.* (1994); Vohra (1980); Zimmerman (1995); Carter (1985); Phillips *et al*. (1935); Ralph 1989)and*Puls(1994)*

Table 1.7. Highest recorded levels of constituents in the North West Province

Constituents	Highest recorded level	Recommended maximum levels	Source
Bicarbonates	515.500 mg/l	98.0 mg/l	Kempster *et al.*, 1981
Nitrates	133.5 mg/l	10.0 mg/l	Waggoner *et al.*, 1994
Sodium	104.300 mg/l	50.0 mg/l	Waggoner *et al.*, 1994
Lanthanum	27.429 µg/l	1.0 µg/l	Vohra, 1980
Titanium	773.680 µg/l	100.0 µg/l	Kempster *et al.*, 1981

Gauteng

Map 1.4. The province of Gauteng where the water samples were taken.



Source: http://www.places.co.za/html

Most of the province lies in the High Veld, a plateau of grassy plains that covers much of central South Africa. The Witwatersrand, (which is Afrikaans for "ridge of white waters") is a rocky ridge that extends for about 80 km (about 50 miles) down the middle of Gauteng and is famous for its rich gold deposits. Average temperatures in Gauteng range from 16° to 32° C (60° to 90° F) in the summer (October to April), and from 6° to 17° C (43° to 63° F) in the winter. Annual rainfall totals 510 mm (20 inches), with most of the rain falling in the summer months (Map 1.4).

Tables 1.8 and 1.9 show the means of constituents present in the samples analysed.

The PHCs observed in Gauteng were bicarbonates, nitrates, manganese, mercury and titanium. The highest recorded levels of these constituents are shown in Table 1.10. No COCs were observed.

Table 1.8. Water quality constituents (mg/l), pH and electrical conductivity (mS/m) of borehole water from selected poultry farms in Gauteng (n = 9).

Measured variable	Mean	SD	Minimum	Maximum	MAX PHC	COC	Adverse effects of excess #
Bicarbonate	35.144	39.802	0	131.2	98	88.2	Non-toxic.
Boron	0.011	0.033	0	0.1	5	4.5	Not a priority pollutant.
Calcium	9.256	5.577	1.9	19.6	600	540	Non-toxic, clogs up pipes.
Carbonate	0.333	1	0	3	500	450	Lower egg production.
Chloride	11.033	12.415	0.9	32.3	250	225	May cause metabolic problems.
Fluoride	0.058	0.082	0	0.24	6	5.4	Lower feed intakes and growth rates.
Magnesium	5.3	4.082	0.3	11.4	125	112.5	Laxative effect.
Nitrate	34.611	46.416	2.5	116.6	10	9	Reduced growth, increased mortality rate.
Nitrite	0	0	0	0	1	0.9	Thyroid enlargement methaemoglobinaemia
Phosphate	0.189	0.567	0	1.7	5	4.5	Indicator of sewage contamination.
Potassium	4.922	4.373	2	16.3	2000	1800	Acts as a laxative.
Sodium							
Sulphate	0.777	0.521	0.1	1.5	250	225	Laxative effect, reduced egg production.
TDS	92.178	59.672	28.2	187	3000	2700	Indication of excessive mineral content.
Hardness	24.222	24.939	0	80.000	-	-	Blocks water systems, scale formation.
pH	6.619	1.697	3.79	8.54	6-9	6-9	Acid - corrosive to pipes. Lower performance, lower egg production.
PHs	9.347	0.737	8.05	10.28	-	-	Stability pH
NAV	5.552	14.433	0.14	44	-	-	-
Electrical conductivity	16.222	11.065	4	34	1980	1782	Related to ions in water, no influence on poultry production.

#Kempster et al., (1981); Waggoner et al. (1994); Vohra (1980); Zimmerman (1995); Carter (1985); Phillips et al. (1935); Ralph (1989), Puls 1994 and Coetzee (1994)

Table 1.9. Water quality constituents (µg/l) of borehole water from selected poultry farms in Gauteng (n = 9).

Measured variable	Mean	SD	Minimum	Maximum	MAX PHC	COC	Adverse effects of excess #
Antimony	719	0.475	0.074	1.38	6	54	Emetic and a cardio-toxin.
Arsenic	4.077	2.174	0.196	7.03	50	45	Toxic substance.
Barium	125.262	86.41	30.77	270.14	2000	1800	Cardio-toxin.
Bismuth	0.268	0.202	0.025	0.704	500	450	Neuro-toxin.
Bromine	0	0	0	0	3000	2700	Reduce growth rate
Cadmium	1.39	0.947	0	2.414	5	4.5	Excess has severe health effects.
Caesium	0	0	0	0	50000	45000	Cyanosis and convulsions.
Chromium	45.841	14.18	22.628	59.016	100	90	May contribute to hardness of water, low toxicity. Essential nutrient, absence causes diabetes.
Cobalt	7.601	12.332	0.646	30.321	1000	900	Nutritionally essential, toxic in excess.
Copper	39.078	39.034	2.881	111.38	1300	1170	Bitter, causes liver damage.
Iron	0	0	0	0.001	6	5.4	Causes odour, bad taste & precipitate.
Lanthanum	0	0	0	0	1	0.9	Low to moderate acute toxicity rating.
Lead	5.901	3.757	1.095	12.141	20	18	Toxic element
Manganese	11130.32	17685.53	96.326	4420.9	4600	4140	May contribute to hardness and turbidity, deposits in pipes and bitterness of water.
Mercury	17.743	14.127	0	34.434	2	1.8	A toxic element with no beneficial physiological function.
Molybdenum	1.445	0.824	0	2.48	100	90	Reduced growth, highly toxic.
Nickel	53.043	25.508	0	89.544	1000	900	Reduced growth.
Platinum	0.514	0.533	0	1.169	-	-	Allergenic.
Rubidium	0	0	0	0	5000	4500	Non-toxic.
Selenium	21.979	16.969	0	41.789	50	45	Reduced growth.
Strontium	44.965	29.035	3.029	90.717	10000	9000	May contribute to hardness of water.
Tin	1.633	1.149	0	2.921	200	180	Essential nutrient, low toxicity.
Titanium	69.197	47.077	27.265	181	100	90	Soluble salts potentially toxic.
Tungsten	2.89	0.194	0	0.602	500	450	Only soluble salts potentially toxic.
Uranium	1.411	1.871	0.12	5.236	4000	3600	Low Toxicity
Vanadium	32.724	20.996	4.839	62.898	100	90	Essential nutrient.
Zinc	344.254	686.62	10.11	2127.4	1500	1350	Astringent taste, may contribute to hardness.
Zirconium	0	0	0	0	1	0.9	Low toxicity.

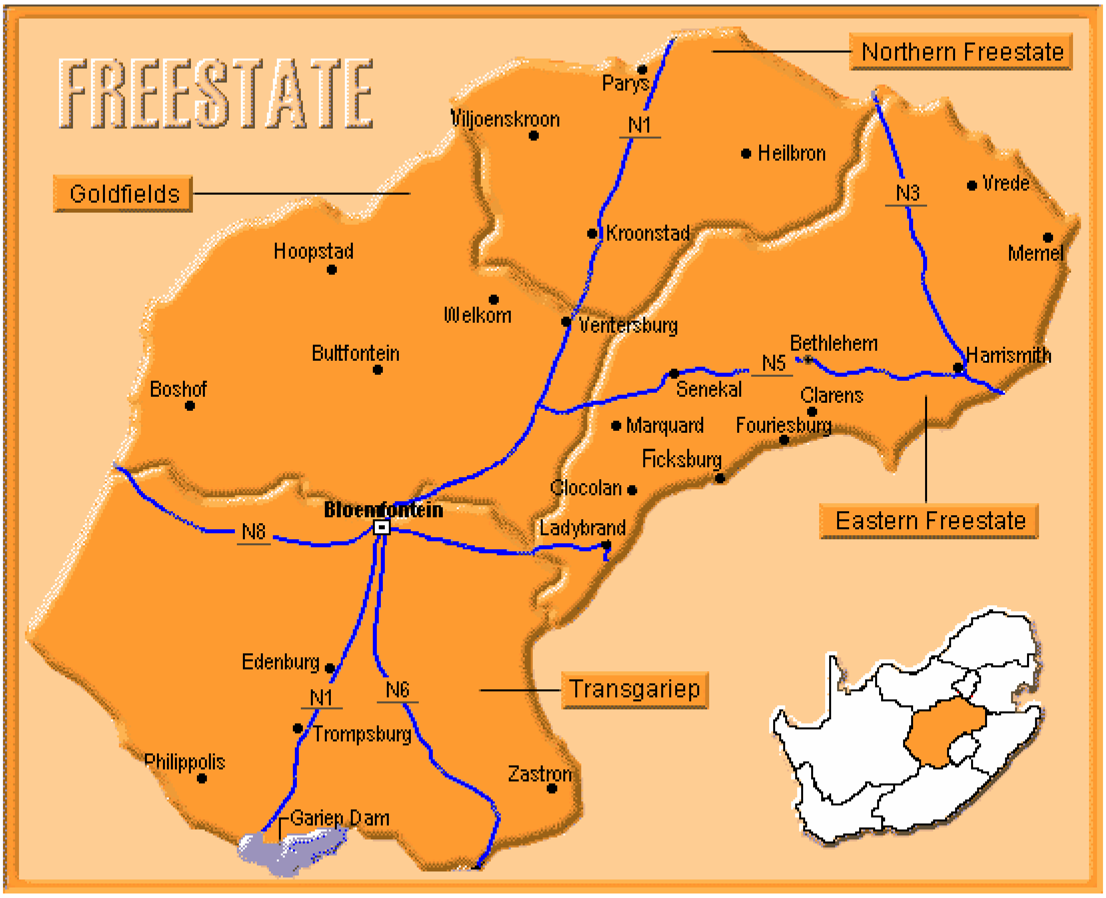
Kempster et al., (1981); Waggoner *et al.* (1994); Vohra (1980); Zimmerman (1995); Carter (1985); Phillips *et al.* (1935); Ralph (1989) and *Puls (1994)*

Table 1.10. Highest recorded levels of constituents in Gauteng

Constituents	Highest recorded level	Recommended maximum levels	Source
Bicarbonates	131.2 mg/l	98.0 mg/l	Kempster *et al.*, 1981
Nitrates	116.6 mg/l	10.0 mg/l	Waggoner *et al.*, 1994
Manganese	4420.9 µg/l	4600.0 µg/l	Kempster *et al.*, 1981
Mercury	34.434 µg/l	2.0 µg/l	Kempster *et al.*, 1981
Titanium	181.000 µg/l	100.0 µg/l	Kempster *et al.*, 1981

The Freestate

Map 1.5. The Freestate Province where the water samples were taken.



Source: http://www.places.co.za/html

The Free State is located on the High Veld, the large plateau that covers much of the central region of South Africa. The far western part of the province is flat and sparsely vegetated, while in the far east the land rises to the Drakensberg Mountains. The rest of the province consists of rolling plains. Average temperatures range from 16° to 31° C (60° to 88° F) in the summer and from 1° to 18° C (34° to 64° F) in the winter. Average annual rainfall totals 360 mm (14 inches) with most of the rain falling in the warmer months, from October to April. The eastern part of the province receives considerably more rain than the western region (Map 1.5).

Tables 1.11 and 1.12 show the means of constituents present in the samples analysed.

The PHCs observed in the Freestate were bicarbonates chlorides, phosphates, bromine, chromium, lanthanum, mercury, selenium, titanium and zirconium. The highest recorded levels of these constituents are shown in Table 1.13. No COCs were observed.

Table 1.11. Water quality constituents (mg/l), pH and electrical conductivity of borehole water from selected poultry farms in the Free State (n =17).

Measured variable	Mean	SD	Minimum	Maximum	MAX PHC	COC	Adverse effects of excess #
Bicarbonate	293.262	195.264	4.9	555.1	98	88.2	Non-toxic.
Boron	0.247	0.56	0	2.4	5	4.5	Not a priority pollutant.
Calcium	121.076	117.952	3.8	291	600	540	Non-toxic, clogs up pipes.
Carbonate	0.356	1.455	0	6	500	450	Lower egg production.
Chloride	222.752	280.581	3.5	907.1	250	225	May cause metabolic problems.
Fluoride	0.025	0.087	0	0.36	6	5.4	Lower feed intakes and growth rates.
Magnesium	22.653	19.915	0.05	60.5	125	112.5	Laxative effect.
Nitrate	0	0	0	0	10	9	Reduced growth, increased mortality rate.
Nitrite	0	0	0	0	1	0.9	Thyroid enlargement methaemoglobinaemia
Phosphate	13.847	11.379	0.2	31.9	5	4.5	Indicator of sewage contamination.
Potassium	192.371	177.662	6.5	786	2000	1800	Acts as a laxative.
Sodium	224.426	218.816	0.55	520.5	50	45	Diuretic, reduced egg production and growth.
Sulphate	41.324	0.521	0.1	1.5	250	225	Laxative effect, reduced egg production.
TDS	1082.91	769.28	72.1	2501.3	3000	2700	Indication of excessive mineral content.
Hardness	199.941	113.942	4	305	-	-	Blocks water systems, scale formation.
pH	7.339	1.136	4.37	8.53	6-9	6-9	Acid - corrosive to pipes. Lower performance, lower egg production.
PHs	7.431	1.04	6.57	9.74	-	-	Stability pH
NAV	8.342	13.327	0.41	53.61	-	-	-
Electrical conductivity	165.529	111.168	13	385	1980	1782	Related to ions in water, no influence on poultry production.

#Kempster et al., (1981); Waggoner et al. (1994); Vohra (1980); Zimmerman (1995); Carter (1985); Phillips et al. (1935); Ralph (1989), Puls 1994 and Coetzee (1994)

Table 1.12. Water quality constituents (µg/l) of borehole water from selected poultry farms in the Free State (n =17).

Measured variable	Mean	SD	Minimum	Maximum	MAX PHC	COC	Adverse effects of excess #
Antimony	0.184	0.135	0.063	0.686	6	5.4	Emetic and a cardio-toxin.
Arsenic	9.881	2.627	6.739	15.753	50	45	Toxic substance.
Barium	76.616	29.233	25.5	113.11	2000	1800	Cardio-toxin.
Bismuth	0.082	0.031	0.024	0.129	500	450	Neuro-toxin.
Bromine	16917.47	11096.88	4045.3	43697	3000	2700	Reduced growth rate
Cadmium	0.797	0.415	0.41	2.079	5	4.5	Excess has severe health effects.
Caesium	0.077	0.096	0.019	0.356	50000	45000	Cyanosis and convulsions.
Chromium	54.134	17.902	20.3	112.81	100	90	May contribute to hardness of water .Essential nutrient; absence causes diabetes, low toxicity.
Cobalt	165.565	229.312	0.631	528.93	1000	900	Essential nutrient, toxic in excess.
Copper	18.366	12.278	5.993	141.27	1300	1170	Bitter, causes liver damage.
Iron	0	0	0	0	6	5.4	Causes odour, bad taste & precipitate.
Lanthanum	2.327	3.295	0.534	12.758	1	0.9	Low to moderate acute toxicity rating.
Lead	2.072	0.804	1.095	4.387	20	18	Toxic element
Manganese	110.306	133.633	23.976	383.73	4600	4140	May contribute to hardness and turbidity, deposits in pipes and bitterness of water.
Mercury	10.358	3.565	6.08	16.338	2	1.8	A toxic element with no beneficial physiological function.
Molybdenum	2.844	2.564	1.061	11.718	100	90	Reduced growth, highly toxic.
Nickel	35.478	5.9518	26.672	47.25	1000	900	Reduced growth.
Platinum	0.346	0.212	0.053	0.814	-	-	Allergenic.
Rubidium	0	0	0	0	5000	4500	Non-toxic.
Selenium	67.957	13.797	50.772	94.996	50	45	Reduced growth.
Strontium	2549.83	2165.42	104.66	5749.4	10000	9000	May contribute to hardness of water.
Tin	0.821	0.368	0.539	2.086	200	180	Essential nutrient, low toxicity.
Titanium	884.182	854.179	56.6	2427.1	100	90	Soluble salts potentially toxic.
Tungsten	0.143	0.057	0.028	0.238	500	450	Only soluble salts potentially toxic.
Uranium	4.045	2.868	0.16	8.892	4000	3600	Low Toxicity
Vanadium	4.81	3.847	0.91	16.051	100	90	Nutritionally essential.
Zinc	171.056	240.236	42.075	1066.8	1500	1350	Astringent taste, may contribute to hardness.
Zirconium	0.923	0.767	0.449	3.586	1	0.9	Low toxicity.

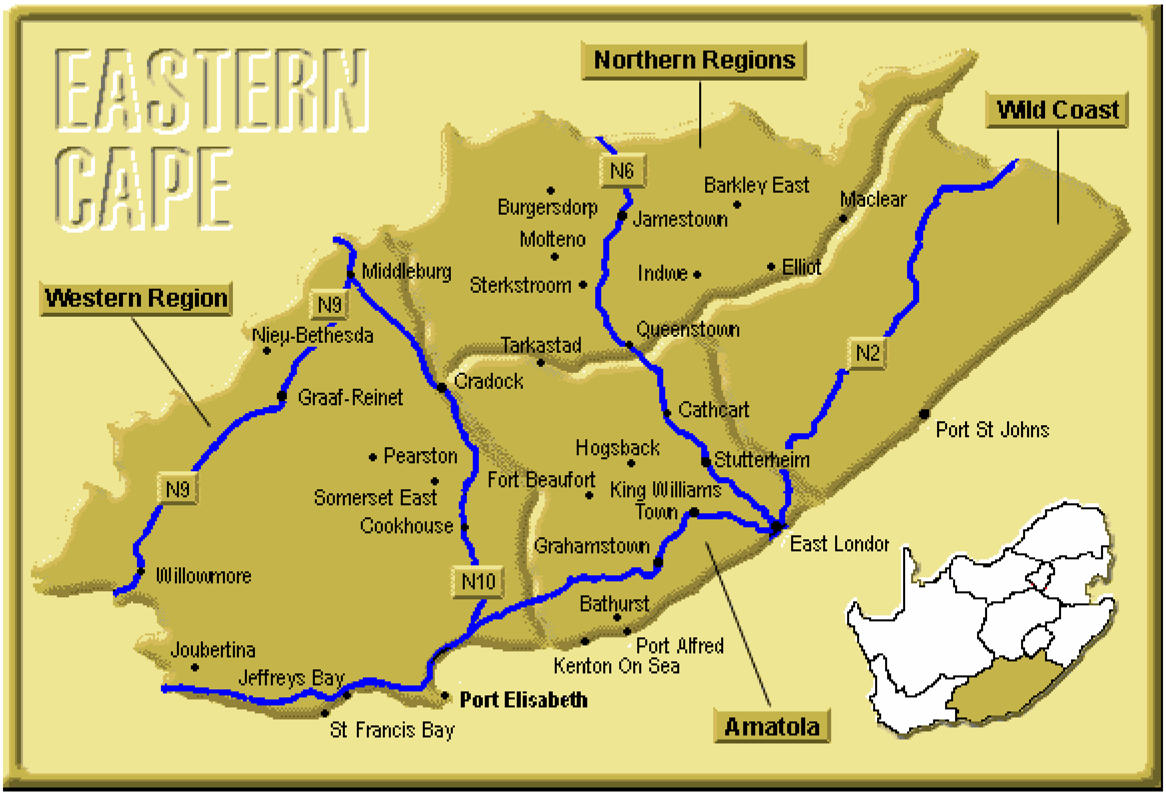
Kempster et al., (1981); Waggoner *et al.* (1994); Vohra (1980); Zimmerman (1995); Carter (1985); Phillips *et al*. (1935); Ralph (1989) and *Puls (1994)*

Table 1.13. Highest recorded levels of constituents in the Freestate

Constituents	Highest recorded level	Recommended maximum levels	Source
Bicarbonates	555.1 mg/l	98.0 mg/l	Kempster *et al.*, 1981
Chlorides	907.1 mg/l	250.0 mg/l	Waggoner *et al.*, 1994
Phosphates	31.9 mg/l	5.0 mg/l	Kempster *et al.*, 1981
Sodium	520.5 mg/l	50.0 mg/l	Waggoner *et al.*, 1994
Bromine	43697 µg/l	3000 µg/l	Vohra, 1980
Chromium	112.810 µg/l	100.0 µg/l	Kempster *et al.*, 1981
Lanthanum	12.758 µg/l	1.0 µg/l	Vohra, 1980
Mercury	16.338 µg/l	2.0 µg/l	Kempster *et al.*, 1981
Selenium	94.996 µg/l	50 µg/l	Kempster *et al.*, 1981
Titanium	2427.1 µg/l	100.0 µg/l	Kempster *et al.*, 1981
Zirconium	3.586 µg/l	1.0 µg/l	Vohra, 1980

The Eastern Cape

Map 1.6. The Eastern Cape Province where the water samples were taken.



Source: http://www.places.co.za/html

The Eastern Cape has a varied topography and climate. Much of the province consists of rolling grasslands, but the northwest section is part of the sparsely vegetated Great Karoo, a large, arid plateau (see Karoo). Extensive forests cover the southern section of the province. A series of mountain ranges runs through the center of Eastern Cape, and the Witteberge Mountains and the Drakensberg Mountains rim the province's northeastern boundary. The Great Fish, the Keiskamma, and the Kei rivers flow through the region. Eastern Cape's coastal area receives abundant rainfall, but the interior is much drier and has had chronic drought problems. The city of East London, located on the coast, receives an average annual rainfall of 900 mm (36 inches), while Cradock, in the interior, receives an average annual rainfall of 310 mm (10 inches). Most rain falls during the warmer months of October through April. Average temperatures in Eastern Cape range from 18° to 27° C (from 64° to 80° F) in the summer and from 8° to 20° C (46° to 68° F) in the winter (Map 1.6).
Tables 1.14 and 1.15 show the means of constituents present in the samples analysed.

The PHCs observed in the Eastern Cape were, bicarbonate, nitrates, sodium, mercury, selenium and titanium. Zirconium was present as a COC. The highest recorded levels of these constituents are shown in Table 1.16.

Table 1.14. Water quality constituents (mg/l), pH and electrical conductivity (mS/m) of borehole water from selected poultry farms in the Eastern Cape (n = 3).

Measured variable	Mean	SD	Minimum	Maximum	MAX PHC	COC	Adverse effects of excess #
Bicarbonate	287.967	33.405	256.9	323.3	98	88.2	Non-toxic.
Boron	0.033	0.058	0	0.1	5	4.5	Not a priority pollutant.
Calcium	26.8	12.093	16.7	40.2	600	540	Non-toxic, clogs up pipes.
Carbonate	0	0	0	0	500	450	Lower egg production.
Chloride	6.867	2.754	4.2	9.7	250	225	May cause metabolic problems.
Fluoride	0.007	0.012	0	0.02	6	5.4	Lower feed intakes and growth rates.
Magnesium	10.967	7.753	3.1	18.6	125	112.5	Laxative effect.
Nitrate	6.267	5.062	2.1	11.9	10	9	Reduced growth, increased mortality rate.
Nitrite	0	0	0	0	1	0.9	Thyroid enlargement methaemoglobinaemia
Phosphate	0	0	0	0	5	4.5	Indicator of sewage contamination.
Potassium	0.933	0.651	0.3	1.6	2000	1800	Acts as a laxative.
Sodium	68.567	34.755	29.1	94.6	50	45	Diuretic, reduced egg production and growth.
Sulphate	12.967	5.636	8.9	19.4	250	225	Laxative effect, reduced egg production.
TDS	294	29.099	360.5	313	3000	2700	Indication of excessive mineral content.
Hardness	113	61.798	55	178	-	-	Blocks water systems, scale formation.
pH	7.963	0.307	7.62	8.21	06-Sep	06-Sep	Acid - corrosive to pipes, lower performance, lower egg production.
PHs	7.617	0.166	7.46	7.79	-	-	Stability pH
NAV	3.333	2.313	0.95	5.57	-	-	-
Electrical conductivity	50.667	3.215	47	53	1980	1782	Related to ions in water, no influence on poultry production.

#Kempster et al., (1981); Waggoner et al. (1994); Vohra (1980); Zimmerman (1995); Carter (1985); Phillips et al. (1935); Ralph (1989), Puls 1994 and Coetzee (1994)

Table 1.15. Water quality constituents (µg/l) of borehole water from selected farms in the Eastern Cape (n = 3).

Measured variable	Mean	SD	Minimum	Maximum	MAX PHC	COC	Adverse effects of excess #
Antimony	0.163	0.083	0.073	0.237	6	5.4	Emetic and a cardio-toxin.
Arsenic	11.41	1.478	9.703	12.281	50	45	Toxic substance.
Barium	94.36	34.917	60.136	129.93	2000	1800	Cardio-toxin.
Bismuth	0.083	0.024	0.065	0.11	500	450	Neuro-toxin.
Bromine	5068.8	335.51	4719	5387.9	3000	2700	Reduced growth rate.
Cadmium	0.655	0.066	0.587	0.718	5	4.5	Excess has severe health effects.
Caesium	0.051	0.011	0.04	0.061	50000	45000	Cyanosis and convulsions.
Chromium	55.188	5.496	49.267	60.126	100	90	May contribute to hardness of water. Essential nutrient; absence causes diabetes, low toxicity.
Cobalt	43.968	72.635	0.91	127.83	1000	900	Essential nutrient, toxic in excess.
Copper	14.026	8.905	7.434	24.157	1300	1170	Bitter, causes liver damage.
Iron	0	0	0	0	6	5.4	Causes odour, bad taste & precipitate.
Lanthanum	0.865	0.234	0.66	1.12	1	0.9	Low to moderate acute toxicity rating.
Lead	7.049	7.359	1.871	15.473	20	18	Toxic element
Manganese	196.903	271.532	31.781	510.29	4600	4140	May contribute to hardness and turbidity, deposits in pipes and bitterness of water.
Mercury	7.553	0.9	6.555	8.305	2	1.8	A toxic element with no beneficial physiological function.
Molybdenum	2.751	1.259	1.86	4.191	100	90	Reduced growth, highly toxic.
Nickel	38.592	4.654	33.946	43.254	1000	900	Reduced growth.
Platinum	0.247	0.134	0.12	0.388	-	-	Allergenic.
Rubidium	0	0	0	0	5000	4500	Non-toxic.
Selenium	67.366	10.143	57.425	77.7	50	45	Reduced growth.
Strontium	693.763	281.415	514.31	1018.1	10000	9000	May contribute to hardness of water.
Tin	0.778	0.128	0.668	0.919	200	180	Essential nutrient, low toxicity.
Titanium	211.85	81.1809	152.64	304.39	100	90	Soluble salts potentially toxic.
Tungsten	0.124	0.018	0.107	0.141	500	450	Only soluble salts potentially toxic.
Uranium	2.669	2.622	0.663	5.636	4000	3600	Low Toxicity
Vanadium	5.125	2.283	3.562	7.746	100	90	Essential nutrient.
Zinc	407.905	397.067	102.59	856.82	1500	1350	Astringent taste, may contribute to hardness.
Zirconium	0.788	0.164	0.67	0.975	1	0.9	Low toxicity.

 # Kempster et al., (1981); Waggoner et al. (1994); Vohra (1980); Zimmerman (1995); Carter (1985); Phillips et al. (1935); Ralph (1989) and Puls (1994)

Table 1.16. Highest recorded levels of constituents in the Eastern Cape Province

Constituents	Highest recorded level	Recommended maximum levels	Source
Bicarbonates	323.3 mg/l	98.0 mg/l	Kempster *et al.*, 1981
Nitrates	11.9 mg/l	10.0 mg/l	Waggoner *et al.*, 1994
Sodium	94.6 mg/l	50.0 mg/l	Waggoner *et al.*, 1994
Mercury	8.305 µg/l	2.0 µg/l	Kempster *et al.*, 1981
Selenium	77.7µg/l	50 µg/l	Kempster *et al.*, 1981
Titanium	304.39 µg/l	100.0 µg/l	Kempster *et al.*, 1981
Zirconium	0.975 µg/l	1.0 µg/l	Vohra, 1980

Table 2.17. Water quality constituents (mg/l) of boreholes from selected poultry farms in the Western Cape, North West, Gauteng, Free State and Eastern Cape Provinces

Variable	PHC	COC	Western Cape		North West		Gauteng		Free State		Eastern Cape		
	>	= / <	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Adverse effects of excess #
Bicarbonate	98	88.2	108.249	43.208	311.789	118.162	35.144	39.802	293.262	195.264	287.967	33.405	Non-toxic.
Boron	5	4.5	0	0	0	0	0.011	0.033	0.247	0.56	0.033	0.058	Not a priority pollutant.
Calcium	600	540	33.391	15.39	46.233	26.189	9.256	5.577	121.076	117.952	26.8	12.093	Non-toxic, clogs up pipes.
Carbonate	500	450	0	0	3.5	3.824	0.333	1	0.356	1.455	0	0	Lower egg production.
Chloride	250	225	326.937	182.132	30.456	23.055	11.033	12.415	222.752	280.581	6.867	2.754	May cause metabolic problems.
Fluoride	6	5.4	0.934	1.521	0.018	0.038	0.058	0.082	0.025	0.087	0.007	0.012	Lower feed intakes and growth rates.
Magnesium	125	112.5	24.471	12.398	34.122	11.345	5.3	4.082	22.653	19.915	10.967	7.753	Laxative effect.
Nitrate	10	9	8.271	8.886	66.167	37.897	34.611	46.416	0	0	6.267	5.062	Reduced growth, increased mortality rate.
Nitrite	1	0.9	0	0	0	0	0	0	0	0	0	0	Thyroid enlargement methaemoglobinaemia.
Phosphate	5	4.5	0.5	2.233	0	0	0.189	0.567	13.847	11.379	0	0	Indicator of sewage contamination.
Potassium	2000	1800	5.129	3.696	2.289	2.599	4.922	4.373	192.371	177.662	0.933	0.651	Acts as a laxative.
Sodium	50	45	153.543	87.555	33.244	31.428	8.111	3.541	224.426	218.816	68.567	34.755	Diuretic, reduced egg production and growth.
Sulphate	250	225	27.36	25.413	14.233	6.788	0.777	0.521	41.324	0.521	12.967	5.636	Laxative effect, reduced egg production.
TDS	3000	2700	634.629	296.569	386.189	135.857	92.178	59.672	1082.91	769.28	294	29.099	Indication of excessive mineral content.
Hardness	-	-	87.2	33.73	241.222	80.298	24.222	24.939	199.941	113.942	113	61.798	Blocks water systems, scale formation.
PH	6-9	6-9	7.602	0.389	8.356	0.314	6.619	1.697	7.339	1.136	7.963	0.307	Acid - corrosive to pipes, lower performance, lower egg production.
PHs	-	-	8.082	0.381	7.463	0.419	9.347	0.737	7.431	1.04	7.617	0.166	Stability pH
NAV	-	-	4.822	2.259	0.899	0.79	5.552	14.433	8.342	13.327	3.333	2.313	-
Electrical conductivity	1980	1782	109.171	49.666	55.333	17.081	16.222	11.065	165.529	111.168	50.667	3.215	Related to ions in water, no influence on poultry production.

Table 2.18. Water quality constituents (µg/l) of boreholes from selected poultry farms in the Western Cape, North West, Gauteng, Free State and Eastern Cape Provinces

Chapter 5 ariable	PHC	COC	Western Cape		North West		Gauteng		Free State		Eastern Cape		
Chapter 6	>	= / <	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Adverse effects of excess #
Antimony	6	5.4	0.420	0.707	0.018	0.029	0719	0.475	0.184	0.135	0.163	0.083	Emetic and a cardio-toxin.
Arsenic	50	45	1.332	2.181	0.006	0.018	4.077	2.174	9.881	2.627	11.410	1.478	Toxic substance.
Barium	2000	1800	69.371	67.776	77.113	67.297	125.262	86.410	76.616	29.233	94.360	34.917	Cardio-toxin.
Bismuth	500	450	0.066	0.033	0.028	0.056	0.268	0.202	0.082	0.031	0.083	0.024	Neuro-toxin.
Bromine	3000	2700	56.442	30.594	0	0	0	0	16917.47	11096.88	5068.800	335.510	Reduced growth rate.
Cadmium	5	4.5	1.371	2.604	0.021	0.061	1.390	0.947	0.797	0.415	0.655	0.066	Excess has severe health effects.
Caesium	50000	4500 0	4.517	8.849	0.008	0.022	0	0	0.077	0.096	0.051	0.011	Cyanosis and convulsions.
Chromium	100	90	35.690	4.108	46.428	3.688	45.841	14.180	54.134	17.902	55.188	5.496	Contributes to hardness. Essential nutrient; absence causes diabetes,low toxicity.
Cobalt	1000	900	4.043	6.706	0.020	0.059	7.601	12.332	165.565	229.312	43.968	72.635	Essential nutrient, toxic in excess.
Copper	1300	1170	25.609	35.602	4.319	8.646	39.078	39.034	18.366	12.278	14.026	8.905	Bitter, causes liver damage.
Iodine	1000	900	110.942	82.558	0	0	0	0	0	0	0	0	Thyroid-related effects.
Iron	6	5.4	3.731	7.858	5.077	9.827	0	0	2.327	3.295	0.865	0.234	Causes odour, bad taste & precipitate.
Lanthanum	1	0.9	0.946	0.393	0.786	0.465	5.901	3.757	2.072	0.804	7.049	7.359	Low to moderate acute toxicity rating.
Lead	20	18	40.288	36.900	0.018	0.029	0719	0.475	0.184	0.135	0.163	0.083	A toxic element
Manganese	4600	4140	649.986	661.358	0	0	11130.32	17685.53	110.306	133.633	196.903	271.532	Contributes to hardness and turbidity, deposits in pipes and bitterness of water.
Mercury	2	1.8	0.956	1.214	0	0	17.743	14.127	10.358	3.565	7.553	0.900	A toxic element with no beneficial physiological function.
Molybdenum	100	90	0.781	1.639	0	0	1.445	0.824	2.844	2.564	2.751	1.259	Reduced growth, highly toxic.
Nickel	1000	900	41.755	21.399	30.177	4.127	53.043	25.508	35.478	5.9518	38.592	4.654	Reduced growth.
Platinum	-	-	0.236	0.154	0.074	0.107	0.514	0.533	0.346	0.212	0.247	0.134	Allergenic.
Rubidium	5000	4500	7.895	7.435	0	0	0	0	0	0	0	0	Non-toxic.
Selenium	50	45	0.076	0.447	7.123	7.788	21.979	16.969	67.957	13.797	67.366	10.143	Reduced growth.
Strontium	10000	9000	289.913	274.323	269.467	145.397	44.965	29.035	2549.830	2165.420	693.763	281.415	May contribute to hardness of water.
Tin	200	180	0.565	0.677	0	0	1.633	1.149	0.821	0.368	0.778	0.128	Essential nutrient, low toxicity.

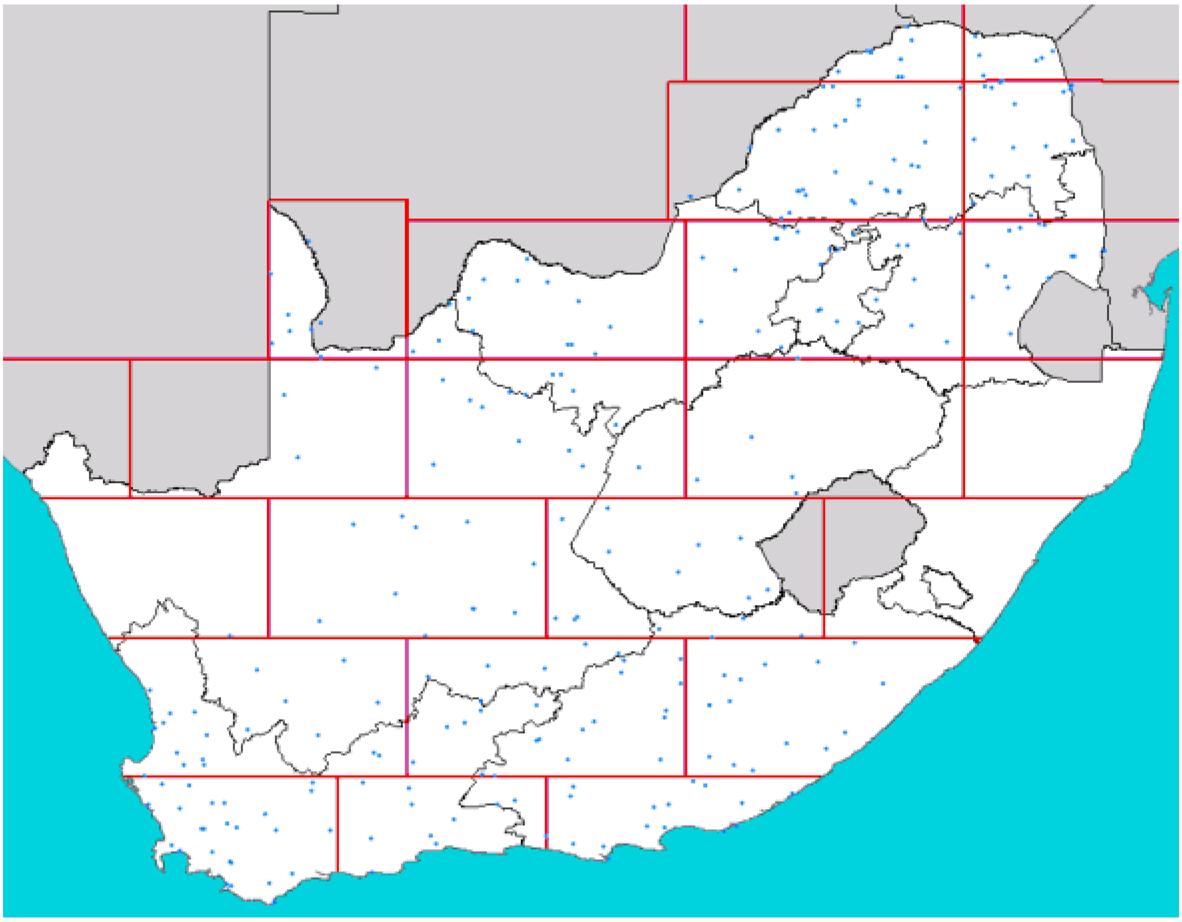
Titanium	100	90	173.348	108.758	377.359	216.745	69.197	47.077	884.182	854.179	211.850	81.1809	Soluble salts potentially toxic.
Tungsten	500	450	0.546	0.597	0.031	0.037	2.890	0.194	0.143	0.057	0.124	0.018	Only soluble salts potentially toxic.
Uranium	4000	3600	26.924	96.931	0.360	0.226	1.411	1.871	4.045	2.868	2.669	2.622	Low Toxicity.
Vanadium	100	90	0.454	1.293	14.894	11.747	32.724	20.996	4.810	3.847	5.125	2.283	Essential nutrient.
Zinc	1500	1350	256.827	388.63	319.309	418.698	344.254	686.62	171.056	240.236	407.905	397.067	Astringent taste, may contribute to hardness.
Zirconium	1	0.9	0.731	0.577	0	0	0	0	0.923	0.767	0.788	0.164	Low toxicity.

Kempster et al., (1981); Waggoner *et al.* (1994); Vohra (1980); Zimmerman (1995); Carter (1985); Phillips *et al*. (1935); Ralph (1989) and *Puls (1994)*

Department of Water Affairs and Forestry sampling results (1996 – 2001)

A project was launched by the Directorate of Geohydrology to ascertain the influence of rainfall on the groundwater quality and to determine the groundwater quality on a national scale. Currently 376 monitoring points are being sampled twice a year. Qualified personnel of the Department of Water Affairs and Forestry undertake the sampling itself. During the sampling procedure personell gather as much information on the monitoring point as possible and that is later stored in the National Groundwater Database. Map 1.7 show the area monitored.

Map 1.7. Monitoring points of the National Groundwater Quality Monitoring Project of South Africa.

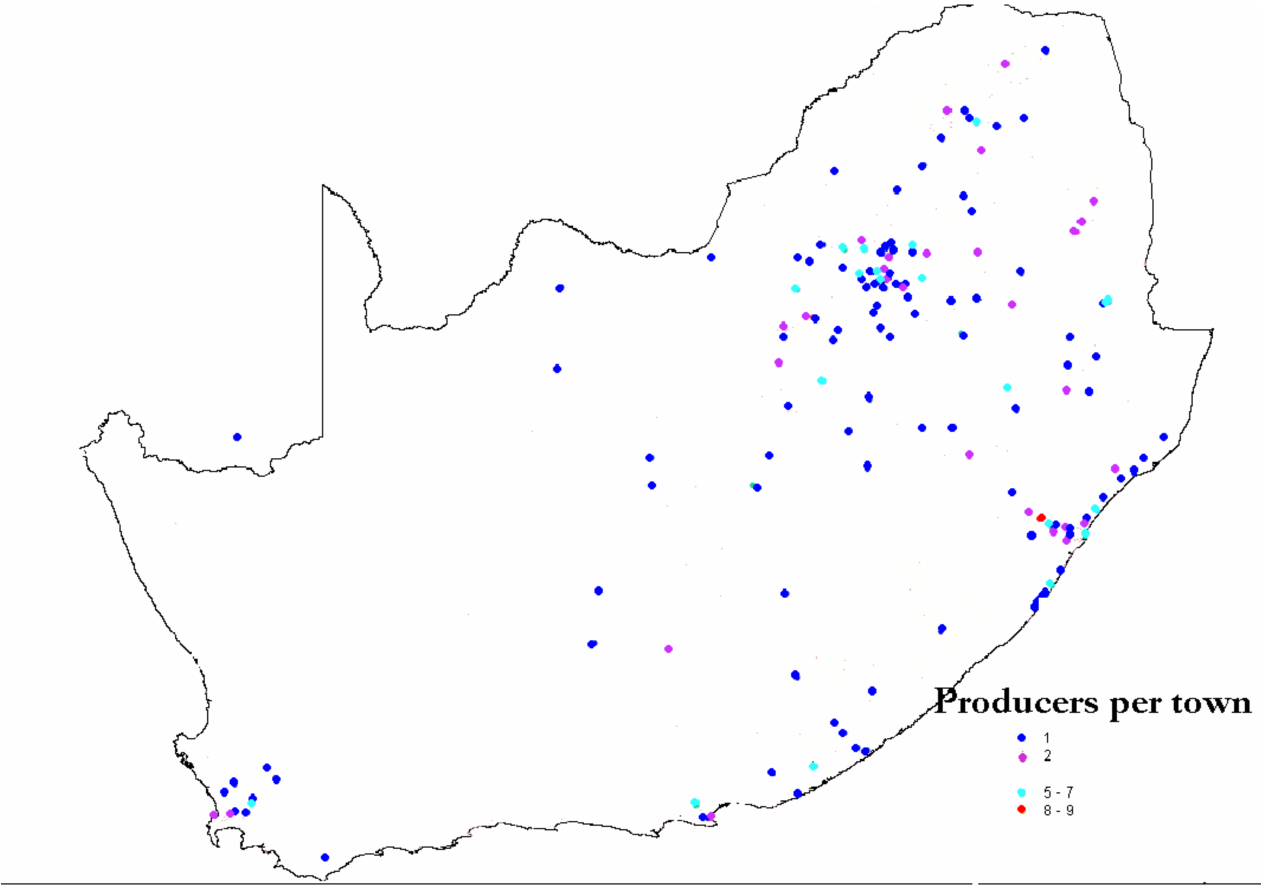


Data and maps of the distribution of groundwater sampling points where water constituent levels exceeded the recommended maximum over the last five years, were obtained from the Directorate: Geohydrology of the Department of Water Affairs and Forestry (DWAF). Following the results of analyses of borehole water at poultry production units across South Africa, it was decided to investigate the effect of magnesium, chlorides, sulphates, sodium, calcium, nitrates and fluoride more closely.

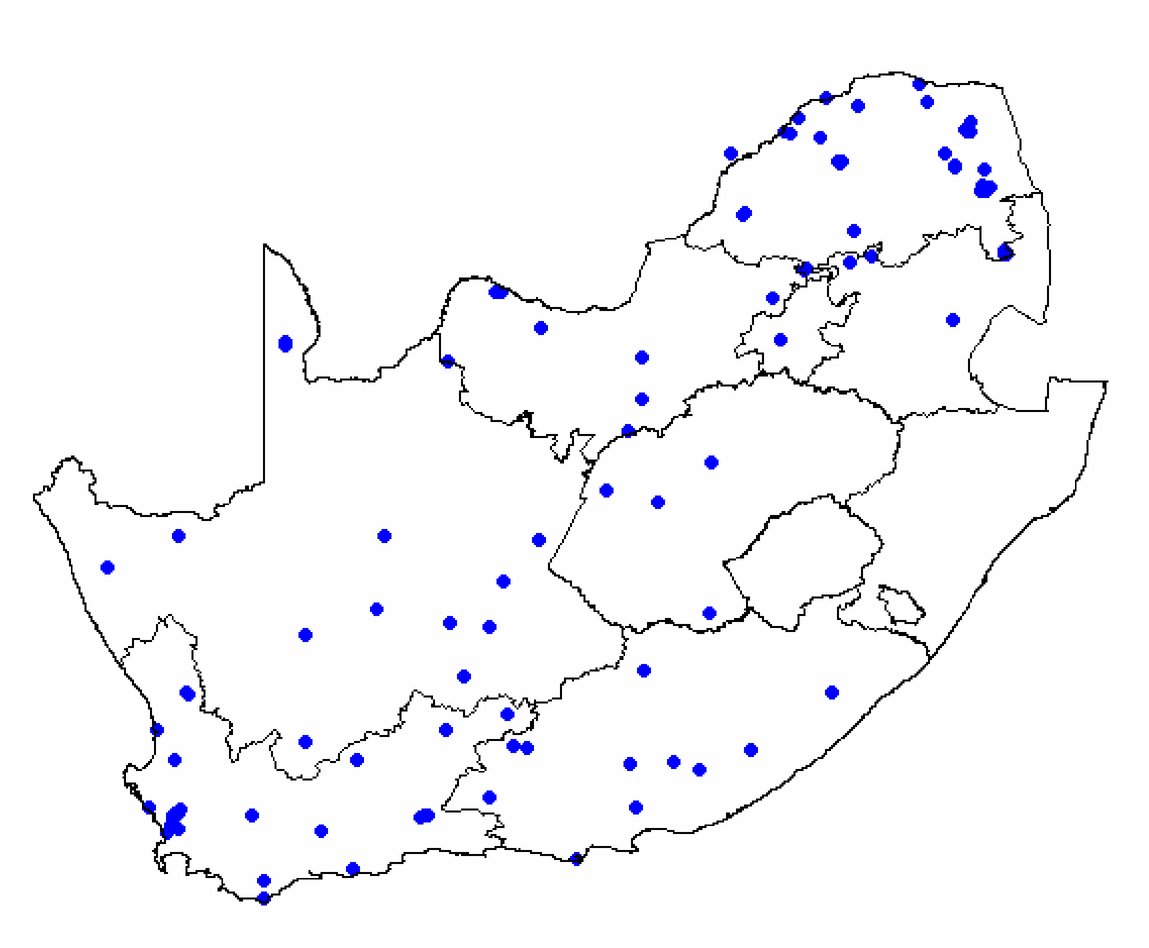
Super-imposing a map showing the distribution of poultry producers with a capacity of more than 20 000 birds (Map 1.8) onto the distribution of mineral sampling points where high levels of

minerals were measured over the last five years, shows that South African Poultry producers are forced to use water with elevated levels of the minerals mentioned above (Maps 1.9 - 1.15). The effect of this on poultry production will be addressed in Chapters 2 - 4.

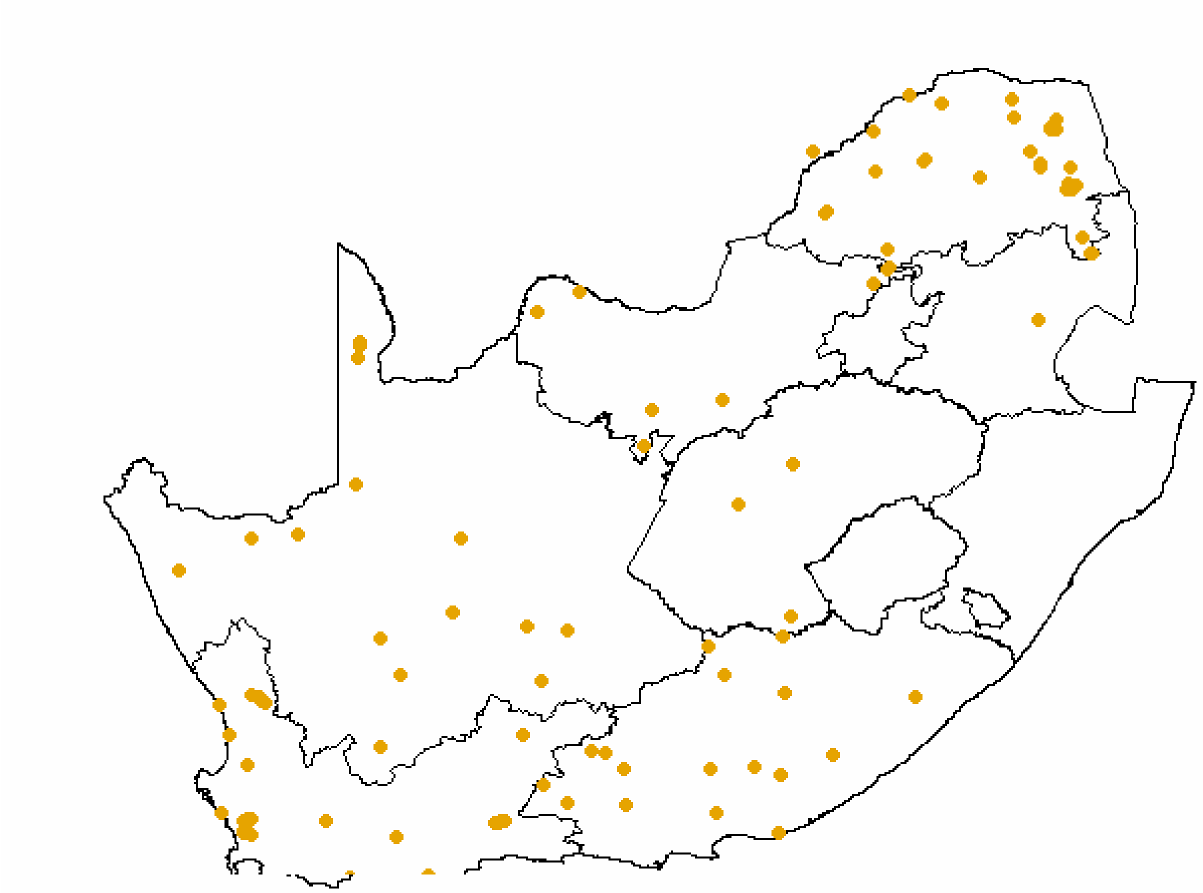
Map 1.8: Distribution of Poultry Producers (>20 000 birds) in South Africa (SA Poultry Association records 2001).



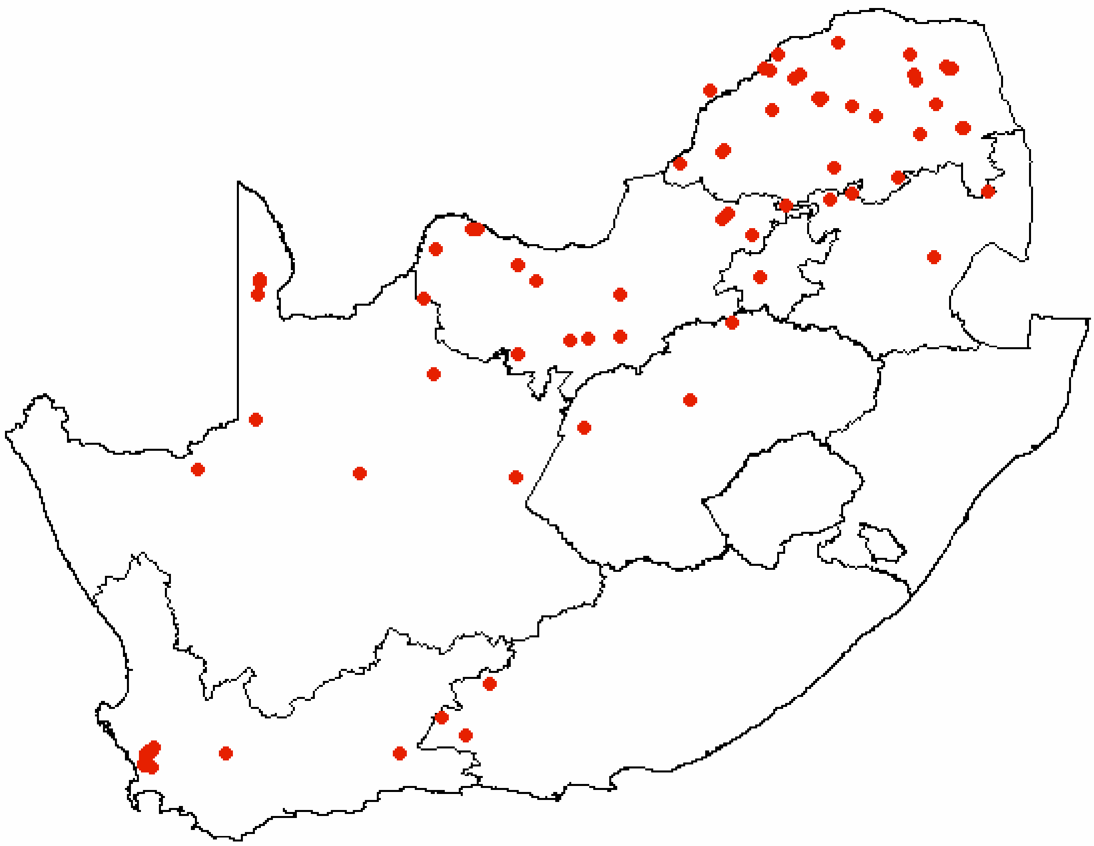
Map 1.9. The sample points where chloride was measured at levels higher than 250 mg/l.



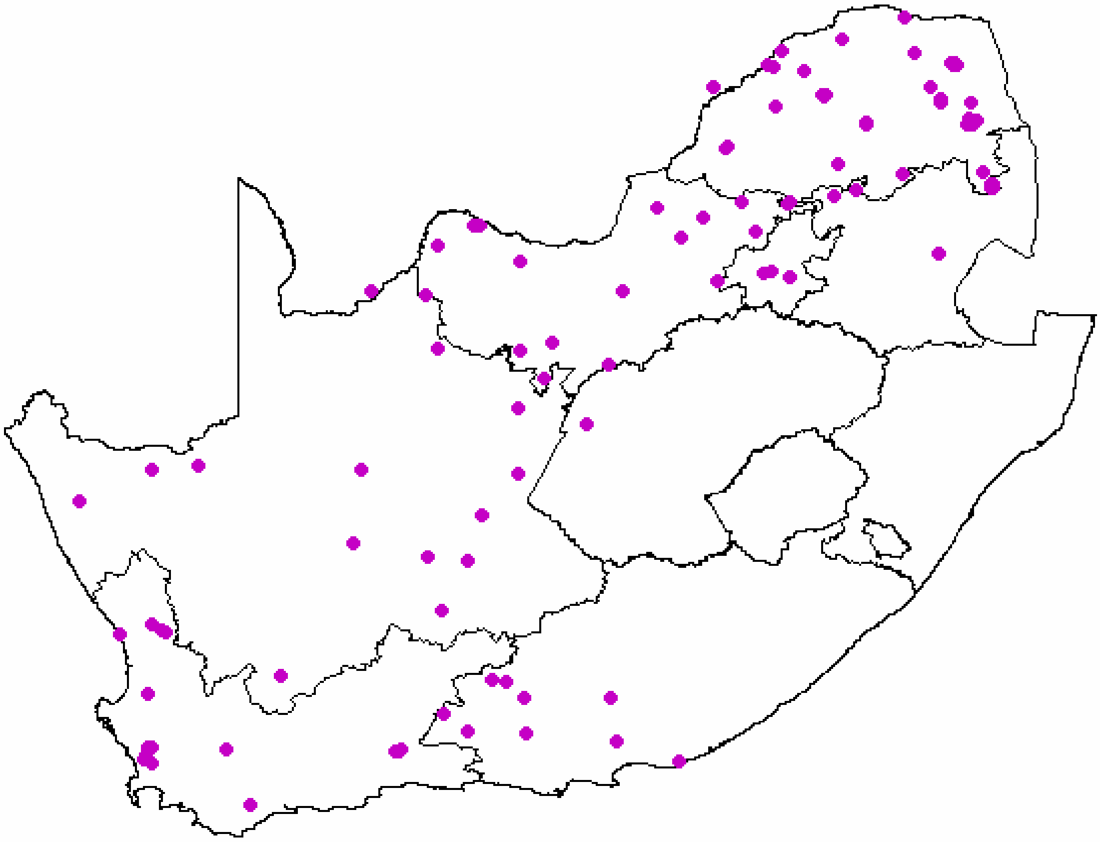
Map 1.10. **The sample points where sodium was measured at levels higher than 50 mg/l.**



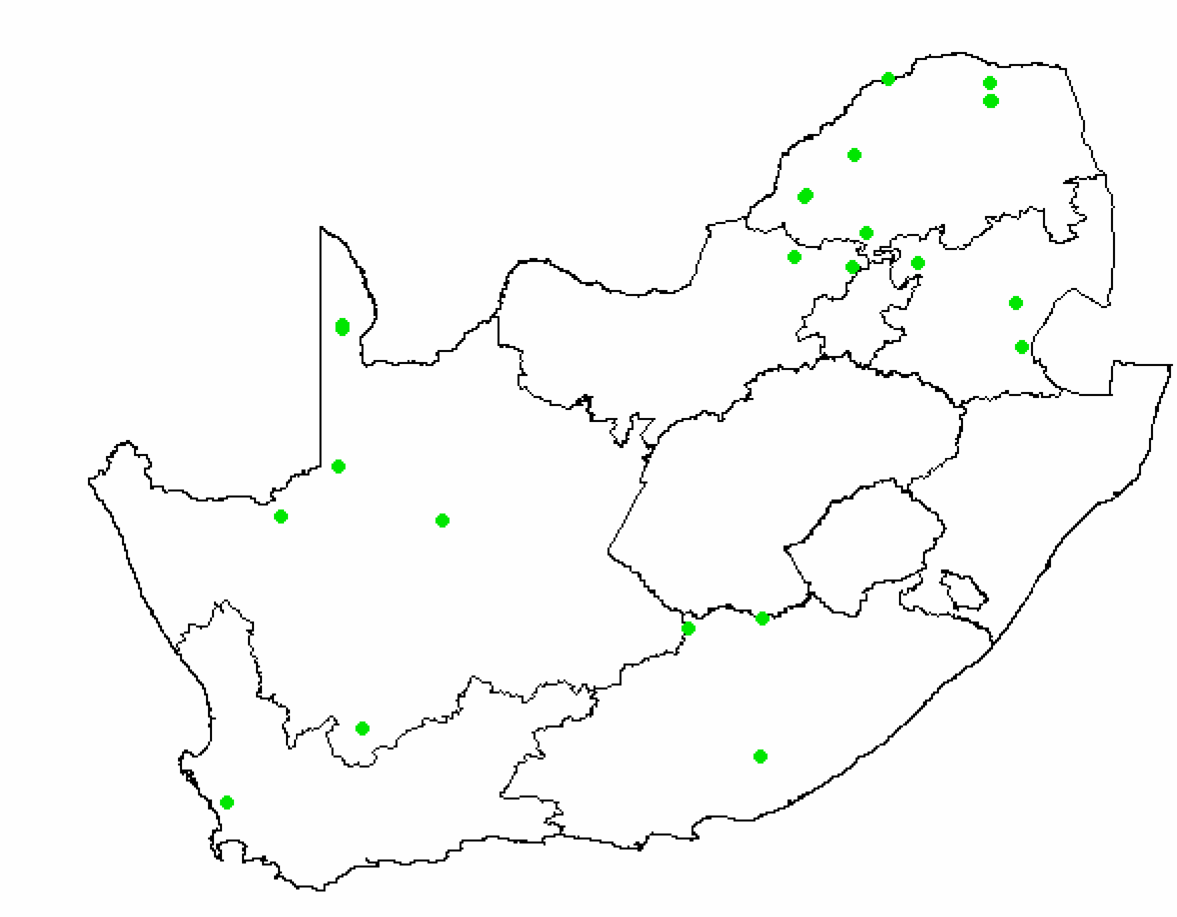
Map 1.11. The sample points where nitrates were measured at levels higher than 10 mg/l.



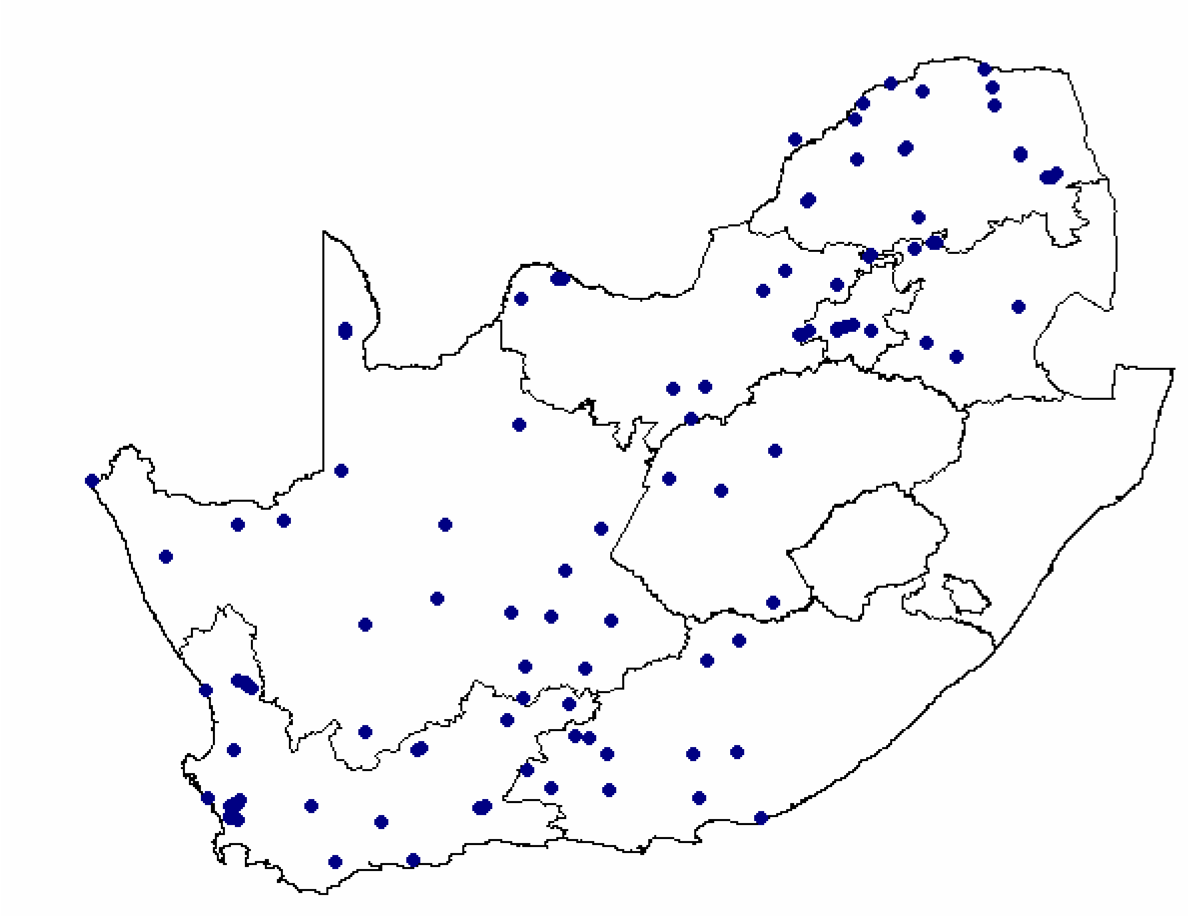
Map 1.12. The sample points where magnesium was measured at levels higher than 125 mg/l.



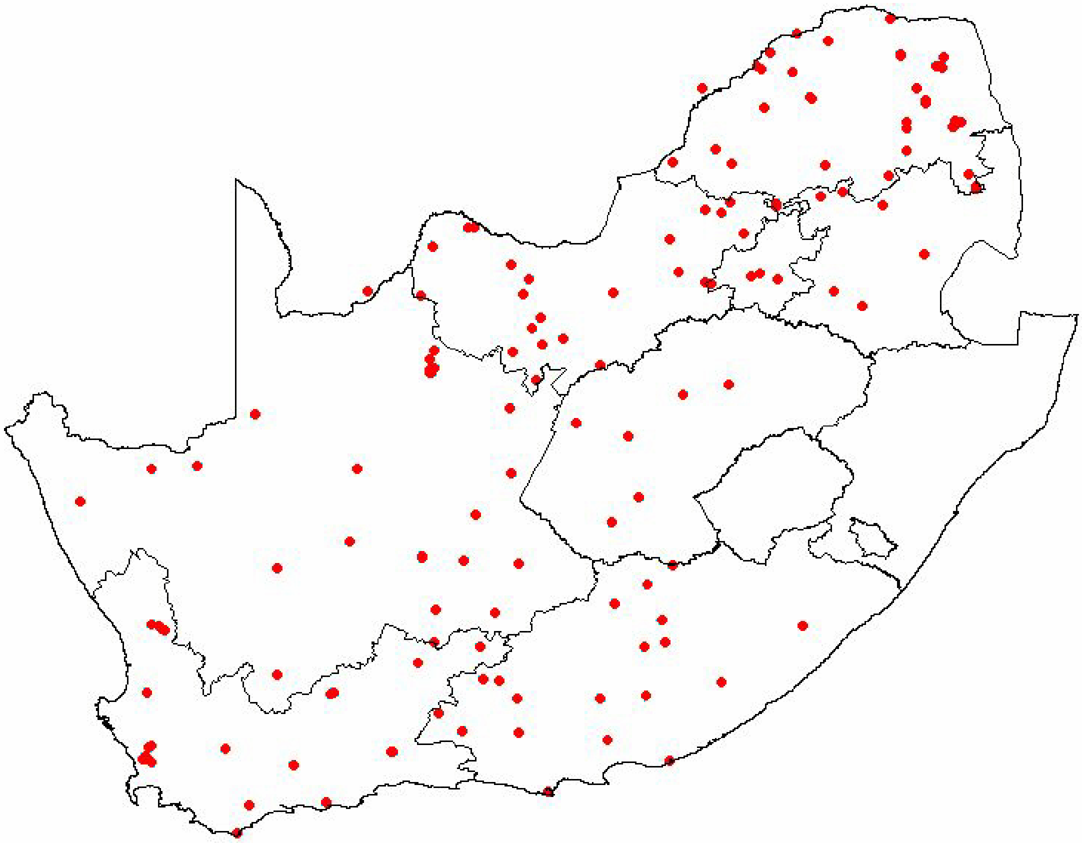
Map 1.13. The sample points where fluoride was measured at levels higher than 6 mg/l.



Map 1.14. The sample points where sulphates were measured at levels higher than 250 mg/l.



Map 1.15. The sample points where calcium was measured at levels higher than 600 mg/l.



Discussion.

The implications of the presence of elevated levels of potentially toxic water constituents, specifically including, fluoride, nitrates, chlorides, bicarbonates, phosphates, sodium, titanium, manganese, lanthanum, mercury and iron (Tables 1.16 and 1.17) on poultry production are that certain concentrations, combinations and/or ratios may have antagonistic or exacerbating effects resulting in sub-optimal production. Most effects are not all or none (Good, 1985). There may be serious detrimental effects on live weight, feed conversion and egg production and quality, often without any clinical symptoms. Water with inclusions higher than the prescribed maximum affects performance in a number of ways. High concentrations of bacteria or potentially toxic anions or cations in the water may affect normal physiological processes of the body, which can result in inferior performance. These concentrations may also reduce the absorption of nutritionally important substances, or reduce the efficacy of therapeutic treatments.

The presence of some constituents may lead to problems with watering systems, such as scaling, sedimentation, clogging and encrustation. This impacts on the cost of equipment replacement, and may lead to other problems including reduced water and feed intake and a requirement for more frequent litter replacement. Leg problems and breast blisters in broilers raised on the floor can result (Keshavarz, 1987). The management of laying hens, which are in cages, is made more difficult.

The results reported by Coetzee et al. (1997), Casey et al. (1998 d) and Meyer (1998), showed that the maximum allowed levels as stipulated by Kempster et al., (1981), Waggoner et al. (1994) and Vohra et al. (1980), for fluoride (2 mg/l), chlorides (600 mg/l), sodium (75 mg/l) and nitrates (10 mg/l) in the drinking water of poultry are too restrictive and classify many South African boreholes as useless for animal production. This amplifies the need for a site-specific ingestion-based approach to water quality guidelines for livestock. Since bicarbonate is currently used to alleviate stress in chickens (Balnave and Gorman, 1993), the maximum allowed level of 98 mg/l recommended by Kempster et al., (1981) seems too restrictive and new recommendations should be established for bicarbonate.

Conclusion

With the developing scarcity of good quality water resources, it is becoming increasingly important that the quality of ground water supplies are monitored and managed properly. This study was the first that focussed on poultry producers in a monitoring exercise and that brought to light that many poultry producers use water sources with mineral and metal inclusions that far exceed existing guidelines. The solution is either to investigate alternative uses for the water sources or to refine current water quality guidelines for optimum use of existing water sources. To readdress water quality guidelines a more in depth look at the effect of individual constituents on growth and production of poultry is needed. Chapters 2 - 4 of this thesis address the effect on poultry production of the most relevant hazardous contituents and Chapter 5 presents a model for alternative use of the water sources.

Chapter 2
Minerals in drinking water and layer production

Published in:

- *Casey, N.H., Meyer, J.A. & Coetzee C.B. (1998 d). An investigation into the quality of water for 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*

Introduction:

Underground water supplies, often containing high concentrations of dissolved salts, are a common source of drinking water for poultry in many countries. Recent evidence suggests that some minerals in drinking water, at concentrations similar to those found in natural sources, may exert adverse effects on the performance of growing broilers and laying hens (Balnave, D. 1998).

Sodium. Excessive levels of sodium (Na) have a diuretic effect. The normal level in water is about 32 mg/l. Studies indicate that a sodium level of 50mg/l is detrimental to broiler performance if the sulphate level is also 50mg/l or higher and the chloride level is 14 mg/l or higher (Carter and Sneed 1996) (Vohra, 1980).

Chloride. Consuming too much chloride (Cl) has a detrimental effect on metabolism. A chloride level of 14mg/l is considered normal for well water. Studies have shown that a level of 14mg/l in drinking water can be detrimental to broilers if combined with 50mg/l of sodium. Chloride levels as high as 25mg/l are not a problem if the sodium level is in the normal range (Carter and Sneed 1996) (Schwartz et al. 1984).

Sulphate. High sulphate (SO_4) levels have a laxative effect and can interfere with the intestinal absorption of minerals such as copper (Blake, J.P. 2001). Levels about 125 mg/l are regarded as normal for well water, but levels as low as 50mg/l can have a negative effect on performance if either the sodium or magnesium level is 50mg/l or more (Carter and Sneed 1996).

Magnesium. A symptom of a high magnesium (Mg) level is loose droppings. The normal level of magnesium in well water is about 14mg/l. This chemical may interact with sulphate. Studies indicate that magnesium alone at 68mg/l does not adversely affect broiler performance, but a level of 50 mg/l can be detrimental if the sulphate level is also 50mg/l or greater (Carter and Sneed 1996).

The main reported effect of waters high in these four minerals is depression of appetite, usually caused by a water imbalance rather than any specific ion. The most common exception is water containing a high level of magnesium, which is known to cause scouring and diarrhoea (FOA report on Water Quality for Agriculture). According to Keshavarz (1987) the permissible levels of Mg, SO_4, Na and Cl for poultry production are Mg 10 mg/l, SO_4 50 mg/l, Na 50 mg/l, Cl 20 mg/l. If these levels are exceeded, the water is considered potentially hazardous. "Potentially hazardous" in terms of water quality risk assessment is not a clearly definable term and refers to a range of conditions from acute toxicity to sub-clinical, manifesting as reduced production.

Both Krista et al. (1961) and Conner et al. (1969) observed differences in the tolerance of individual chickens to sodium chloride in the drinking water. The latter workers noted a similar variation in tolerance to sodium sulphate, but not to calcium and magnesium chlorides. The results presented in Chapter 1 on Mg, Na, SO_4 and Cl were found present in excess of those reported to have adverse effects by Carter and Sneed (1996).

Because of the interactions between these four constituents, they were tested simultaneously in a trial aimed at establishing whether Mg at inclusions of 250 mg/l and lower, Na at inclusions of 250 mg/l and lower, SO_4 at inclusions of 250 mg/l and lower and Cl at inclusions of 500 mg/l and lower in the drinking water of layers had a detrimental effect on production.

Materials and methods

720 Amber Link point of lay hens (20 weeks old), reared and vaccinated by a reputable organization to standard practices of the poultry industry were used as experimental animals. Water was administered to each repetition (20 birds) from a nipple drinker system connected to a calibrated 15 l Perspex cylinder via 5 nipples on a 3 m long pipe. Each nipple had the capacity to supply water to 12 layers. This nipple gives adequate amounts of water, yet maintains very dry litter and is maintenance free. The cylinders had removable lids for easy access and treatment administration and an outlet at the bottom to simplify cleaning and refilling (Figure 2.1).

Figure 2.1: Water treatment system with calibrated cylinders.

Hens were kept in a mechanically ventilated broiler house on a floor system with sawdust as bedding material. The house was divided into 36 pens of 2x3 m. Each pen housed 20 hens and was fitted with five wire nest boxes with wooden lids and hay as nesting material, placed on the floor of the broiler house. The temperature was measured every day in 5 evenly distributed spots throughout the house with twin bulb minimum/maximum thermometers. The thermometers were suspended about 1.5 m above floor level at the entrance, in the middle and at the end of the house. Ventilation shafts were opened and electric fans functioned for the duration of the trial to curb ammonia poisoning. The lighting programme during lay was according to supplier specification. A commercial laying diet with a vitamin and mineral premix was fed throughout the laying period.

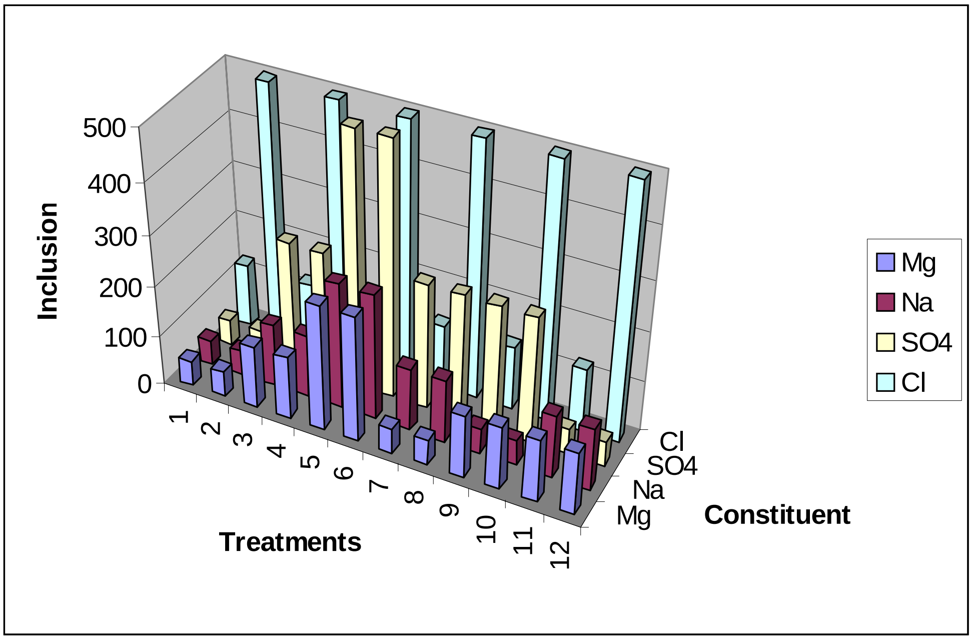
Two round pan feeders were suspended from the roof of each cage. The brim of the feeder was kept at the same height as the backs of the birds. Mg, Na, Cl and SO_4 were administered to the hens via the drinking water at the inclusion levels shown in Table 2.1. No negative control was included in the trial design. The anions and cations were added regardless of the contributions by the feed and water. These levels were selected to include the maximum acceptable level (American Water Quality

Guidelines for Poultry - Schwartz et al. 1984), a level considered average and a level more or less twice the acceptable maximum level of these four constituents. These levels were, however, still representative of the Na, Cl, SO_4 and Mg levels present in the water used by some of South Africa's poultry producers. The trial design was twelve combinations of these constituents with three repetitions and 20 birds per replicate (12 x 3 x 20). Water from the Pretoria Municipal Source was used. $MgSO_4$, $NaSO_4$, NaCl and $CaCl_2$ were used to supplement the Mg, Na, Cl and SO_4.

Table 2.1 Inclusion levels of constituents.

Constituent (mg/l)	Trt 1	Trt 2	Trt 3	Trt 4	Trt 5	Trt 6	Trt 7	Trt 8	Trt 9	Trt 10	Trt 11	Trt 12
Mg	50	50	125	125	250	250	50	50	125	125	125	125
Na	50	50	125	125	250	250	125	125	50	50	125	125
SO_4	50	50	250	250	500	500	250	250	250	250	50	50
Cl	125	500	125	500	125	500	125	500	125	500	125	500

Figure 2.2. Inclusion levels of constituents (mg/l)



Water intake, feed intake, body weight, egg production and egg weights were measured weekly over a 20 week period. A representative sample of eggs of each repetition was analyzed for eggshell thickness. The SO_4, Na, Cl and Mg contents of the eggs on a dry basis were determined. Mortalities with accompanying post mortem reports were recorded. According to Dzienkónski & Kulczycki (1975) the NaCl content of liver muscle and intestines has no diagnostic value. Therefore no analysis was done on soft tissue. Temperature was measured daily.

Statistical analysis

An analysis of variance with the GLM model (Statistical Analysis System, 1994) was used to determine the significance of differences between treatments of body weights, feed intakes, water intakes and egg production. The level of significance ($P < 0.05$) of the differences between the data observed was calculated by means of Fisher's Exact test (Samuel, 1989).

The following model was fitted to estimate covariance components for the respective ion contents of the eggs:

$Y_i = \mu + T_i + b_iB + e_i$

Y = Dependent variable, levels of Mg, SO_4, Na and Cl in the eggs:

μ = Population mean

T_I = Treatment

b_iB = Covariant, SO_4 in the case of Mg

Na in the case of SO_4

Cl in the case of Na

Ca in the case of Cl

e_I = Random effects

The following covariant components were included in the model to correct for variations in the different Mg, SO_4, Na and Cl levels in the eggs, since $MgSO_4$, $NaSO_4$, NaCl and $CaCl_2$ were used to supplement the Mg, Na, Cl and SO_4 in the feed and municipal water.

SO_4, in the case of Mg,

Na, in the case of SO_4,

Chloride, in the case of Na,

Ca, in the case of Cl.

Results and discussion

Contradicting results reported by Ross et al. (1972), which showed that a growth response was obtained from feeding SO_4 to chickens, this study shows that twelve different combinations of Mg, Na, SO_4 and Cl in the drinking water of layers over 20 weeks had no significant effect on food intake, water intake, body weight and egg production.

Balnave and Scott (1986) reported that adding a range of mineral salts to the drinking water of laying hens induced significant increases in egg shell defects. In this trial, however, egg weight and egg shell thickness were not significantly affected by adding 12 different combinations of Mg, Na, SO_4 and Cl to the drinking water of layers (Tables 2.2 – 2.11).

Mortalities were not linked to the addition of Mg, Na, SO_4 or Cl to the drinking water

The Na and Mg contents of the eggs did not differ significantly between treatments, but the Cl and SO_4 contents did show significant differences (Table 2.12), which support the work done by Machlin et al. (1953). The Cl level in treatment three (Mg - 125; Na – 125; Cl – 125 and SO_4 – 250 mg/l) was 6735.69 mg/kg and in treatment eleven (Mg - 125; Na – 125; Cl – 125 and SO_4 – 50 mg/l) it was 8234.43 mg/kg. The differences between treatments seven and ten is proportionate to the 125 mg/l and 500 mg/l Cl added to the drinking water. The SO_4 contents of the eggs of treatments three (337.77 mg/kg) differed significantly from the levels present in treatments six (118.84 mg/kg) and treatment nine (126.02 mg/kg). The differences between treatments three and six are in agreement with the amounts of SO_4 added to the water, 250 and 500 mg/l respectively, but the significance of the differences between treatments three and nine are not clear since they both received 250 mg/l SO_4 added to the water.

No significant interactions occurred between minerals administered. The treatments given to the hens in the water had no significant influence on egg production (P = 0.7449) (Table 2.2, 2.3 and 2.4). There were no interactions between the treatments given and the week of production (P = 0.1839).

Table 2.2 Mean egg production criteria of hens receiving different levels of Mg, SO_4, Na and Cl in the drinking water.

Trt	Egg production eggs/hen/week (SD±0.1027) (P = 0.7449)	Egg production % (SD±1.4666) (P = 0.7449)	Egg weight g/egg (SD±0.6798) (P = 0.2959)	Egg shell thickness (mm) (P = 0.4291)
1	5.639[a]	80.558[a]	53.856[a]	0.333[a] (SD±0.0115) SD±0.0115
2	5.681[a]	81.156[a]	52.501[a]	0.330[a] (SD±0.0100) SD±0.0100
3	5.521[a]	78.870[a]	52.758[a]	0.337[a] (SD±0.0058) SD±0.0058
4	5.655[a]	80.784[a]	52.417[a]	0.343[a] (SD±0.0153) SD±0.0153
5	5.778[a]	82.544[a]	53.418[a]	0.333[a] (SD±0.0058) SD±0.0058
6	5.784[a]	82.639[a]	52.473[a]	0.336[a] (SD±0.0058) SD±0.0058

7	5.787[a]	82.672[a]	52.970[a]	0.340[a] (SD±0.0000) SD±0.0000
8	5.655[a]	80.789[a]	53.068[a]	0.340[a] (SD±0.0100) SD±0.0100
9	5.669[a]	80.990[a]	54.564[a]	0.350[a] (SD±0.0000) SD±0.0000
10	5.761[a]	82.295[a]	54.297[a]	0.337[a] (SD±0.0153) SD±0.0153
11	5.603[a]	80.042[a]	53.503[a]	0.347[a] (SD±0.0058) SD±0.0058
12	5.604[a]	80.064[a]	52.195[a]	0.330[a] (SD±0.0200) (SD±0.0200) SD±0.0200

- Means with different superscripts, differed significantly at a $P < 0.05$ significance level.

The egg weights (Table 2.2 and 2.5) were not significantly influenced by the treatments given ($P = 0.2959$). The eggs increased in weight as the hens got older. No interactions occurred between the treatments given and the production week of the hens ($P = 0.0843$).

Table 2.3. Weekly egg production of hens (eggs/hen/week) receiving 12 different combinations of Na, Cl, Mg and SO_4.

Weeks	Treatments											
	1	2	3	4	5	6	7	8	9	10	11	12
21	0.033	0.000	0.050	0.050	0.100	0.017	0.000	0.000	0.100	0.133	0.033	0.017
22	0.950	1.000	0.800	1.217	1.267	1.017	0.967	0.867	1.200	1.400	0.733	1.067
23	4.383	4.400	3.150	3.667	3.683	3.683	3.600	3.650	4.333	3.967	3.200	3.817
24	6.117	5.583	6.117	5.800	6.067	6.333	6.517	6.067	6.050	6.167	6.050	6.100
25	6.533	6.500	6.767	6.667	6.550	6.733	6.717	6.467	6.433	6.417	6.467	6.500
26	6.217	6.450	6.450	6.550	6.600	6.817	6.617	6.600	6.417	6.583	6.517	6.483
27	6.550	6.683	6.300	6.650	6.533	6.750	6.704	6.267	6.467	6.117	6.233	6.418
28	6.850	6.766	7.050	6.917	7.133	7.117	6.967	7.000	6.667	7.017	7.000	6.817
29	6.183	6.333	6.367	6.400	6.433	6.467	6.433	6.383	6.417	6.483	6.350	6.300
30	6.577	6.626	6.563	6.600	6.917	6.867	6.750	6.683	6.661	6.675	6.589	6.467
31	6.736	6.311	6.363	6.217	6.783	6.784	6.683	6.517	6.531	6.473	6.404	6.633
32	6.560	6.765	6.275	6.583	6.833	6.746	6.767	6.717	6.574	6.742	6.587	6.450
33	6.357	6.241	5.971	6.383	6.500	6.394	6.417	6.433	6.216	6.574	5.961	6.317

Table 2.3. Weekly egg production of hens (eggs/hen/week) receiving 12 different combinations of Na, Cl, Mg and SO_4 (continued).

Weeks	Treatments											
	1	2	3	4	5	6	7	8	9	10	11	12
34	5.800	6.183	5.869	6.233	6.333	6.099	6.223	6.100	6.137	6.458	5.979	6.032
35	6.067	6.346	5.943	6.200	6.283	6.186	6.427	6.017	6.340	6.477	6.281	6.221
36	6.019	6.074	5.911	6.050	6.117	6.070	6.321	6.350	6.052	6.592	6.255	5.850
37	6.136	6.389	6.402	6.392	6.450	6.381	6.579	6.217	6.190	6.628	6.436	6.081

Table 2.4. Weekly egg production (%) of hens receiving 12 different combinations of Na, Cl, Mg and SO_4.

Weeks	Treatments											
	1	2	3	4	5	6	7	8	9	10	11	12
21	0.476	0.000	0.714	0.714	1.429	0.238	0.000	0.000	1.429	1.905	0.476	0.238
22	13.571	14.286	11.429	17.381	18.095	14.524	13.810	12.381	17.143	20.000	10.476	15.238
23	62.619	62.857	45.000	52.381	52.619	52.619	51.429	52.143	61.905	56.667	45.714	54.524
24	87.380	79.762	87.381	82.857	86.667	90.476	93.095	86.667	86.429	88.095	86.429	87.143
25	93.333	92.857	96.667	95.238	93.571	96.190	95.952	92.381	91.905	91.667	92.381	92.857
26	88.810	92.143	92.143	93.571	94.286	97.381	94.524	94.286	91.667	94.048	93.095	92.619

Table 2.4. Weekly egg production (%) of hens receiving 12 different combinations of Na, Cl, Mg and SO_4 (continued).

Weeks	Treatment											
	1	2	3	4	5	6	7	8	9	10	11	12
27	93.571	95.476	90.000	95.000	93.333	96.429	95.777	89.524	92.381	87.381	89.048	91.679
28	97.857	96.667	100.714	98.810	101.905	101.667	99.524	100.000	95.238	100.238	100.000	97.381
29	88.333	90.476	90.952	91.429	91.905	92.381	91.905	91.190	91.667	92.619	90.714	90.000
30	92.719	94.709	87.619	89.524	92.143	95.238	90.714	90.952	90.238	88.095	93.271	91.190
31	93.960	94.656	93.759	94.286	98.810	98.095	96.429	95.476	95.150	95.363	94.135	92.381
32	96.228	90.159	90.902	88.810	96.905	96.917	95.476	93.095	93.296	92.469	91.491	94.762
33	93.709	96.640	89.637	94.048	97.619	96.378	96.667	95.952	93.910	96.316	94.098	92.143
34	90.815	89.153	85.301	91.190	92.857	91.341	91.667	91.905	88.797	93.910	85.163	90.238
35	82.857	88.333	83.847	89.048	90.476	87.130	88.897	87.143	87.669	92.256	85.414	86.178
36	86.667	90.661	84.900	88.571	89.762	88.371	91.817	85.952	90.576	92.531	89.724	88.872
37	85.990	86.772	84.436	86.429	87.381	86.717	90.301	90.714	86.453	94.173	89.361	83.571
38	87.657	91.270	91.462	91.328	92.143	91.153	93.985	88.810	88.434	94.6887	91.942	86.867

Table 2.5. Weekly egg weight (g) of eggs of hens receiving 12 different combinations of Na, Cl, Mg and SO_4.

Weeks	Treatments											
	1	2	3	4	5	6	7	8	9	10	11	12
21	17.167	0.000	13.067	13.800	13.128	10.433	0.000	0.000	27.822	40.706	12.100	11.967
22	42.672	40.778	42.127	41.115	40.060	42.132	41.820	43.129	42.696	42.070	42.770	40.751
23	45.534	44.717	44.890	43.753	44.866	44.701	45.945	45.280	45.964	44.570	50.844	44.648
24	54.906	53.402	49.837	49.749	51.143	50.821	51.763	51.227	51.039	50.574	50.530	49.787
25	53.614	52.352	51.669	51.717	52.147	52.179	53.592	52.911	53.080	52.100	52.750	51.434
26	53.707	53.820	53.079	53.079	53.634	53.090	54.501	54.568	54.004	52.887	53.880	52.423
27	54.496	54.841	53.868	53.535	54.509	53.897	55.441	55.517	55.136	5.649	54.324	53.531
28	55.446	55.176	54.771	54.587	55.836	54.967	55.852	56.041	56.222	54.931	55.287	54.246
29	57.190	56.177	55.376	55.353	56.652	55.916	56.988	56.907	56.766	55.666	56.212	55.180
30	56.694	56.178	55.752	55.363	56.505	55.712	56.995	56.461	56.417	55.774	56.167	55.016
31	57.720	55.400	57.527	56.035	57.774	56.182	57.195	57.635	57.999	56.786	57.537	56.107
32	58.919	58.458	56.325	55.624	59.149	57.093	57.628	58.954	58.883	57.499	58.203	56.900
33	59.013	58.979	59.089	59.723	59.594	58.458	59.564	59.549	59.906	58.727	59.269	57.721

Table 2.5. Weekly egg weight (g) of eggs of hens receiving 12 different combinations of Na, Cl, Mg and SO_4 (continued).

Weeks	Treatment											
	1	2	3	4	5	6	7	8	9	10	11	12
34	59.922	59.535	59.471	58.771	60.269	58.638	59.886	60.259	59.987	59.301	59.381	59.140
35	59.949	59.937	59.507	59.307	60.595	59.004	60.642	60.299	60.416	59.648	61.447	58.978
36	58.674	60.136	59.937	59.508	60.417	59.217	60.396	60.424	60.824	59.700	59.846	59.348
37	59.700	59.876	59.175	59.188	60.343	58.715	60.328	60.551	60.604	59.762	59.440	58.755
38	59.356	59.396	59.066	58.284	59.526	58.257	59.538	59.684	60.049	59.061	57.984	58.199
39	58.591	58.386	57.868	57.412	58.800	57.607	58.354	58.906	59.031	58.420	58.588	57.574

Food intake over the whole experimental period was not significantly influenced by the addition of Mg, SO_4, Na and Cl to the drinking water (Table 2.6).

Table 2.6. LS Means for food intake (kg) of hens receiving different levels of Mg, SO_4, Na and Cl in the drinking water.

Treatment	Food intake (kg)/hen/day (SD±0.0073) (P = 0.9809)
1	0.149[a]
2	0.154[a]
3	0.145[a]
4	0.151[a]
5	0.144[a]
6	0.141[a]
7	0.146[a]
8	0.145[a]
9	0.142[a]
10	0.144[a]
11	0.149[a]
12	0.145[a]

- Means with different superscripts, differed significantly at a $P < 0.05$ significance level.

The weekly food intake (Table 2.7) was not significantly influenced ($P = 0.9809$) by the addition of Mg, SO_4, Na and Cl to the drinking water. As the hens aged, food intake and egg production increased over the weeks. There was no significant interaction between the treatments given to the hens and the week in which the treatment was given ($P = 0.3783$).

Table 2.7. Weekly food intake (kg) of hens receiving 12 different combinations of Na, Cl, Mg and SO_4.

Weeks	Treatments											
	1	2	3	4	5	6	7	8	9	10	11	12
21	0.099	0.106	0.094	0.110	0.097	0.088	0.093	0.090	0.104	0.090	0.082	0.093
22	0.140	0.145	0.136	0.137	0.135	0.128	0.134	0.138	0.135	0.130	0.131	0.128
23	0.149	0.152	0.140	0.141	0.144	0.123	0.137	0.129	0.134	0.128	0.137	0.134
24	0.150	0.146	0.139	0.135	0.138	0.128	0.139	0.135	0.135	0.128	0.137	0.130
25	0.150	0.142	0.142	0.136	0.138	0.130	0.142	0.135	0.134	0.133	0.146	0.134
26	0.144	0.146	0.142	0.136	0.133	0.134	0.140	0.138	0.135	0.135	0.149	0.128
27	0.136	0.134	0.135	0.131	0.127	0.127	0.137	0.131	0.126	0.125	0.154	0.129
28	0.144	0.143	0.133	0.134	0.131	0.132	0.133	0.132	0.132	0.130	0.141	0.134
29	0.142	0.140	0.135	0.121	0.129	0.134	0.134	0.131	0.129	0.130	0.144	0.130

Table 2.7. Weekly food intake (kg) of hens receiving 12 different combinations of Na, Cl, Mg and SO_4 (continued).

Weeks	Treatment											
	1	2	3	4	5	6	7	8	9	10	11	12
30	0.141	0.146	0.139	0.175	0.135	0.133	0.135	0.138	0.130	0.136	0.150	0.140
31	0.156	0.160	0.158	0.160	0.161	0.153	0.152	0.159	0.152	0.158	0.157	0.162
32	0.163	0.173	0.164	0.165	0.158	0.156	0.158	0.166	0.151	0.158	0.158	0.158
33	0.167	0.174	0.162	0.167	0.163	0.167	0.162	0.165	0.160	0.175	0.169	0.168
34	0.164	0.177	0.157	0.167	0.158	0.159	0.163	0.154	0.156	0.168	0.151	0.164
35	0.164	0.181	0.157	0.172	0.159	0.161	0.165	0.163	0.164	0.170	0.167	0.172
36	0.172	0.187	0.180	0.181	0.174	0.172	0.180	0.180	0.177	0.185	0.175	0.175
37	0.155	0.167	0.150	0.169	0.146	0.152	0.154	0.157	0.148	0.155	0.160	0.165
38	0.157	0.168	0.149	0.176	0.161	0.149	0.160	0.166	0.153	0.156	0.157	0.159
39	0.153	0.160	0.154	0.174	0.156	0.156	0.157	0.165	0.157	0.156	0.160	0.158

The addition of Mg, SO_4, Na and Cl, to the drinking water showed no significant effect on body weights of the hens over the trial period (Table, 2.8).

Table 2.8. LS Means for body weight (kg/hen) of hens receiving different levels of Mg, SO_4, Na and Cl in the drinking water.

Treatment	**Body weight (kg/hen) (SD±0.02090) (P = 0.4542)**
1	1.846
2	1.859
3	1.833
4	1.839
5	1.849
6	1.808
7	1.818
8	1.820
9	1.859
10	1.858
11	1.806
12	1.805

The weekly body weights (Table 2.9) were not significantly influenced (P = 0.4542) by the addition of Mg, SO_4, Na and Cl to the drinking water. Body weight increased over weeks as the hens aged. There was no significant interaction between the treatments given to the hens and the week in which the treatment was given (P = 0.2116).

Table 2.9. Weekly body weight (kg/hen) of hens receiving 12 different combinations of Na, Cl, Mg and SO_4 (SD±0.024)

Weeks	Treatments											
	1	2	3	4	5	6	7	8	9	10	11	12
20	1.498	1.521	1.484	1.524	1.520	1.497	1.516	1.508	1.545	1.516	1.447	1.493
21	1.618	1.639	1.589	1.642	1.648	1.596	1.606	1.599	1.651	1.630	1.545	1.579
22	1.754	1.744	1.700	1.728	1.748	1.699	1.715	1.727	1.761	1.733	1.677	1.697
23	1.769	1.753	1.768	1.767	1.808	1.740	1.769	1.762	1.797	1.772	1.734	1.696
24	1.805	1.784	1.784	1.799	1.819	1.761	1.786	1.742	1.795	1.801	1.753	1.755
25	1.823	1.812	1.791	1.821	1.845	1.778	1.812	1.810	1.837	1.843	1.779	1.786
26	1.829	1.847	1.829	1.835	1.868	1.798	1.818	1.824	1.851	1.818	1.794	1.787
27	1.834	1.848	1.829	1.835	1.845	1.780	1.845	1.810	1.848	1.818	1.775	1.813
28	1.858	1.881	1.849	1.861	1.876	1.827	1.814	1.854	1.903	1.862	1.828	1.791
29	1.858	1.880	1.842	1.855	1.873	1.826	1.845	1.843	1.871	1.839	1.835	1.807
30	1.911	1.964	1.877	1.896	1.906	1.887	1.900	1.910	1.914	1.866	1.910	1.868
31	1.938	1.901	1.849	1.870	1.892	1.835	1.859	1.860	1.918	1.899	1.851	1.854
32	1.923	1.945	1.939	1.918	1.941	1.884	1.906	1.905	1.949	1.982	1.890	1.891
33	1.865	1.884	1.906	1.900	1.939	1.925	1.812	1.735	1.839	1.843	1.842	1.783
34	1.928	1.964	1.938	1.926	1.915	1.927	1.923	1.942	1.951	1.974	1.945	1.911

Table 2.9. Weekly body weight (kg/hen) of hens receiving 12 different combinations of Na, Cl, Mg and SO_4 (SD±0.024) (continued).

Weeks	Treatments											
	1	2	3	4	5	6	7	8	9	10	11	12
36	1.919	1.947	1.910	1.869	1.908	1.748	1.912	1.905	1.925	1.941	1.859	1.927
37	1.928	1.974	1.908	1.918	1.846	1.903	1.852	1.887	1.961	1.981	1.901	1.876
38	1.909	1.892	1.893	1.878	1.891	1.877	1.855	1.891	1.943	1.977	1.874	1.890
39	1.931	1.950	1.938	1.930	1.908	1.885	1.868	1.892	1.927	1.978	1896	1.893
40	1.928	1.948	1.950	1.952	1.894	1.892	1.850	1.889	1.918	1.975	1.895	1.909

Table 2.10. LS Means for water intake (l) of hens receiving different levels of Na, Mg, Cl and SO_4 in the drinking water.

Treatment	Water intake (l)/hen/day (SD±0.0046) (P = 0.5557)
1	0.224[a]
2	0.230[a]
3	0.220[a]
4	0.224[a]
5	0.230[a]
6	0.225[a]
7	0.229[a]
8	0.224[a]
9	0.225[a]
10	0.216[a]
11	0.230[a]
12	0.221[a]

The weekly water intake (Table 2.11) was significantly influenced (P = 0.0001) by the addition of Cl, SO_4, Na and Mg to the water.

Water intake increased over weeks as the hens aged and egg production increased. This is due to a marked increase in water intake during the period when an egg is formed. 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 (Howard, 1975).

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). They are quantitatively insufficient to account for the increased fluid intake occurring at that time (Howard, 1975). There was a significant interaction between the treatments given to the hens and the week in which the treatment was given (P = 0.0098). This effect was however not sustained when looking at the whole trial period. No significant differences in water intake occurred between treatments over the experimental period (Table 2.10).

Table 2.11. Weekly water intake of hens receiving 12 different combinations of Na, Cl, Mg and SO_4.

Weeks	Treatments											
	1	2	3	4	5	6	7	8	9	10	11	12
21	0.146	0.149	0.141	0.147	0.153	0.137	0.140	0.140	0.155	0.146	0.142	0.134
22	0.196	0.193	0.189	0.188	0.184	0.283	0.186	0.196	0.191	0.195	0.204	0.179
23	0.220	0.212	0.214	0.209	0.217	0.202	0.217	0.219	0.213	0.217	0.225	0.199
24	0.216	0.210	0.215	0.223	0.210	0.213	0.217	0.220	0.217	0.204	0.227	0.194
25	0.218	0.221	0.223	0.230	0.227	0.223	0.228	0.226	0.219	0.217	0.235	0.216
26	0.226	0.240	0.232	0.232	0.237	0.238	0.235	0.233	0.233	0.220	0.236	0.215
27	0.230	0.243	0.227	0.237	0.239	0.237	0.248	0.242	0.234	0.225	0.242	0.237
28	0.238	0.247	0.233	0.244	0.242	0.248	0.242	0.240	0.233	0.225	0.238	0.227
29	0.215	0.219	0.206	0.215	0.217	0.218	0.214	0.215	0.207	0.208	0.219	0.217
30	0.242	0.243	0.229	0.235	0.245	0.243	0.243	0.239	0.236	0.226	0.241	0.245
31	0.279	0.279	0.248	0.260	0.278	0.277	0.277	0.262	0.281	0.244	0.261	0.262
32	0.248	0.248	0.248	0.249	0.265	0.261	0.255	0.249	0.238	0.239	0.254	0.248
33	0.226	0.225	0.217	0.216	0.235	0.227	0.224	0.220	0.222	0.206	0.229	0.231

Table 2.11. Weekly water intake of hens receiving 12 different combinations of Na, Cl, Mg and SO_4 (continued)

Weeks	Treatment											
	1	2	3	4	5	6	7	8	9	10	11	12
35	0.229	0.245	0.231	0.235	0.246	0.239	0.240	0.231	0.238	0.229	0.234	0.238
36	0.218	0.227	0.212	0.221	0.228	0.211	0.224	0.213	0.222	0.214	0.242	0.230
37	0.236	0.249	0.234	0.235	0.250	0.236	0.252	0.228	0.247	0.226	0.254	0.240
38	0.215	0.229	0.208	0.220	0.223	0.220	0.226	0.215	0.226	0.209	0.224	0.217
39	0.242	0.245	0.236	0.246	0.252	0.240	0.254	0.237	0.248	0.232	0.246	0.248
40	0.224	0.234	0.231	0.230	0.226	0.230	0.231	0.226	0.226	0.229	0.228	0.230

Levels of Cl, Na, SO_4 and Mg ions (mg/kg) present in the eggs (Table 2.12).

SO_4, Na, Cl and calcium were included in the model as covariance components to correct for variations in the different Mg, SO_4, Na and Cl levels in the eggs, since $MgSO_4$, $NaSO_4$, NaCl and $CaCl_2$ were used to supplement the Mg, Na, Cl and SO_4.

Chloride contents of the eggs:

Chloride with calcium as a covariant had a P-value of 0.1906 and Cl with Na as a covariant had a P-value of 0.3738. Neither of the interactions between the covariants and treatments were significant.

The Cl contents of the eggs differed significantly (P = 0.0032). The Cl level in treatment three (Cl of 125 and SO_4 of 250 mg/l) was 6735.69 mg/kg and 8234.43 mg/kg for treatment 11 (Cl of 125 and SO_4 of 50 mg/l). The significance of this is not clear since both treatments received 125 mg/l Cl in the drinking water, but it highlights the significance of the interactions between these four elements, since only the SO_4 levels differed between treatments. The differences between treatments seven and ten are however proportionate to the 125 mg/l and 500 mg/l Cl added to the drinking water.

Sulphate contents of the eggs:

The SO_4 contents of the eggs of treatments three (337.77 mg/kg) differed significantly (P = 0062) from the levels present in treatments six (118.84 mg/kg) and nine (126.02 mg/kg). The differences between treatments three and six are in agreement with the amounts of SO4 added to the water (250 and 500 mg/l respectively), but the significance of the differences between treatments three and nine are not clear since they both received 250 mg/l SO_4 added to the water.

Sulphate with Na as covariant had a P-value of 0.6083 and SO_4 with Mg covariant had a P-value of 0.6122. Neither of the interactions between the covariants and treatments was significant.

Na contents of the eggs:

No significant differences occurred between treatments given and the Na levels found in the eggs (P = 0.2920).

Na with SO_4 as covariant had a P - value of 0.9980 and Na with Cl as covariant had a P - value of 0.8409. The interaction between Cl and treatment was significant (P = 0.0001) which implies that in some treatments, the Cl levels had a different influence on the Na levels in other treatments.

Mg contents of the eggs:

No significant differences occurred between treatments given and the Mg levels found in the eggs (P = 0.2409).

Magnesium with SO_4 as covariant had a P - value of 0.3221. No significant interactions occurred between the covariant and treatments given.

Ca contents of the eggs:

No significant differences occurred between treatments given and the calcium levels found in the eggs ($P = 0.3585$).

Ca with Cl as covariant had a P - value of 0.9863. No significant interactions occurred between the covariant and treatments given.

Table 2.12. Levels of Cl, Na, SO_4 and Mg ions present in the eggs (mg/kg)

Treatment	Chloride (SD ± 273.76)	Sulphates (SD ± 39.47)	Sodium - SD	Magnesium (SD ± 162.03)	Calcium (SD ± 235.88)
1	6973.03[a]	292.55[a]	5699.93[a] (SD ± 197.76)	1623.05a	2998.09[a]
2	7525.76[a]	227.21[a]	6087.09[a] (SD ±143.71)	1786.90a	2467.04[a]
3	6735.69[ab]	337.77[ab]	5944.22[a] (SD ±175.00)	1359.91[a]	2468.57[a]
4	6877.76[a]	174.40[a]	6022.40[a] (SD ± 366.52)	1440.45[a]	2533.26[a]
5	7108.77[a]	194.17[a]	6240.55[a] (SD ± 154.05)	1395.84[a]	2564.05[a]
6	7066.79[ac]	118.84[c]	5568.65[a] (SD ± 636.88)	1197.97[a]	2489.72[a]
7	6409.41[bc]	138.99[a]	5620.40[a] (SD ± 792.30)	1293.93[a]	2445.63[a]
8	6907.07[a]	139.12[a]	5931.51[a] (SD ± 140.28)	1270.32[a]	2731.94[a]
9	7494.88[a]	126.02[cd]	5580.26[a] (SD ± 157.11)	1272.69[a]	2796.67[a]
10	8044.47[d]	169.08[a]	5159.12[a] (SD ± 204.08)	1592.91[a]	3207.99[a]
11	8234.43[c]	285.64[a]	4730.77[a] (SD ± 1129.46)	1209.03[a]	2358.63[a]
12	7370.41[a]	233.23[a]	5536.02[a] (SD ± 168.63)	1195.96[a]	2516.78[a]

A large number of chemicals occur naturally in ground water. They are usually present in amounts that do not interfere with the metabolism or digestive functions of chickens or turkeys. When the levels of certain chemicals are out of balance, however, they can - by themselves or in combination with other chemicals - affect poultry performance. Excessive levels of Na have a diuretic effect. The normal Na level in water is about 32 mg/l. Carter and Sneed (1996) indicated that a Na level of 50 mg/l is detrimental to broiler performance if the SO_4 level is also 50 mg/l or higher and the Cl level is 14 mg/l or higher.

Consuming too much Cl has a detrimental effect on metabolism. A Cl level of 14 mg/l is considered normal for well water. Carter and Sneed, (1996) have shown that a level of 14 mg/l in drinking water can be detrimental to broilers if combined with 50 mg/l of Na. Cl levels as high as 25 mg/l are not a problem if the Na level is in the normal range.

Because of the conflicting reports on recommended maximum tolerable levels of SO_4 in the drinking water for poultry, it is important to consider dietary sulphur contributions when evaluating the potential problems associated with high SO_4 concentrations in the water for poultry. Clinical signs of decreased production or increased faecal moisture may be an indication that SO_4 or sulphur concentrations in the feed and water need to be evaluated. Because of limited studies involving the role of S-compounds in the nutrition of simple-stomached mammals, the biologic importance or possible detrimental effect of inorganic SO_4 is poorly understood (Veenhuizen et al. 1992). High $S0_4$ levels have a laxative effect. Levels of about 125 mg/l are regarded as normal for well water, but levels as low as 50 mg/l can have a negative effect on performance if either the Na or Mg level is 50 mg/l or more (Carter and Sneed, 1996).

$MgSO_4$ was more toxic for chickens than was Na_2SO_4 when given in water at a concentration of 4000 mg/l. Lethal concentrations of Na and $MgSO_4$ were said to be between 16000 and 20000 mg/l of 23000 mg/l of total salt. It is therefore important to evaluate the source of SO_4 as well as the amount of total salts in the water in order to measure the potential impact on performance, because Mg may be more detrimental than Na when combined with SO_4 in water (Adams *et al*., 1975).

Waterborne Mg can make an important contribution to the total daily intake of Mg. Waterborne Mg is in the form of hydrated ions and has a higher bioavailability than Mg in food. The contribution of water Mg to animals that drink water with high Mg levels could be crucial in the prevention of Mg deficiency (Durlach et al. 1989). A symptom of a high Mg level is loose droppings. The normal level of Mg in well water is about 14 mg/l. This chemical may interact with SO_4. Carter and Sneed (1996) indicated that Mg alone at 68 mg/l does not adversely affect broiler performance, but a level of 50 mg/l can be detrimental if the SO_4 level is also 50 mg/l or greater.

Pang et al. (1977) found that tolerance to saline drinking water markedly increased with age. This susceptibility is because of a relative renal insufficiency in regulation of salt and water excretion at a young age.

Conclusion

Previously, so-called saline ground water sources in southern Africa with naturally high levels of Na Cl, Na_2SO_4 and Mg SO_4 were considered unsuitable for livestock and poultry consumption. This study shows that 12 different combinations of Mg, Na, Cl and SO_4 had no significant effect on growth, food and water intake, egg production or egg quality.

Poultry producers in areas with naturally high levels of these minerals in their ground water can therefore continue to function successfully if the concentrations present are up to 250 mg/l of Mg, 500 mg/l of Cl, 500 mg/l of SO_4 and 250 mg/l of Na.

At these levels the minerals manifested themselves in the egg contents and the effect thereof on the consumer needs to be investigated further. Machlin et al. (1953) presented data showing that the hen could incorporate inorganic SO_4 into the egg.

Since artificially enriched eggs are in the order of the day in this century, the possibility of creating a niche market for “mineral enriched eggs” is a possibility.

Chapter 3
The effect of elevated levels of $NaNO_3$ in the drinking water of layers and broilers.

Published in:

- *Casey, N.H., Meyer, J.A. & Coetzee C.B. (1998 d). An investigation into the quality of water for 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*

Introduction

Nitrates in feedstuffs occur primarily in the leaves and stems of non-leguminous plants such as oats, corn, barley, wheat and sorghum (Whitehead, 1956). Since these plant materials make up a very small portion of modern poultry rations, it would appear that water represents the greatest potential nitrate hazard for poultry. Nitrate forms N-nitroso compounds, many of which are known animal carcinogens. Biochemical studies in humans have shown that nitrate in water combines with amino acids to form these compounds (Whitehead, 1956).

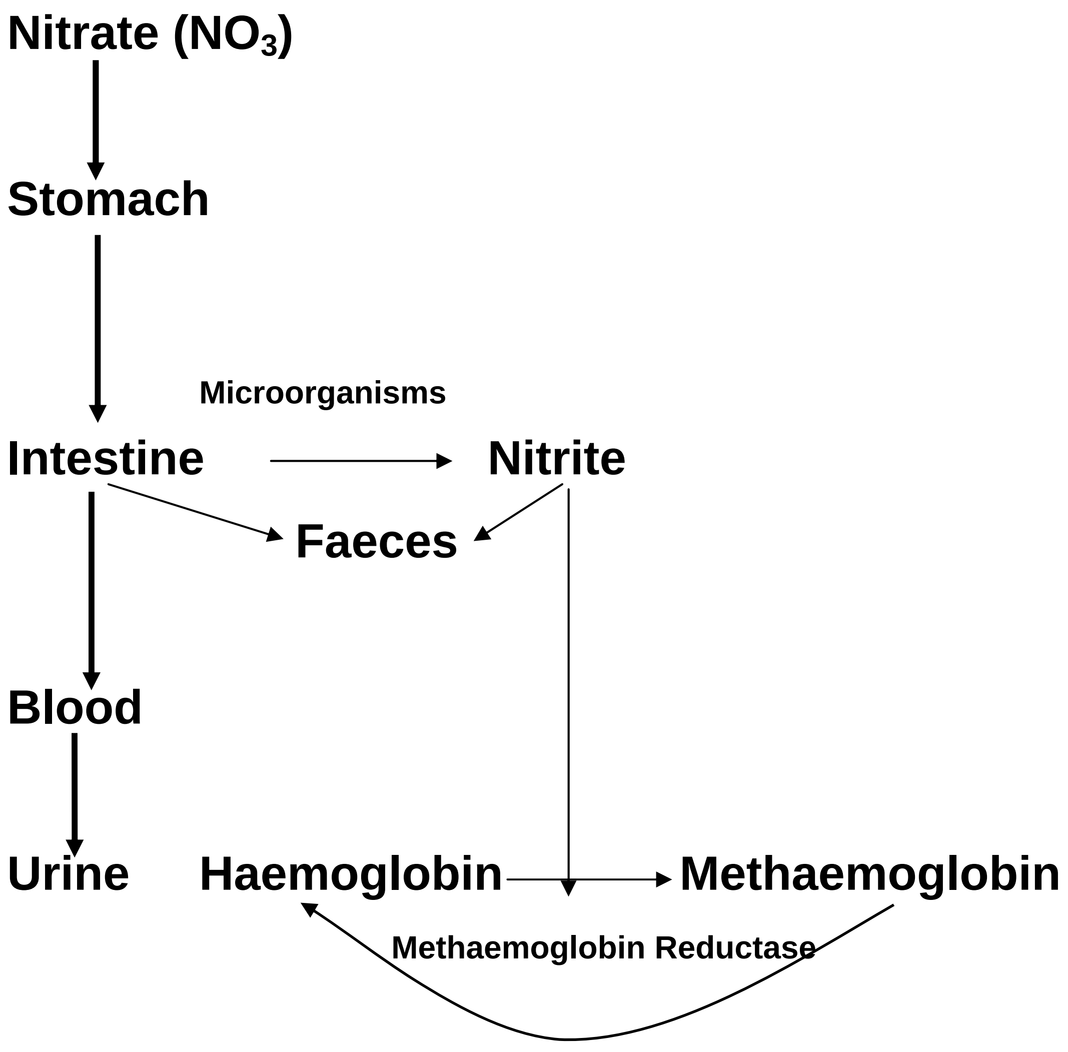
The presence of nitrates in the soil is largely as a result of natural biological processes associated with the decomposition of plant residues and organic matter. Nitrogen becomes a concern to water quality when nitrogen in the soil is converted to the nitrate (NO_3) form. It is a concern because nitrate is very mobile and easily moves with water in the soil. Its inclusion in groundwater is a cause for concern. However, nitrates can also enter surface waters such as ponds, streams and rivers. Nitrates also occur in rainwater, animal manure and nitrogen fertilizers. Whether or not nitrates actually enter groundwater depends on underlying soil and/or bedrock conditions, as well as the depth to groundwater. If depth to groundwater is shallow and the underlying soil is sandy, the potential for nitrates to enter groundwater is relatively high. However, if depth to groundwater is deep and the underlying soil is heavy clay, groundwater contamination from nitrates is not likely (Killpack and Buchholz, 1993).

Nitrate is relatively nontoxic. The primary health hazard from drinking water with nitrate-nitrogen occurs when bacteria in the digestive system transform nitrate to nitrite. When it is reduced to nitrite its toxicity increases greatly.

Nitrite is readily absorbed into the bloodstream. (Mommers et al., 1997). The nitrite then oxidizes iron in the hemoglobin of red blood cells to form methemoglobin, which lacks the oxygen-carrying ability of hemoglobin. This creates the condition known as methemoglobinemia (sometimes referred to as "blue baby syndrome") (Skipton and Hay, 1998). Nitrite binds to this oxidized haem and is capable of oxidizing haem. The exact mechanism is not well defined. Normally, oxygenation of hemoglobin causes a partial transfer of one electron from the iron to the bound oxygen. Iron in this state resembles ferric iron (Fe3+) and oxygen resembles super oxide (O2-). Deoxygenation returns the electron to the iron, with the release of oxygen. Methemoglobin is formed when an electron is not returned. Methemoglobin is incapable of binding oxygen, contrary to hemoglobin. This results in problems with oxygen transportation. The conversion of hemoglobin into methemoglobin occurs naturally, but the level is normally maintained below 2 % by methemoglobin-reducing enzymes. A clinical cyanosis will arise if the concentration of methemoglobin reaches 10 % of total hemoglobin amount (Mommers et al., 1997).

In monogastric animals such as swine and poultry, there is no fermentation vat similar to the rumen to aid in the digestion of roughage and to change nitrate to nitrite. In contrast monogastric animals convert nitrate to nitrite in the intestine, closer to the end of the digestive tract (Figure 3.1), where there is less opportunity for the nitrites to be absorbed by the blood. It is this difference in the site of conversion that makes nitrate poisoning a significantly smaller concern in monogastric animals (Yaremcio, 2000)

Figure 3.1: A simplified pathway for nitrates in swine and poultry. (Bergsrud & Linn, 1990)



It is difficult to determine the toxicity of nitrate in animals since it depends on the rate that the substance is ingested. A few hundred milligrams of nitrate may cause poisoning if ingested in a few hours. But, spread over a whole day, 1000 mg nitrate may cause no signs of toxicity. Common symptoms include abdominal pain, diarrhea, muscular weakness or poor coordination. Affected animals will have blood that is a chocolate- brown color. If the problem is diagnosed in time, they can fully recover with a treatment of methylene blue. Pregnant animals may abort within a few days. Nitrate also exists in animal feeds and fodder. Drought stressed forage plants commonly have high nitrate levels. These plants can have a cumulative effect when consumed with high levels of nitrate in the drinking water (Self and Waskom, 1992)

The toxicity of nitrates to poultry varies with the age of the birds, older birds being more tolerant. Levels in excess of 50 mg/l for chickens and 75 mg/l for turkeys have proven harmful in laboratory trials. Carter and Sneed, (1996) suspected that levels above 3mg/l were likely to affect egg production in layers and growth in broilers. Nitrites are toxic at much lower levels than nitrates; concentrations as low as 1 mg/l can be toxic.

The potential health hazard for poultry depends on the individual's reaction to nitrate-nitrogen and the total ingestion of nitrate-nitrogen and nitrates from all sources. The clinical signs of acute nitrate toxicity vary according to species. In general, ruminant animals develop methemoglobinemia while monogastric animals exhibit severe gastritis. Nitrate ingestion has also been linked to impairment of thyroid function, decreased feed consumption and interference with vitamin A and E metabolism.

Hematological changes seen with chronic high nitrate exposure include both compensatory increases in red blood cells and anemia, along with increased neutrophils and eosinophils. Unlike nitrate, nitrite is capable of inducing methemoglobinemia in a wide range of species, i.e. cattle, sheep, swine, dogs, guinea pigs, rats, chickens and turkeys (Bruning – Fann and Kaneene, 1993).

A potential cancer risk from nitrate (and nitrite) in water and food has been reported. A possibility exists that nitrate can react with amines or amides in the body to form nitrosamine, which is known to cause cancer. Nitrate must be converted to nitrite before nitrosamine can be formed. The magnitude of the cancer risk from nitrate in drinking water is not known (Jasa et al., 1998).

Consuming water from a source containing 10 or less mg/l nitrate-nitrogen provides assurance that methemoglobinemia should not result from drinking water.

Although nitrate occurs naturally in some groundwater, higher levels are thought to be the result of human activities in most cases.

Nitrate is easily dissolved in water, which means that it is difficult to remove. Three water treatment systems that remove nitrate are distillation, reverse osmosis and ion exchange. The distillation process boils water, then catches and condenses the steam while nitrate and other minerals remain in the boiling tank. Reverse osmosis forces water under pressure through a membrane to filter out contaminants. Ion exchange introduces another substance, normally chloride, to "trade places" with nitrate in water (Jennings and Sneed, 1996).

Nitrate in drinking water is measured either in terms of the amount of nitrogen present or in terms of both nitrogen and oxygen. In 1962, the U.S. Public Health Service adopted drinking water standards and set the recommended limit for nitrate-nitrogen at 10 mg/l. This drinking water standard was established to protect the health of infants and was based on the best knowledge available at that time. The Environmental Protection Agency (EPA) has since adopted the 10 mg/l standard as the maximum contaminant level (MCL) for nitrate-nitrogen in public water systems. The South African standard for nitrate and nitrite levels in livestock drinking water has been set at 100 mg/l for nitrate and 10 mg/l for nitrite (DWAF, 1996).

Subsequent reviews of this standard have not resulted in any changes. However, it is difficult to establish an exact level at which nitrogen concentrations in water are safe or unsafe.

Adams *et al*. (1966) administered various levels of either sodium nitrate or nitrite continuously in the drinking water of day-old chicks or poults and laying hens. The stock was maintained in otherwise standard conditions and fed practical diets containing 9500, 14 000, and 9850 I.U. of vitamin A activity/kg, respectively. Up to 200 and 300 mg/l of nitrite and nitrate nitrogen, respectively, had very little effect on blood methemoglobin, mortality and feed and water consumption of chicks. A reduction in growth and liver vitamin A was observed with 200 mg/l nitrite nitrogen. Lloyd (1977), found that levels of up to 1867 mg/l of nitrate-nitrogen had such high mortality and morbidity levels, that the treatment was discontinued at the end of one week and the chicks were given nitrate free water. These chicks recovered quickly but remained lighter in weight than chicks on lower treatments. Chicks at all other levels appeared healthy. Growth retardation at the 466 and 933 mg/l level was significant but not severe. Water consumption increased with each addition of nitrate up to 933 mg/l in the drinking water.

Contradicting the above, Arendz (1967), found that sodium nitrate supplying 675 mg/l of nitrate in the drinking water of turkey poults during the first 4 weeks, caused increased weight gains at subsequent periods. Males were affected more than females. Sodium nitrate in the feed at 1000 mg/l nitrate for the first four weeks did not promote growth at subsequent ages. There was no effect from sodium nitrate in drinking water upon spleen, adrenal and thyroid sizes or thyroid activity as measured by $I\text{-}^{131}$ trapping rate at either four or twenty-four weeks of age. No differences were found in haematocrit or blood glucose level at twenty-four weeks of age. A relatively large difference was noted in testes size at 24 weeks of age. The sodium nitrate treated birds' testes were about half the weight of the controls. These differences in testes size and body weights indicate that sodium nitrate may be upsetting normal gonadal hormone metabolism. A hypothesis is postulated that this apparent hormone imbalance may cause increased retention.

Marrett and Sunde (1968) reported that chicks up to five weeks old were more tolerant to nitrate and nitrite in the feed than poults. They also found that mortality and rate of respiration were increased and growth reduced when high levels of nitrate and nitrite were fed in the presence of marginal levels of vitamin A.

Experimental evidence has been presented showing that dietary nitrate accelerates the depletion of vitamin A from body stores of ruminants (Hatfield *et al*., 1961) and that dietary nitrite or nitrate exerts similar effects on the rat (Smith *et al*., 1961). Roberts and Sell (1963) found that vitamin A is destroyed in the presence of nitrite in the ventriculus area of the digestive tract, where the pH is approximately 4 and that the nitrite depressed growth primarily by reducing feed consumption of chicks not receiving supplemental vitamin A.
Bloomfield and Welsh (1961) found it conceivable that the vitamin A deficiency that occurs when excess nitrate is found in the drinking water, is an indirect result of abnormal thyroid function induced by the nitrate.

Adams, (1974) reported that chickens and turkeys were tolerant to levels of nitrate commonly found in water (up to 1320 and 1485 mg/l nitrate for chickens and turkeys respectively). In commercial poultry production in the year 2001, nitrate inclusions as high as this will not be tolerated by the hen. Commercial meat- and egg-type chickens are exposed to high levels of environmental stress (stocking densities of up to 22 birds/m^2) and metabolic stresses. They need optimal nutritional conditions to achieve their genetic potential. Water Quality Guidelines for poultry in South Africa should therefore not be based on the amount of a constituent that a bird can tolerate, but rather on the maximum inclusion of the constituent without compromising production.

The aim of this study:
Firstly, to establish the effect of high levels of nitrate on the growth, physiology and production of layers (Experiment 1) and broilers (Experiment 2) and the alleviating effect of vitamin A on them.

Materials and Methods

Experiment 1: Layers

The same type of birds, water administration, housing and temperature control, vaccination, feeding regime and lighting schedule were used as discussed in Chapter 2.

Six levels of $NaNO_3$ (0, 25, 100, 150, 200, 300 mg/l) were administered to 720 Hy-line layers (Table 3.2). Each pen was stocked with 20 hens in a 6 X 3 factorial experiment (360 birds). These six treatments were repeated, with the repeat group receiving 8000 mg/l of additional vitamin A administered through the drinking water. Pretoria Municipal Water was used and the nitrates present in the water were taken into account when formulating the inclusion levels. The sodium content of the water was 4.1 mg/l.

Alberta Agriculture Food and Rural Department (1996) developed a guideline for nitrate inclusion levels in livestock watering (Table 3.1). This was used as a guideline for the inclusion levels in this experiment.

Table 3.1. A Guide to the use of waters containing nitrate for livestock

Nitrate content* (mg/l nitrate nitrogen)	Comments
Less than 100'*	Experimental evidence to date indicates that this water should not harm livestock or poultry.
100 to 300**	This water should not in itself harm poultry. When feeds contain nitrates, this water could add greatly to the nitrate intake to make it dangerous. This could be of some concern in the case of cattle or sheep when circumstances cause nitrates to accumulate in the plant; e.g., frost, hail, drought, and especially if the animals are given water containing levels of nitrates that approach the upper limits.
Over 300***	This water could cause typical nitrate poisoning in cattle and sheep, and its use for these animals is not recommended. Because this level of nitrate contributes significantly to salinity and also because experimental work with levels of nitrate nitrogen in excess of this are meager, the use of this water for swine, horses, or poultry should also be avoided.

* Includes nitrite nitrogen.
** Less than 443 mg/l of nitrate or less than 607 mg/l of $NaNO_3$
***Over 1329 mg/l of nitrate or over 1821 mg/l of $NaNO_3$

Table 3.2. Inclusion levels of nitrates:

Treatment Group	Nitrate inclusion level (mg/l)
1	0
2	25
3	100
4	150
5	200
6	300

Table 3.3. The vitamin A levels present in the feed:

Feed	Vitamin A level
Starter	12 000
Grower/Finisher	10 000
Layer	8 000

Water intake, feed intake, body weight, egg production and egg weight and temperature were measured weekly. Mortalities were recorded and post mortems conducted on them. The trial ended after 12 weeks. Eggshell thickness of a representative sample of eggs of each treatment was measured. A representative sample of hens from each treatment group was slaughtered at the end of the trial period according to The Slaughter of Poultry (Humane Conditions) Regulations (Amendment) 1990. Kidney, liver, spleen and pancreatic samples were examined histopathologically and the nitrite content of the colon and caecum contents were determined. Blood samples were taken from each slaughtered bird. Pathologists established the methemoglobin contents of each blood sample by means of a blood gas analyses done on a co-oximeter. The Vitamin A levels in the feed are shown in Table 3.3.

Statistical analysis:
Statistical analysis was conducted using the PC - SAS Version 6.08 commercial software. Several measurements taken on the same experimental unit tend to be correlated with each other. The correlation of measurements of qualitatively different parameters such as weight, length, and width, is taken into account using multivariate methods of analyses. Measurements considered to be responses to levels of an experimental factor of interest, such as time, treatment, or dose, are analyzed using a repeated measures analysis of variance.

PROC GLM provides both univariate and multivariate tests for repeated measures for one response (Winer (1971)). The multivariate approach is covered in Cole and Grizzle (1966). LaTour and Miniard (1983) discussed the relative merits of the two approaches. Means for parameters measured were analysed, using analysis of variance - PROC GLM methods. Main factors were treatment, vitamin inclusion, organ where sample was taken and interactions between these factors. These factors were analysed with week being the predictor. The significance of differences between treatments were determined with Bonveroni test at a $P < 0.05$ significance level.

Results
Differences in nitrite levels observed in the caecum and colon, were not significantly different ($P = 0.2167$), (Table 3.4), although numerically less nitrite was found in the colon than caecum and more nitrite occurred in hens, receiving 8000 IU Vitamin A. No significant interactions occurred between nitrate levels, addition of Vitamin A or the organ sampled.

Table 3.4. **Nitrite levels in the caecum and colon (mg/kg) (P = 0.2167), (SD ± 7.224)**

Nitrate (mg/l)	Caecum with Vitamin A	Caecum without Vitamin A	Colon with Vitamin A	Colon without Vitamin A

0	1.650	0.743	2.867	3.183
25	1.383	1.113	2.647	1.973
100	0.923	6.397	7.4000	2.610
150	0.567	33.633	2.240	4.113
200	28.140	4.243	35.773	2.670
300	5.753	3.633	3.067	2.927

No methemoglobin was found in the blood (Table 3.5).

Table 3.5. **Percentage of methemoglobin in blood**

Treatment	Methemoglobin level without Vitamin A	Methemoglobin level with Vitamin A
1	-1.700	-1.800
2	-1.833	-1.733
3	-2.233	-1.967
4	-1.900	-1.933
5	-1.733	-1.633
6	-1.500	-1.733

The addition of 8000 mg/l of Vitamin A had a significant positive influence on egg production (Table 3.8) (P=0.0305) during weeks 21, 22 and 23. Within nitrate treatments, the groups receiving the added Vitamin A produced more eggs than the treatments without the added Vitamin A. This implies that the onset of lay was earlier and quicker in treatments receiving the Vitamin A. Later on the treatments without the Vitamin A caught up with treatments with the Vitamin A and the initial spurt was equalised. Egg weight was not influenced by added nitrate levels. Hens receiving 300 mg/l of sodium nitrate without Vitamin A had an egg production percentage (Table 3.9) of 85% versus the 82.62 % of the control in week 23. Elevated nitrate levels did not significantly influence egg weights.

The addition of Vitamin A had no significant influence on food intake (Table 3.10). The 300 mg/l nitrate addition group of hens receiving no added Vitamin A however had markedly lower food intakes than the 25 and 100 mg/l treatment groups in the 22, 25, 27, 28 and 29th weeks.

The addition of Vitamin A to the drinking water had a significant positive effect on body weights in all the treatments over all the weeks (Table 3.12). Hens receiving elevated nitrate levels without added Vitamin A had significant higher body weights than the controls, in weeks 22 and 28. In week 32 however, the control had significantly higher bodyweights than all the other treatments without the added Vitamin A.

Water intakes (Table 3.11) were not influenced by nitrate treatment. The addition of Vitamin A to the water however had a significant influence on water intakes in week 32.
Mortalities were not linked to nitrate administration.

Histopathology:

Hearts

Treatment 5 without Vitamin A showed a few microscopical foci of round cell infiltration (mainly lymphocytes = lymphoid foci) in the myocardium. These were also present, but milder, in Treatment 1 with Vitamin A and Treatment 5 with Vitamin A.

Kidneys

A number of kidneys showed scattered foci of lymphocytic cell infiltration (lymphoid foci). The treatment and the number of occurrences in each treatment are shown in the Table 3.6. below.

Table 3.6. Number of lymphoid foci in the kidneys.

Treatment	No Vitamin A	With Vitamin A
1	1	1
2	2	1
3	2	1
4	1	1
5	2	1
6	1	0

Intestines and pancreas

A number of sections showed evidence of chronic serositis (inflammation of the serous membrane covering the outside of the intestine). This was mild, subacute, and multifocal in Treatments 1, without Vitamin A, Treatment 2 with Vitamin A, Treatment 3 with Vitamin A and Treatment 5 with Vitamin A. The inflammatory reaction was more chronic in Treatments 2 without Vitamin A, Treatment 1 with Vitamin A, Treatment 2 with Vitamin A and Treatment 5 with Vitamin A. In a few of these cases, but especially in Treatment 2 with Vitamin A, droplets of egg yolk were observed. This indicates that the serositis is part of a syndrome k own as "egg yolk peritonitis". This is a common but un-important finding in laying birds (Table 3.7).

Table 3.7. Number of serositis in the intestines and pancreas.

Treatment	No Vitamin A	With Vitamin A
1	1	1
2	1	2
3	0	1

4	0	0
5	0	2
6	0	0

Livers

Lymphoid foci were present in all the livers, to varying degrees.

Table 3.8. **Weekly egg production (eggs/hen/week) of layers receiving 6 different levels of sodium nitrate, each treatment with and without the addition of 8000 mg/l of Vitamin A**

		Egg Production			
		No Vitamin A		With Vitamin A	
Treatment	Week	Mean	± SD	Mean	± SD
1	21	1.000	0.397	1.450	0.409
1	22	3.500	0.218	3.800	0.180
1	23	5.500	0.879	5.780	0.584
1	24	6.330	0.355	6.530	0.256
1	25	6.420	0.176	6.460	0.275
1	26	6.650	0.132	6.670	0.161
1	27	6.670	0.076	6.550	0.180
1	28	6.780	0.293	6.920	0.029
1	29	6.630	0.029	6.630	0.153
1	30	6.500	0.218	6.850	0.050
1	31	6.830	0.104	6.870	0.284
1	32	6.630	0.252	6.730	0.029
2	21	0.617	0.247	1.167	0.764
2	22	2.920	0.247	3.420	0.553
2	23	4.980	0.535	6.950	0.050
2	24	6.080	1.052	6.630	0.225
2	25	6.360	0.242	6.270	0.104
2	26	6.680	0.157	6.700	0.132
2	27	6.810	0.065	6.520	0.104
2	28	6.880	0.027	6.770	0.189
2	29	6.600	0.246	6.580	0.160
2	30	6.590	0.227	6.770	0.126
2	31	6.950	0.088	6.930	0.126
2	32	6.540	0.076	6.780	0.202
3	21	0.730	0.850	0.930	0.058
3	22	3.230	0.759	3.420	0.275
3	23	4.620	0.275	5.350	0.409
3	24	6.180	0.454	6.050	0.654
3	25	5.930	0.153	6.000	0.436
3	26	6.480	0.275	6.620	0.058
3	27	6.500	0.180	6.500	0.265
3	28	6.630	0.293	6.630	0.301
3	29	6.430	0.144	6.500	0.087
3	30	6.750	0.050	6.770	0.076
3	31	6.750	0.132	6.800	0.250

Table 3.8. **Weekly egg production (eggs/hen/week) of layers receiving 6 different levels of sodium nitrate, each treatment with and without the addition of 8000 mg/l of Vitamin A (continued).**

Treatment	Week	Egg Production			
		No Vitamin A		With Vitamin A	
		Mean	± SD	Mean	± SD
3	32	6.450	0.100	6.600	0.173
4	21	0.770	0.416	1.180	0.465
4	22	3.133	0.850	3.780	0.723
4	23	4.988	0.868	5.700	0.229
4	24	6.670	0.765	6.900	0.050
4	25	6.320	0.158	6.550	0.132
4	26	6.820	0.176	6.960	0.076
4	27	6.490	0.039	6.500	0.100
4	28	6.760	0.150	6.850	0.132
4	29	6.600	0.225	6.510	0.029
4	30	6.820	0.346	6.800	0.087
4	31	6.920	0.117	6.720	0.301
4	32	6.730	0.200	6.420	0.189
5	21	1.230	0.104	1.380	0.275
5	22	3.570	0.425	4.070	0.379
5	23	5.780	0.225	5.550	0.361
5	24	6.950	0.100	6.320	0.404
5	25	6.370	0.126	6.500	0.436
5	26	6.850	0.173	6.910	0.080
5	27	6.530	0.161	6.660	0.223
5	28	6.680	0.104	6.680	0.071
5	29	6.630	0.161	6.460	0.115
5	30	6.600	0.132	6.600	0.451
5	31	6.600	0.087	6.730	0.501
5	32	6.730	0.301	6.640	0.166
6	21	1.250	0.436	1.350	0.050
6	22	3.900	0.218	4.020	0.404
6	23	5.570	0.236	5.950	0.173
6	24	6.700	0.050	6.780	0.355
6	25	6.070	0.184	6.520	0.369
6	26	6.570	0.247	6.920	0.375
6	27	6.650	0.100	6.780	0.104
6	28	6.720	0.355	6.820	0.153
6	29	6.680	0.029	6.500	0.132
6	30	6.800	0.100	6.820	0.029
6	31	6.730	0.419	6.800	0.087
6	32	6.750	0.180	6.530	0.144

Table 3.9. **Weekly egg weight of eggs of layers receiving 6 different levels of sodium nitrate, each treatment with and without the addition of 8000 mg/l of Vitamin A**

Treatment	Week	Egg Weight			
		No Vitamin A		With Vitamin A	
		Mean	± SD	Mean	± SD
1	21	37.159	0.842	39.849	1.961
1	22	41.990	0.725	43.020	0.402
1	23	46.532	1.081	44.773	0.883
1	24	48.622	0.922	47.767	1.062
1	25	50.280	0.983	51.071	1.577
1	26	52.135	0.689	51.332	1.086
1	27	53.420	1.142	51.968	1.174
1	28	53.734	0.616	53.111	1.904
1	29	54.380	0.578	54.175	1.287
1	30	55.449	0.658	55.282	1.372
1	31	56.274	0.760	55.544	1.205
1	32	56.641	0.809	55.456	2.324
2	21	39.984	1.459	38.235	0.885
2	22	41.567	0.245	41.832	1.286
2	23	45.622	0.863	44.718	0.844
2	24	53.209	9.788	47.598	0.585
2	25	49.906	0.805	49.634	0.614
2	26	51.710	0.462	51.074	0.997
2	27	52.505	0.980	51.989	0.945
2	28	53.447	1.371	52.649	0.687
2	29	54.024	0.650	54.156	0.452
2	30	54.532	1.296	54.983	0.312
2	31	55.416	1.412	55.405	0.219
2	32	55.632	1.374	55.693	0.143
3	21	40.985	1.654	37.963	2.784
3	22	42.827	1.108	42.471	1.436
3	23	47.420	2.762	45.975	0.462
3	24	48.111	0.808	52.498	7.412
3	25	50.132	0.760	50.131	0.629
3	26	52.121	0.966	51.813	0.530
3	27	53.039	0.828	52.922	0.524
3	28	53.303	0.636	53.624	1.348
3	29	54.113	0.220	54.037	0.282
3	30	55.219	0.295	54.377	1.223

Table 3.9. **Weekly egg weight of eggs of layers receiving 6 different levels of sodium nitrate, each treatment with and without the addition of 8000 mg/l of Vitamin A (continued).**

	Week	No Vitamin A		With Vitamin A	
		Mean	± SD	Mean	± SD
3	31	55.212	0.498	55.505	0.390
3	32	55.454	0.315	56.102	0.524
4	21	37.532	0.994	38.356	0.685
4	22	41.034	1.700	41.667	0.512
4	23	45.385	1.024	44.809	0.295
4	24	47.099	0.476	47.487	0.863
4	25	49.084	1.092	49.380	1.117
4	26	51.203	0.499	51.055	1.685
4	27	52.547	1.020	52.273	1.094
4	28	52.389	0.987	52.860	1.551
4	29	53.755	1.004	53.468	1.409
4	30	54.505	1.068	54.137	1.130
4	31	54.644	0.852	54.627	1.288
4	32	55.326	0.522	54.974	1.555
5	21	39.806	0.194	38.343	1.162
5	22	42.232	0.305	42.800	0.463
5	23	45.811	0.529	45.622	1.047
5	24	47.691	1.032	48.603	0.907
5	25	50.124	0.052	50.299	1.038
5	26	51.339	0.822	52.356	0.525
5	27	52.322	1.023	53.033	0.547
5	28	54.114	2.481	54.031	0.379
5	29	53.974	1.108	53.984	0.403
5	30	54.927	1.171	54.619	0.448
5	31	54.955	1.180	55.096	0.161
5	32	55.612	0.969	55.803	0.485
6	21	39.158	1.332	38.426	0.880
6	22	42.472	0.715	42.485	0.254
6	23	45.509	0.321	45.694	0.650
6	24	47.993	0.481	50.045	2.915
6	25	55.379	9.143	50.738	0.418
6	26	50.993	0.455	51.015	1.892
6	27	52.701	0.374	53.390	0.473
6	28	53.012	0.803	54.098	0.506
6	29	53.787	0.790	54.657	0.567
6	30	54.874	0.898	54.979	0.119
6	31	55.110	0.772	55.506	0.350
6	32	55.222	0.589	56.063	0.349

Table 3.10. **Daily food intake (g) of layers receiving 6 different levels of sodium nitrate, each treatment with and without the addition of 8000 mg/l of Vitamin A**

Treatment	Week	Feed intake			
		No Vitamin A		With Vitamin A	
		Mean	± SD	Mean	± SD
1	21	98.2	5.8	96.1	5.0
1	22	121.5	1.5	121.6	13.1
1	23	123.2	5.4	129.1	9.7
1	24	132.2	3.3	131.9	8.9
1	25	140.7	2.0	141.8	12.3
1	26	138.2	14.5	142.3	10.1
1	27	138.7	5.5	146.2	10.4
1	28	149.3	7.0	147.5	13.9
1	29	140.7	7.8	152.4	13.7
1	30	155.2	9.4	161.1	18.0
1	31	163.1	13.2	161.4	18.4
1	32	160.5	5.7	167.8	18.2
2	21	109.0	6.4	99.0	3.0
2	22	131.6	15.6	123.0	4.0
2	23	138.2	20.1	126.0	7.0
2	24	151.6	22.8	132.0	6.0
2	25	158.6	22.7	143.0	5.0
2	26	164.4	24.1	143.0	2.0
2	27	158.7	17.0	146.0	7.0
2	28	168.7	11.8	148.0	3.0
2	29	163.1	11.1	150.0	6.0
2	30	168.8	7.4	162.0	2.0
2	31	189.4	5.6	158.0	1.0
2	32	177.3	5.8	169.0	8.0
3	21	101.1	15.0	91.0	6.0
3	22	114.0	10.0	113.0	4.0
3	23	118.0	9.0	115.0	2.0
3	24	131.0	7.0	123.0	2.0
3	25	137.0	5.0	134.0	6.0
3	26	144.0	5.0	139.0	6.0
3	27	148.0	2.0	142.0	9.0
3	28	147.0	4.0	148.0	4.0
3	29	151.0	9.0	146.0	4.0
3	30	156.0	8.0	162.0	7.0
3	31	158.0	7.0	153.0	3.0

Table 3.10. **Daily food intake (g) of layers receiving 6 different levels of sodium nitrate, each treatment with and without the addition of 8000 mg/l of Vitamin A (continued).**

Treatment	Week	Feed intake			
		No Vitamin A		With Vitamin A	
		Mean	± SD	Mean	± SD
3	32	164.0	9.0	162.0	2.0
4	21	90.2	3.1	104.5	4.6
4	22	107.3	4.6	121.8	4.3
4	23	116.2	11.7	128.0	4.7
4	24	122.1	18.1	136.3	8.4
4	25	135.2	17.4	141.6	2.8
4	26	133.3	11.5	144.1	4.5
4	27	135.3	8.0	143.9	15.4
4	28	141.1	4.3	152.2	3.8
4	29	143.3	16.8	146.1	6.1
4	30	154.4	16.5	155.8	4.5
4	31	156.1	20.4	158.4	3.3
4	32	161.6	23.7	164.1	3.6
5	21	90.5	4.6	95.1	9.1
5	22	107.8	5.8	114.3	12.2
5	23	119.0	6.9	125.2	10.1
5	24	127.2	6.2	127.6	10.9
5	25	129.7	4.6	132.1	10.9
5	26	133.7	4.9	139.0	13.6
5	27	131.2	6.4	143.2	19.2
5	28	141.3	1.6	144.8	18.6
5	29	137.1	5.9	137.7	12.5
5	30	150.5	2.6	155.8	8.9
5	31	148.8	4.0	156.0	19.5
5	32	158.3	4.5	163.8	18.0
6	21	91.4	4.4	99.2	6.1
6	22	106.8	6.3	119.4	10.6
6	23	123.2	4.5	124.3	1.9
6	24	124.1	4.3	138.7	4.9
6	25	136.6	2.6	144.9	4.9
6	26	134.4	7.4	137.0	2.1
6	27	137.1	6.2	144.1	2.1
6	28	142.2	7.1	146.3	2.0
6	29	140.6	4.3	146.4	4.8
6	30	154.4	7.4	154.3	5.9
6	31	152.9	9.3	156.5	4.8
6	32	156.8	11.0	161.4	7.8

Table 3.11. **Daily water intake (ml) of layers receiving 6 different levels of sodium nitrate, each treatment with and without the addition of 8000 mg/l of Vitamin A**

Treatment	Week	Water intake			
		No Vitamin A		With Vitamin A	
		Mean	± SD	Mean	± SD
1	20	156.4	5.7	150.5	3.2
1	21	202.3	11.4	198.5	7.9
1	22	219.9	3.4	204.6	8.2
1	23	216.5	4.4	205.6	8.1
1	24	216.2	4.6	217.1	2.0
1	25	214.6	4.7	209.3	10.7
1	26	221.7	6.9	203.9	5.7
1	27	214.0	7.4	210.4	20.1
1	28	240.0	9.3	223.3	6.4
1	29	243.8	3.2	237.6	6.1
1	30	240.2	4.5	230.6	11.6
1	31	236.3	3.4	223.5	8.9
2	20	152.5	6.5	159.4	6.6
2	21	193.7	18.7	215.6	5.4
2	22	216.9	15.1	216.1	5.4
2	23	215.4	6.6	218.9	12.3
2	24	216.1	8.1	221.3	7.2
2	25	223.7	17.3	218.1	11.9
2	26	229.7	10.5	222.3	12.0
2	27	217.5	10.1	211.5	3.0
2	28	238.3	10.3	232.9	9.0
2	29	245.2	5.6	238.9	2.0
2	30	244.7	12.8	233.7	11.1
2	31	242.4	13.9	231.7	10.6
3	20	161.5	7.4	156.9	3.4
3	21	215.8	17.2	207.1	3.6
3	22	213.5	15.2	212.7	12.5
3	23	221.2	14.8	211.0	9.4
3	24	223.1	15.9	214.4	10.9
3	25	222.3	8.1	224.5	16.4
3	26	231.4	9.7	224.3	14.6
3	27	214.6	10.6	216.8	13.7
3	28	240.0	13.1	234.8	16.3
3	29	248.1	6.9	243.7	4.8
3	30	236.4	2.2	234.0	5.5

Table 3.11. Daily water intake (ml) of layers receiving 6 different levels of sodium nitrate, each treatment with and without the addition of 8000 mg/l of Vitamin A (continued).

Treatment	Week	Water intake			
		No Vitamin A		With Vitamin A	
		Mean	± SD	Mean	± SD
3	31	243.8	2.4	232.7	12.2
4	20	162.6	4.6	160.2	1.8
4	21	213.2	5.3	206.3	2.9
4	22	222.4	7.4	213.5	3.2
4	23	227.4	6.5	211.5	3.5
4	24	220.7	7.7	214.3	6.5
4	25	228.7	14.3	212.5	4.8
4	26	231.6	10.0	216.5	5.4
4	27	217.1	9.9	215.0	4.1
4	28	244.0	14.2	231.1	4.1
4	29	244.4	6.2	240.5	6.1
4	30	238.0	6.2	227.5	6.8
4	31	242.8	5.2	232.1	8.1
5	20	159.2	4.0	164.0	4.0
5	21	215.7	3.9	213.7	7.8
5	22	230.8	9.0	228.7	10.4
5	23	200.8	42.2	220.0	12.8
5	24	224.4	6.6	221.5	7.0
5	25	223.7	12.6	215.8	11.6
5	26	221.8	11.2	223.9	10.4
5	27	212.6	14.6	222.9	7.5
5	28	235.2	15.8	244.4	13.4
5	29	241.5	11.6	243.0	5.1
5	30	236.8	16.9	248.8	5.0
5	31	238.2	9.8	245.0	9.4
6	20	157.7	5.7	159.2	3.2
6	21	211.0	15.0	209.6	8.1
6	22	226.9	16.0	230.7	8.7
6	23	217.4	18.6	221.2	5.9
6	24	216.0	12.7	193.8	48.2
6	25	218.3	14.9	212.3	4.3
6	26	213.7	11.7	223.5	3.4
6	27	215.1	6.5	211.9	4.2
6	28	238.2	9.3	236.4	4.6
6	29	245.8	2.2	241.5	5.2
6	30	237.1	5.9	244.5	2.9
6	31	241.1	9.0	236.9	3.0

Table 3.12. Weekly body weights of layers receiving 6 different levels of sodium nitrate, each treatment with and without the addition of 8000 mg/l of Vitamin A

Treatment	Body Weight

	Week	No Vitamin A		With Vitamin A	
		Mean	± SD	Mean	± SD
1	20	1.575	0.042	1.611	0.055
1	21	1.635	0.027	1.682	0.034
1	22	1.507	0.061	1.708	0.032
1	23	1.722	0.046	1.749	0.007
1	24	1.738	0.037	1.743	0.007
1	25	1.783	0.045	1.773	0.015
1	26	1.777	0.046	1.795	0.014
1	27	1.792	0.033	1.814	0.007
1	28	1.810	0.031	1.816	0.012
1	29	1.813	0.038	1.836	0.008
1	30	1.800	0.040	1.835	0.011
1	31	1.819	0.033	1.844	0.002
1	32	1.846	0.039	1.853	0.017
2	20	1.575	0.026	1.595	0.044
2	21	1.654	0.049	1.675	0.016
2	22	1.685	0.058	1.739	0.004
2	23	1.759	0.078	1.767	0.010
2	24	1.715	0.039	1.756	0.018
2	25	1.724	0.036	1.751	0.039
2	26	1.700	0.034	1.802	0.014
2	27	1.735	0.034	1.786	0.038
2	28	1.766	0.039	1.851	0.053
2	29	1.769	0.031	1.842	0.021
2	30	1.754	0.038	1.828	0.043
2	31	1.754	0.038	1.842	0.048
2	32	1.794	0.043	1.858	0.021
3	20	1.568	0.023	1.601	0.015
3	21	1.662	0.030	1.673	0.020
3	22	1.714	0.045	1.722	0.012
3	23	1.782	0.071	1.746	0.024
3	24	1.729	0.033	1.729	0.009
3	25	1.753	0.034	1.744	0.025
3	26	1.771	0.031	1.784	0.027
3	27	1.773	0.022	1.741	0.084
3	28	1.793	0.024	1.817	0.017
3	29	1.752	0.085	1.789	0.018
3	30	1.790	0.027	1.823	0.033

Table 3.12. Weekly body weights of layers receiving 6 different levels of sodium nitrate, each treatment with and without the addition of 8000 mg/l of Vitamin A (continued)

Treatment	Week	Body Weight			
		No Vitamin A		With Vitamin A	
		Mean	± SD	Mean	± SD

3	31	1.812	0.025	1.833	0.038
3	32	1.835	0.018	1.880	0.027
4	20	1.523	0.051	1.590	0.045
4	21	1.623	0.036	1.686	0.022
4	22	1.668	0.011	1.715	0.032
4	23	1.682	0.058	1.732	0.034
4	24	1.680	0.047	1.734	0.028
4	25	1.708	0.021	1.761	0.026
4	26	1.728	0.022	1.788	0.046
4	27	1.740	0.022	1.772	0.036
4	28	1.756	0.013	1.797	0.019
4	29	1.773	0.031	1.803	0.029
4	30	1.763	0.031	1.787	0.033
4	31	1.783	0.041	1.801	0.021
4	32	1.809	0.043	1.786	0.049
5	20	1.577	0.086	1.597	0.034
5	21	1.647	0.068	1.702	0.041
5	22	1.691	0.042	1.730	0.036
5	23	1.728	0.062	1.756	0.042
5	24	1.643	0.025	1.761	0.047
5	25	1.732	0.051	1.783	0.040
5	26	1.739	0.055	1.786	0.041
5	27	1.740	0.063	1.786	0.042
5	28	1.765	0.061	1.810	0.014
5	29	1.770	0.063	1.837	0.048
5	30	1.776	0.052	1.818	0.050
5	31	1.775	0.051	1.829	0.035
5	32	1.807	0.059	1.863	0.038
6	20	1.653	0.033	1.622	0.024
6	21	1.708	0.032	1.696	0.015
6	22	1.722	0.028	1.733	0.020
6	23	1.749	0.021	1.766	0.017
6	24	1.736	0.032	1.772	0.011
6	25	1.732	0.014	1.794	0.015
6	26	1.763	0.030	1.809	0.017
6	27	1.771	0.033	1.809	0.015

Table 3.12. Weekly body weights of layers receiving 6 different levels of sodium nitrate, each treatment with and without the addition of 8000 mg/l of Vitamin A (continued)

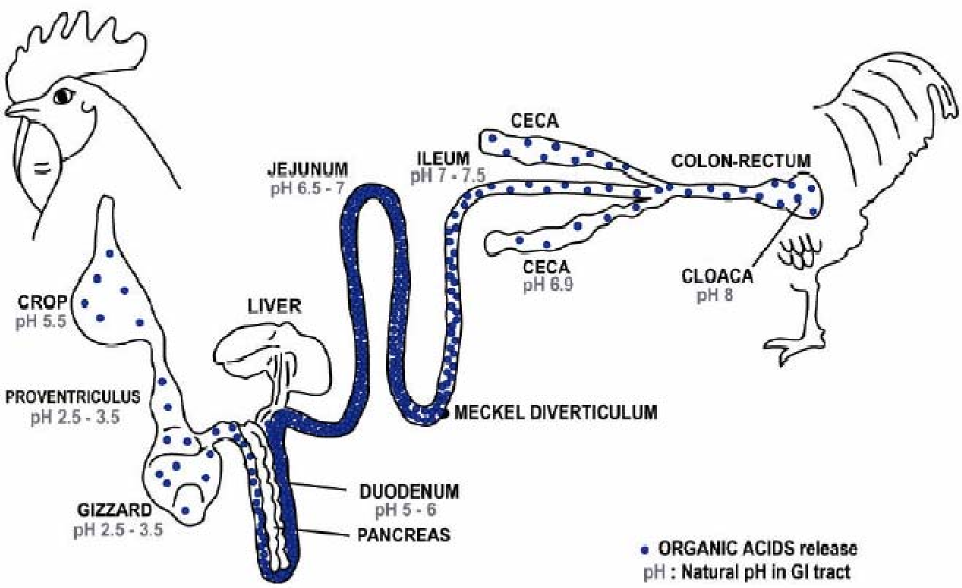
Treatment	Week	Body Weight			
		No Vitamin A		With Vitamin A	
		Mean	± SD	Mean	± SD
6	28	1.825	0.031	1.837	0.017
6	29	1.769	0.054	1.842	0.012
6	30	1.796	0.034	1.837	0.004
6	31	1.796	0.026	1.825	0.018
6	32	1.827	0.025	1.865	0.024

Discussion

Nitrate poisoning usually occurs subsequent to reduction to nitrite (Bruning-Fann and Kaneene, 1993). Acute nitrate poisoning, though common in ruminants, is rare in monogastric animals. Nitrite is approximately 2.5 times more toxic for ruminants and 10 times more toxic for monogastrics than nitrate (Emerick, 1974).

Pugh et al.; (1962) presented evidence that Vitamin A destruction in the presence of nitrite is dependent on pH. In Figure 3.2 below the natural pH of the GI tract of the chicken is shown.

Figure 3.2. pH of gastro intestinal tract of the chicken (Pugh et al; 1962)



Adapted and redrawn from Riis & Jokobsen, 1969 Hill, 1971, Simon & Versteeg, 1989 and Herpol and Van Grembergen, 1967

Roberts and Sell, (1963) found that rapid Vitamin A destruction took place in the ventriculus where the pH was below 4, and not in the crop or small and large intestines. The fact that no significant differences in nitrite levels measured in the caecum and colon in this experiment occurred support the fact that the nitrite effect reported by Roberts and Sell, (1963) indeed takes place in the ventriculus of birds before they were killed.

Supporting the findings of Adams *et al*, (1966) who found no consistent relationship in the rate of egg production, egg weight or shell thickness in chickens consuming up to 300 ppm of nitrate, the nitrate levels administered to the water in this experiment had no significant effects on the egg parameters monitored. The addition of Vitamin A however significantly increased egg production.

The decrease in feed intake observed by birds receiving the higher levels of nitrate in the water coincides with work reported by Adams *et al*., (1966).

Vough *et al*. (2000) wrote in a report on nitrate poisoning in livestock that as with feed, frequent intake of water appears to increase the total amount of nitrate that can be consumed daily without harmful effects. Conversely, water consumption limited to only once daily will reduce the level of tolerable nitrates in water before poisoning symptoms appear. This and the fact that monogastrics are less prone to nitrate poisoning would explain why no significant effects on production parameters in the layers were observed.

Conclusion

This experiment showed increased body weights in some weeks with the addition of nitrate to the water. The addition of Vitamin A to the nitrate treated water further increased body weights of hens. The increase in body weight was however not due to increased food intakes, as food intakes decreased in hens receiving elevated levels of nitrate in the drinking water. This could either be due to better feed utilization or experimental error. The addition of 8000 IU of Vitamin A had no significant influence on food intake or water intake. The hens receiving up to 300 mg/l of nitrate in the drinking water showed no significant differences in egg production or egg weight over a 12 week period.

This experiment therefore shows that relatively high concentrations of NaNO3 in drinking water are required before reductions in growth and egg production are observed in poultry.

Experiment 2: Broilers
Materials and Methods

972 Ross male day old chicks were subjected to different levels of Sodium nitrate through the drinking water. The trial design was six levels of sodium nitrate (Table 3.13) with three repetitions and 27 birds per replicate. This was then repeated with the addition of 8000 mg/l vitamin A supplemented to the water. The water from the Pretoria Municipal Source was used and the nitrates present in the water was taken into account when formulating the inclusion levels. All groups received the same commercial diet, and the prescribed vaccination program was followed. Water intake, feed intake, body weight and temperature was measured weekly. Mortalities with accompanying *post mortem* reports were acquired. After 6 weeks the trial was terminated. A representative sample of each group was sacrificed. Liver vitamin A, liver weights, thyroid weights, blood haemoglobin and methemoglobin levels were determined.

Table 3.13. Inclusion levels of nitrates:

Treatments	LEVEL (MG/L)
1	0
2	25

3	100
4	150
5	200
6	300

Statistical Analysis

Statistical analysis was done or performed using the PC - SAS Version 6.08 commercial software. Repeated measures were determined as described in Experiment 1. Means for parameters measured were analysed, using analysis of variance - PROC GLM methods. Main factors were treatment, vitamin inclusion, organ where sample was taken and interactions between these factors. These factors were analysed with week being the predictor. The significance of differences between treatments were determined with Bonveroni test at a $P < 0.05$ significance level.

Method for the determination of the Vitamin A content of the chicken livers (University of Pretoria)

Defrost livers (which have been stored at –70°C) and take a sample of approximately 2 g from each of the 2 prominent lobes of the livers. Cut into small pieces and wash with saline solution containing 0.5mg/ml EDTA and 0.5 mg/ml Vitamin C. Dry samples on filter paper, determine weight of sample and homogenise with equal amounts of saline water using an Ultra-turax.

Measure 100 µl liver homogenate into a 2ml Eppendorf micro centrifugal tube. Add 200 µl saline, 400 µl ethanol, 200 µl KOH (100%). Heat the tube for 30 minutes at 70 °C on a hotplate. Remove from plate, to cool to room temperature.

Dilute the mixture 20 times and add 100 µl in a 2 ml Eppendorf tube. Add 1 ml hexane and vortex vigorously for 50 seconds. Retain a 800 µl supernatant and put in a 1.5 ml Eppendorf tube and leave to dry making use of liquid nitrogen.

Add 50 µl methanol to the samples and vortex for 20 seconds. Put contents in a HPLC tube and chromatography.

Results

Histopathology results:

No histological lesions were evident in the gizzards, spleens, intestines and pancreas or the Bursa of Fabricius.

Hearts

Lymphoid foci were found in the treatments tabulated below. In Treatment 3 with the Vitamin A addition there was severe, chronic epicarditis (inflammation of the outside covering of the heart). The cause of the epicarditis could not be established (Table 3.14).

Table 3.14. Number of lymphoid foci found in the hearts

Treatment	No Vitamin A	With Vitamin A
1	0	2
2	2	0
3	0	1
4	2	2
5	0	1
6	0	2

Kidneys

Most kidney sections had one or more lymphoid foci present in the renal parenchyma. They were judged as mild or moderate as shown in the Table 3.15 below.

Table 3.15. Treatments where mild and moderate lymphoid foci were observed.

Treatment	No Vitamin A	With Vitamin A
Mild		
1	2	2
2	2	2
3	1	2
4	2	2
5	1	1
6	0	1
Moderate		
Treatment	**No Vitamin A**	**With Vitamin A**
1	1	0
2	0	1
3	1	1
4	0	0
5	0	0
6	1	0

The lymphoid foci found in various organs are indicative of an immune response to a persistent antigen. Most likely the antigen is a virus or mycoplasma of low pathogenicity, i.e. one that does not cause overt clinically recognizable disease.

Table 3.16. **LS Means of daily food intake (g) of broilers receiving 6 different levels of sodium nitrate, each treatment with and without the addition of 8000 mg/l of Vitamin A.**

Treatment	Week	Feed intake			
		No Vitamin A		With Vitamin A	
		Mean	± SD	Mean	± SD
1	1	13.0	0.3	14.0	0.0
1	2	44.0	2.0	44.0	1.0
1	3	96.0	3.0	94.0	5.0
1	4	120.0	4.0	117.0	3.0
1	5	136.0	3.0	137.0	5.0
1	6	151.0	6.0	151.0	0.5
2	1	14.0	0.0	14.0	0.2
2	2	45.0	3.0	42.0	0.8
2	3	97.0	5.0	89.0	1.0
2	4	123.0	1.0	113.0	3.0
2	5	139.0	1.0	134.0	3.0
2	6	144.0	7.0	146.0	2.0
3	1	14.0	0.1	14.0	0.2
3	2	44.0	3.0	42.0	1.0
3	3	98.0	2.0	93.0	0.4
3	4	122.0	2.0	115.0	0.7
3	5	141.0	6.0	135.0	4.0
3	6	140.0	3.0	150.0	3.0
4	1	14.0	0.2	14.0	0.4
4	2	44.0	0.4	42.0	1.0
4	3	98.0	4.0	91.0	1.0
4	4	125.0	5.0	113.0	1.0
4	5	134.0	2.0	129.0	3.0
4	6	145.0	8.0	144.0	5.0
5	1	14.0	0.7	13.0	0.4
5	2	44.0	1.0	41.0	1.1
5	3	96.0	5.0	86.0	5.0
5	4	120.0	2.0	110.0	4.0
5	5	137.0	4.0	129.0	3.0
5	6	147.0	2.0	144.0	3.0
6	1	14.0	0.3	14.0	0.3
6	2	42.0	1.5	43.0	1.0
6	3	93.0	3.0	91.0	2.0
6	4	115.0	2.0	114.0	5.0
6	5	133.0	3.0	135.0	6.0
6	6	143.0	3.0	144.0	1.0

Table 3.17. **LS Means of daily water intake (ml) broilers receiving 6 different levels of sodium nitrate, each treatment with and without the addition of 8000 mg/l of Vitamin A**

Treatment	WATER INTAKE				
	Week	No Vitamin A		With Vitamin A	
		Mean	± SD	Mean	± SD
1	1	53.0	2.0	44.5	8.0
1	2	82.0	1.9	84.0	3.0
1	3	150.0	31.5	139.0	1.0
1	4	180.0	5.2	175.0	5.0
1	5	252.0	6.8	257.0	19.7
1	6	285.0	10.8	287.0	26.0
2	1	49.6	1.7	40.7	5.0
2	2	86.8	2.0	79.0	2.6
2	3	147.0	2.9	132.9	2.4
2	4	186.0	2.5	166.5	2.9
2	5	268.6	1.7	254.4	8.0
2	6	275.6	4.5	270.0	4.9
3	1	49.9	3.0	40.0	10.2
3	2	85.5	0.3	81.8	1.7
3	3	147.0	1.0	139.0	1.5
3	4	190.5	1.5	174.0	4.7
3	5	278.0	8.0	269.8	4.2
3	6	279.0	2.6	281.6	10.2
4	1	52.6	1.6	44.9	4.6
4	2	87.0	2.6	82.9	2.3
4	3	148.0	4.6	140.6	3.6
4	4	190.9	3.4	177.2	2.0
4	5	280.0	6.9	266.9	15.5
4	6	292.0	1.5	280.3	6.0
5	1	50.8	3.0	44.7	4.0
5	2	86.0	1.0	82.0	0.7
5	3	149.8	2.0	137.0	1.4
5	4	188.5	7.0	174.0	4.2
5	5	283.7	9.0	252.0	11.3
5	6	303.0	3.0	288.0	17.2
6	1	44.7	0.9	41.0	1.0
6	2	81.7	1.7	77.8	3.6
6	3	145.5	3.7	143.0	1.2
6	4	185.1	3.2	182.6	6.8
6	5	286.7	15.3	270.0	10.3
6	6	294.0	3.8	298.0	6.0

Table 3.18. LS Means of weekly body weights of broilers receiving 6 different levels of sodium nitrate, each treatment with and without the addition of 8000 mg/l of Vitamin A

Treatment	*Body Weight*

	Week	No Vitamin A		With Vitamin A	
		Mean	± SD	Mean	± SD
1	1	0.039	0.000	0.039	0.000
1	2	0.118	0.012	0.109	0.005
1	3	0.330	0.004	0.318	0.014
1	4	0.712	0.019	0.677	0.030
1	5	1.213	0.210	1.177	0.050
1	6	1.714	0.002	1.650	0.064
1	7	2.210	0.036	2.195	0.064
2	1	0.038	0.001	0.038	0.000
2	2	0.114	0.002	0.107	0.006
2	3	0.338	0.006	0.313	0.013
2	4	0.712	0.127	0.666	0.024
2	5	1.238	0.022	1.165	0.047
2	6	1.720	0.012	1.637	0.059
2	7	2.205	0.056	2.166	0.015
3	1	0.039	0.001	0.039	0.001
3	2	0.118	0.004	0.107	0.004
3	3	0.337	0.006	0.318	0.005
3	4	0.714	0.015	0.684	0.009
3	5	1.232	0.033	1.185	0.015
3	6	1.733	0.036	1.581	0.061
3	7	2.181	0.031	2.151	0.004
4	1	0.040	0.000	0.039	0.001
4	2	0.123	0.007	0.103	0.005
4	3	0.348	0.004	0.305	0.012
4	4	0.731	0.009	0.666	0.019
4	5	1.1.246	0.020	1.153	0.013
4	6	1.716	0.045	1.588	0.020
4	7	2.196	0.065	2.093	0.014
5	1	0.040	0.001	0.039	0.001
5	2	0.123	0.008	0.108	0.006
5	3	0.340	0.003	0.304	0.009
5	4	0.714	0.008	0.647	0.017
5	5	1.236	0.009	1.122	0.008
5	6	1.727	0.027	1.588	0.029
5	7	2.412	0.008	2.083	0.047

Table 3.18. LS Means of weekly body weights of broilers receiving 6 different levels of sodium nitrate, each treatment with and without the addition of 8000 mg/l of Vitamin A (continued).

Treatment	Body Weight				
		No Vitamin A		With Vitamin A	
	Week	Mean	± SD	Mean	± SD
6	1	0.038	0.002	0.039	0.000
6	2	0.117	0.003	0.111	0.007
6	3	0.323	0.013	0.326	0.015
6	4	0.679	0.011	0.699	0.025
6	5	1.181	0.023	1.204	0.050
6	6	1.671	0.067	1.704	0.089
6	7	2.161	0.028	2.224	0.088

Table 3.19. LS Means of weekly feed conversion ratios of broilers receiving 6 different levels of sodium nitrate, each treatment with and without the addition of 8000 mg/l of Vitamin A

		FEED CONVERSION RATIO			
		No Vitamin A		With Vitamin A	
Treatment	**Week**	**Mean**	**Std Dev**	**Mean**	**Std Dev**
1	1	1.20	0.19	1.38	0.10
1	2	1.45	0.14	1.46	0.07
1	3	1.75	0.03	1.83	0.08
1	4	1.68	0.08	1.64	0.04
1	5	1.90	0.04	2.03	0.13
1	6	2.13	0.08	1.95	0.01
2	1	1.29	0.02	1.38	0.09
2	2	1.43	0.12	1.43	0.04
2	3	1.80	0.08	1.77	0.07
2	4	1.63	0.02	1.59	0.03
2	5	2.02	0.04	1.99	0.09
2	6	2.09	0.11	1.94	0.03
3	1	1.23	0.06	1.43	0.10
3	2	1.41	0.09	1.40	0.07
3	3	1.83	0.13	1.78	0.06
3	4	1.65	0.03	1.61	0.02
3	5	1.98	0.05	2.42	0.44
3	6	2.18	0.08	1.85	0.18
4	1	5.00	0.08	1.51	0.15
4	2	1.38	0.05	1.45	0.13
4	3	1.79	0.08	1.76	0.10
4	4	1.70	0.15	1.62	0.02
4	5	2.00	0.16	2.08	0.06
4	6	2.12	0.09	2.00	0.04
5	1	1.19	0.10	1.36	0.09
5	2	1.40	0.08	1.44	0.03
5	3	1.81	0.07	1.76	0.11
5	4	1.61	0.03	1.62	0.03
5	5	1.96	0.08	1.94	0.06
5	6	2.00	0.09	2.03	0.07
6	1	1.22	0.06	1.32	0.10
6	2	1.44	0.02	1.40	0.00
6	3	1.82	0.08	1.70	0.02
6	4	1.60	0.02	1.58	0.05
6	5	1.92	0.13	1.89	0.10
6	6	2.05	0.18	1.93	0.03

Table 3.20. LS Means of methemoglobin content (%) in blood (P = 0.8335) (SD±0.2476)

Treatment	**Methemoglobin level without Vitamin A**	**Methemoglobin level with Vitamin A**
1	-1.700	-1.800
2	-1.833	-1.733
3	-2.233	-1.967
4	-1.900	-1.933
5	-1.733	-1.633
6	-1.500	-1.733

Table 3.21. LS Means of liver weights (g) of broilers receiving 6 different levels of sodium nitrate, each treatment with and without the addition of 8000 mg/l of Vitamin A (P = 0.2200) (SD±4.0644)

Treatment	**Mean liver weights of chicks without Vitamin A in drinking water**	**Mean liver weights of chicks receiving 8000 IU of Vitamin A in drinking water**
1	45.5	38.3
2	39.6	43.333
3	38.433	46.467
4	42.2	42.367
5	37.4	44.433
6	49.333	53.767

Table 3.22. LS Means of thyroid weights (g) of broilers receiving 6 different levels of sodium nitrate, each treatment with and without the addition of 8000 mg/l of Vitamin A (P = 0.7564) (SD±1.1905)

Treatment	**Thyroid weight of chicks with no Vitamin A addition to drinking water**	**Thyroid weight of chicks receiving 8000 IU of Vitamin A in the drinking water**
1	7.867	7.133
2	8.233	7.400
3	6.033	8.200
4	8.700	8.800
5	8.300	9.100
6	8.133	6.233

Table 3.23. LS Means of liver Vitamin A concentration (mg/100g wet liver) of broilers receiving 6 different levels of sodium nitrate, each treatment with and without the addition of 8000 mg/l of Vitamin A (P = 0.0001)

Treatment	Mean liver Vitamin A concentration of chicks without Vitamin A in drinking water	SD	Mean liver Vitamin A concentration of chicks receiving 8000 IU of Vitamin A in drinking water	SD
1	18.83	±1.75	72.17	±12.93
2	17.30	±2.02	111.93	±42.48
3	14.83	±3.88	77.00	±17.61
4	19.53	±6.13	101.83	±33.12
5	25.03	±4.31	70.67	±21.31
6	19.23	±2.52	71.1	±30.27

Discussion

Sell and Roberts (1963), compared the effects of added Vitamin A to the diet versus Vitamin A administered by intramuscular injection. They reported that chicks receiving Vitamin A by injection did not utilize the vitamin as well in terms of liver storage as chicks receiving Vitamin A as part of the ration. In this experiment the Vitamin A was therefore added to the diet (water administration).

Carver and Pfander, (1973) reported a tendency for dietary nitrate administration to decrease thyroid activity. The thyroid is important in the conversion of carotene to Vitamin A (Johnson and Bauman, 1947). Since the thyroid is important in transforming carotene to Vitamin A, anything, which alters thyroid activity, should also affect Vitamin A status. Thyroid weights were therefore measured and were found not to be influenced by nitrate administration or Vitamin A addition (Table 3.22).

The Vitamin A concentrations in the livers (Table 3.23) clearly indicate that the added Vitamin A was ingested and stored in the liver.

No methemoglobin was found in the blood (Table 3.20) of any treatment group and the liver weights were not significantly influenced in any treatment (Table 3.21)

Bruning-Fann and Kaneene (1993) found that nitrite toxicity syndrome could be reproduced with potassium nitrite but not with sodium nitrate. They concluded that the weight of evidence points to the reduction of nitrate to nitrite in the plants prior to consumption by the chickens and not in vivo. This therefore supports the findings of this study that nitrate levels of up to 300mg/l of sodium nitrate have no negative influence on the food intake (Table 3.16), water intake (Table 3.18), body weights (Table 3.17) and feed conversion ratios (Table 3.19) of broilers.

Conclusion

In this experiment no negative effects on broiler production and growth were observed. However, there is a suspicion among many broiler producers that the minerals in natural sources of drinking water may affect broiler performance. This has been examined in a large-scale survey of the effect of well water on broiler performance in Arkansas (Barton, 1989). This survey used 100 broiler farms from each of three integrated poultry companies. By separating the best and poorest producers in each company, attempts were made to define the factors affecting broiler growth, food conversion, liveability and condemnation. The only mineral ion to show a significant effect on performance was nitrate, with lower nitrate concentrations in well water being associated with better performance (Balnave, 1998).

Chapter 4

Influence of Ca and P in the drinking water on egg production, egg quality, bone integrity and shell strength.

Introduction

Good shell quality is assumed to result from feeding diets high in calcium and low in phosphorus (Hartel 1990). Findings contest this assumption. Diets high in calcium are detrimental to egg weight (Ousterhout 1980) and sometimes to rates of lay (Moran et al. 1970). Insufficient dietary phosphorus depresses egg production and raises mortality (Singsen et al. 1962 and 1969, Harms and Miles 1977). It follows that there can be no single diet capable of supplying the amounts of calcium and phosphorus required for both maximal egg production and optimal shell quality.

Most nutritional studies with minerals have been carried out using dietary supplements. Little attention has been given to the role of minerals in drinking water. Underground water supplies, often containing high concentrations of dissolved salts, are a common source of drinking water for poultry in South Africa. Recent evidence suggests that some minerals in drinking water may exert adverse effects on the performance of laying hens when present at concentrations similar to those found in natural sources (Balnave and Scott 1986).

Water samples taken at poultry producers in certain areas of South Africa contained high levels of Ca and P (up to 291 and 32 mg/l respectively). This water may contribute significantly to the calcium and phosphorus status of layers. Establishing the contribution of Ca and P in the drinking water to egg shell quality and general egg production thus has immediate practical application.

The aim of this study was to establish the effect of different levels and combinations of Ca and P through the drinking water on growth, production and eggshell characteristics.

Materials and methods

The experimental animals were 720 Amber Link point of lay hens (20 weeks old), reared and vaccinated by a reputable organization to standard practices of the poultry industry. Water was administered to each repetition (20 birds) from a nipple drinker system connected to a calibrated 15 l Perspex cylinder via 5 nipples on a 3 m long pipe. Each nipple had the capacity to supply water to 12 layers. This nipple gives adequate amounts of water, yet maintains dry litter and is maintenance free. Lids on cylinders were removable for easy access and treatment administration. An outlet at the bottom simplified cleaning and refilling.

Hens were kept in a mechanically ventilated broiler house on a floor system with sawdust as bedding material. The house was divided into 36 pens of 2x3 m. Each pen housed 20 hens and was fitted with 5 wire nest boxes with wooden lids and hay as nesting material, placed on the floor of the broiler house. The temperature was measured every day in 5 evenly distributed spots throughout the house with twin bulb minimum/maximum thermometers. The thermometers were suspended about 1.5 m above floor level at the entrance, in the middle and at the end of the house. Ventilation shafts were opened and electric fans functioned for the duration of the trial to curb ammonia poisoning. The lighting program during lay was according to supplier specification. A commercial laying diet with a vitamin and mineral premix was fed throughout the laying period. The Ca level in the feed was 36.89 g/kg and the P level was 5.05 g/kg.

Two round pan feeders were suspended from the roof of each cage. The brim of the feeder was kept at the same height as the backs of the birds. The hens were subjected to different levels and combinations of Ca and P through the drinking water (Table 4.1).

Calcium lactate was tested as a source of feed calcium for hens by several workers (Heywang 1946, Essary and Holmes 1966). They determined that it was equivalent to ground limestone and precipitated calcium carbonate for supporting whole egg weight and eggshell quality. Calcium lactate was therefore used as Ca source in this trial and P was supplied with Potassium phosphate.

The trial design was 4 levels of Ca and 3 levels of P as well as 6 combinations of both. There were 3 repetitions and 20 birds per replicate. The water from the Pretoria municipal source was used and the Ca and P present in the water was taken into account when formulating the inclusion levels. Chickens were housed in an environmentally controlled broiler house, on a floor system.

Water intake, feed intake, body weight, egg production, egg weight and temperature were measured weekly. Egg yolk colour was measured using the Roché Colour Fan. Egg-breaking strengths, eggshell thickness and the plasma Ca contents of representative samples of hens were established after 6 and 12 weeks.

After 12 weeks the trial was terminated. Mortalities were recorded and post mortem reports acquired. A representative sample of hens from each treatment group was sacrificed at the end of the trial period according to The Slaughter of Poultry (Humane Conditions) Regulations (Amendment) 1990. Kidney, liver, spleen and pancreatic samples were examined histopathologically. The breaking strength of the femora was determined on raw bones using the Allo Kreamer Shear Press (Rowland et al. 1967). Pieces of representative samples of eggs from each treatment were mounted on buttons and covered with Gold Palladium for Electron Microscopic Investigation.

Table 4.1. Inclusion levels of Ca and P:

Treatment	Ca addition mg/l	P addition mg/l
1	0	0
2	100	0
3	200	0
4	300	0
5	0	150
6	100	150
7	200	150
8	300	150
9	0	300
19	100	300
11	200	300
12	300	300

Results and Discussion

Several factors are involved in eggshell formation and its subsequent quality (Butcher 1996). Major factors include, but are not limited to, the source and level of calcium in the diet, phosphorus level in the diet and temporal intake of these minerals.

Phosphorus is an important mineral for eggshell formation. Eggshells contain little phosphorus (Ca : P in eggshell is approximately 100 : 1), but this element interacts with calcium in bone formation. Calcium is stored in the skeleton almost entirely as calcium phosphate; synthesis of medullary bone requires dietary phosphorus. This phosphorus is, however, essentially superfluous, because if the calcium is used for shell formation, the phosphorus must be excreted.

Nutritional interest in phosphorus has been stimulated by several observations that dietary excess of this element has a detrimental effect on shell quality (Arscott et al. 1962, Taylor 1965, Harms 1982a and 1982b). It is not clear whether this phosphorus excess, by accumulating in the blood, interferes with mobilization of skeletal reserves of calcium phosphate during shell formation, or whether there is a direct antagonistic effect of blood phosphorus on the shell forming process. Whatever the mechanism, there is no doubt that diets which lead to an increase in plasma phosphate cause a decline in egg specific gravity and thus in shell quality. Miles and Harms (1982) showed a clear negative linear correlation between specific gravity and plasma phosphate over a range of treatments.

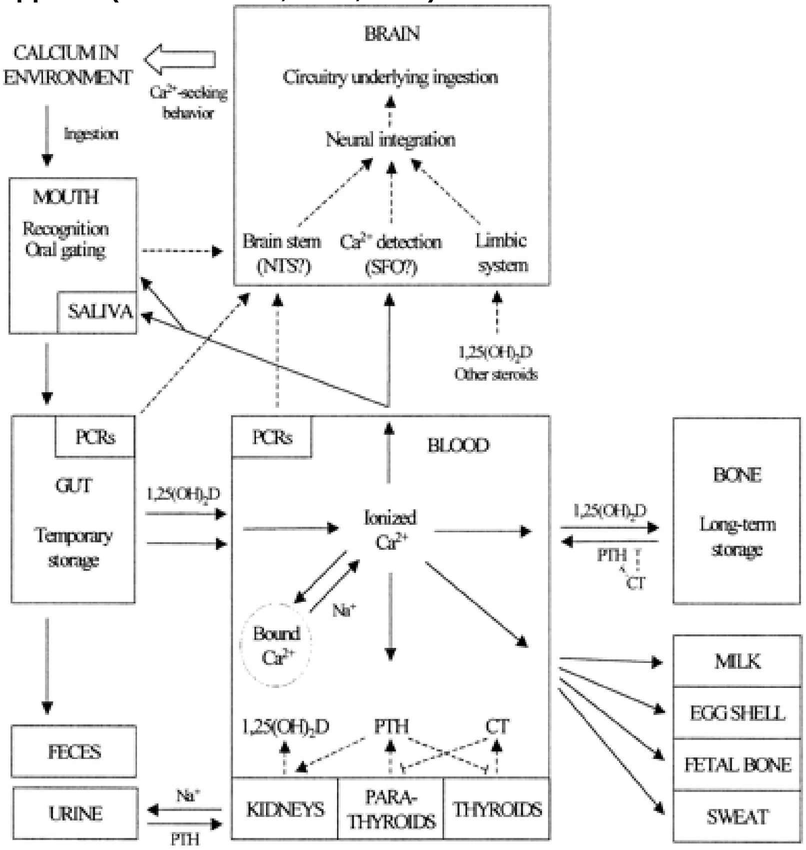
Peak plasma and organic phosphorus concentration 15 hours after ovulation may be attributable to medullary bone resorption during shell formation (Van de Velde et al. 1986). It is speculated that this rise in blood phosphorus level interferes with the mechanisms of eggshell calcification, on one hand, and taxes the hen's body through excess excretion, on the other (Anwar and Balander 2004).

The fraction of dietary Ca absorbed varies with body Ca requirements, daily Ca intake and age. The factors that increase or decrease intestinal Ca absorption are presented in Table 4.2 (Favus 1992).

Table 4.2. The factors that increase or decrease intestinal Ca absorption

Increase	**Decrease**
Vitamin D	Aging
Parathyroid hormone	Glucocorticoids
Low-Ca diet	Thyroid hormone
Growth	Phytate
Lactation	Oxalate
Pregnancy	Thiazide diuretics
Lactose	Gastric surgery
Estrogen	Metabolic acidosis
Alkalosis	

Figure 4.1. A simplified model of the relationship between calcium homeostasis and calcium appetite (Tordoff et al.; 1998, 2001)



According to this model, the primary signal for calcium appetite is derived from ionized calcium levels in the blood, which are detected by calcium receptors, perhaps in the subfornical organ (SFO). Signals concerning calcium status also arise from the oral cavity and peripheral pre- and post absorptive calcium receptors (PCRs). These may be integrated in the nucleus tractus solitarius (NTS) or other early brain stem nuclei. The influences of parathyroid hormone (PTH), calcitonin (CT) and 1,25-dihydroxyvitamin D [1,25-$(OH)_2$D] are mostly secondary to their actions on ionized calcium in the blood. However, 1,25$(OH)_2$D and other hormones may exert a direct effect on the brain to influence calcium appetite (Tordoff et.al. 1998, 2001, Figure 4.1).

In laying domestic hens (*Gallus domesticus*) 125 mg of calcium are deposited every hour (Reynolds 1997). This mobilization represents a total clearance of blood calcium every 12 min. Each eggshell requires approximately 2 g of calcium. A digestive bottleneck restricts the amount of calcium available from dietary sources to approximately 1 g per day. The shortfall is met by mobilization of calcium from the medullary bone. In extreme cases, as much as 10% of the skeletal mass can be mobilized in less than 24 hours. Although medullary bone has been reported on in other species, its role as a calcium source during egg production in small birds is poorly understood.

The calcium content of the blood of normal chickens, except hens producing eggs, was found to be practically the same as that of other animals. As pullets matured, indicated by comb development, the calcium content of the blood increased. During egg production the calcium content of the blood remained high, being from two to three times the ordinary amount. When laying ceased, either from molting or setting, the calcium content dropped to the normal level. It rose to a high level again when egg laying resumed. During egg production the amount of calcium in the blood did not remain constant, as is usually the case, but fluctuated as much as 10 milligrams from week to week. The cause of the fluctuation has not been determined.

Both the calcium and phosphorus contents of the blood are higher for hens than for cocks (Kansas State College of Agriculture and Applied Sciences, Technical Bulletin 34, 1933). Moreover, bone stores of adult hens are substantial, and calcium is conserved efficiently, making a long period of deprivation necessary (Hughes and Wood-Gush 1971).

Ninety-seven percent of the eggshell consists of calcium carbonate. The shell weighs approximately 6.0 g, so almost 6.0 g of calcium carbonate must be synthesized and deposited on the shell each time the hen produces an egg. For many hens, this is almost daily for long sequences. Calcium carbonate is 40% calcium, thus about 2.5 g of elemental calcium must be found and transported to the shell gland in the 18-20 hours it takes to form the eggshell. The calcium content of blood at any given time is no more than 30 mg. Thus the shell contains over 80 times more calcium than the blood (Hunton 2005).

In a study done by Scheideler et al. (1995) the serum Ca levels of broilers fed 140% of the NRC recommendation was 9.21 mg/dl. In this study the Ca level in the blood ranged from 195.833 mg/l in treatment 8 to 267.917 mg/l in treatment 5. These differences were, however, not significant ($P = 0.2394$, Table 4.3).

Eggshell is a relatively constant proportion of egg weight (Djader 1982). Lennards et al. (1981) found no relationship between serum calcium and shell weight or egg weight. They concluded that the normal variation in serum calcium is not related to the hen’s ability to produce eggshell.

Table 4.3 Blood Ca levels of hens receiving different levels and combinations of Ca and P (mg/l) P = 0.2394

Treatment	Ca inclusion in water (mg/l)	P inclusion in water (mg/l)	Mean blood Ca levels after 12 weeks	*SD*
1	0	0	260.000[a]	±38.058
2	100	0	228.750[a]	±55.043
3	200	0	214.167[a]	±23.596
4	300	0	223.750[a]	±26.605
5	0	150	267.917[a]	±34.286
6	100	150	224.583[a]	±21.878
7	200	150	196.250[a]	±14.416
8	300	150	195.833[a]	±32.890
9	0	300	212.500[a]	±45.208
10	100	300	228.333[a]	±41.727
11	200	300	248.333[a]	±12.521
12	300	300	219.583[a]	±22.512

Ca and P treatment had a significant influence (P = 0.0001) on weekly body weight (Table 4.4). The mean body weights, measured over the whole period were, however, not significantly affected by Ca and P administration (P = 0.7624). There were no significant interactions between Ca and P levels and the duration of exposure to treatments, 6 or 12 weeks, on body weight (P = 0.3534).

Table 4.4. LS Means of body weight (kg) of hens receiving different levels of Ca and P in the drinking water.

LS Means for weekly body weight (kg)														
Treatment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
1	1.438	1.760	1.674	1.691	1.699	1.727	1.749	1.763	1.764	1.782	1.786	1.789	1.786	1.812
±SD	*0.066*	*0.221*	*0.059*	*0.059*	*0.058*	*0.051*	*0.045*	*0.040*	*0.040*	*0.041*	*0.023*	*0.029*	*0.017*	*0.006*
2	1.476	1.757	1.713	1.726	1.717	1.759	1.782	1.791	1.805	1.811	1.829	1.820	1.838	1.865
±SD	*0.019*	*0.335*	*0.016*	*0.016*	*0.017*	*0.007*	*0.009*	*0.018*	*0.011*	*0.011*	*0.003*	*0.007*	*0.011*	*0.021*
3	1.441	1.535	1.672	1.706	1.718	1.737	1.756	1.765	1.773	1.790	1.795	1.792	1.825	1.856
±SD	*0.045*	*0.041*	*0.034*	*0.041*	*0.042*	*0.035*	*0.039*	*0.033*	*0.032*	*0.042*	*0.035*	*0.050*	*0.055*	*0.046*
4	1.488	1.562	1.669	1.695	1.720	1.749	1.769	1.775	1.785	1.801	1.814	1.806	1.822	1.844
±SD	*0.039*	*0.042*	*0.052*	*0.025*	*0.046*	*0.036*	*0.052*	*0.042*	*0.054*	*0.038*	*0.034*	*0.039*	*0.034*	*0.056*
5	1.446	1.537	1.666	1.700	1.727	1.754	1.763	1.764	1.772	1.789	1.801	1.796	1.810	1.815
±SD	*0.027*	*0.027*	*0.017*	*0.025*	*0.042*	*0.036*	*0.019*	*0.015*	*0.023*	*0.027*	*0.036*	*0.039*	*0.043*	*0.050*
6	1.430	1.584	1.669	1.671	1.685	1.713	1.752	1.767	1.775	1.807	1.797	1.799	1.811	1.833
±SD	*0.022*	*0.098*	*0.035*	*0.045*	*0.044*	*0.042*	*0.010*	*0.027*	*0.022*	*0.054*	*0.020*	*0.013*	*0.023*	*0.027*
7	1.492	1.571	1.680	1.709	1.744	1.762	1.792	1.787	1.798	1.786	1.823	1.826	1.844	1.834
±SD	*0.040*	*0.037*	*0.027*	*0.031*	*0.016*	*0.020*	*0.042*	*0.022*	*0.027*	*0.057*	*0.041*	*0.040*	*0.029*	*0.023*

Table 4.4. LS Means of body weight (kg) of hens receiving different levels of Ca and P in the drinking water (continued).

LS Means for weekly body weight (kg)														
Treat ment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
8	1.504	1.592	1.710	1.730	1.747	1.763	1.787	1.783	1.797	1.831	1.815	1.811	1.830	1.837
±SD	*0.021*	*0.035*	*0.022*	*0.015*	*0.028*	*0.020*	*0.029*	*0.022*	*0.024*	*0.029*	*0.037*	*0.030*	*0.028*	*0.026*
9	1.439	1.556	1.671	1.690	1.703	1.732	1.754	1.763	1.770	1.784	1.787	1.787	1.797	1.809
±SD	*0.017*	*0.013*	*0.031*	*0.035*	*0.044*	*0.033*	*0.056*	*0.045*	*0.046*	*0.046*	*0.056*	*0.051*	*0.048*	*0.055*
10	1.409	1.523	1.666	1.680	1.697	1.719	1.738	1.749	1.764	1.803	1.786	1.785	1.805	1.818
±SD	*0.058*	*0.043*	*0.038*	*0.043*	*0.048*	*0.049*	*0.040*	*0.037*	*0.050*	*0.064*	*0.052*	*0.048*	*0.049*	*0.045*
11	1.449	1.562	0.681	1.701	1.719	1.747	1.766	1.746	1.776	1.790	1.807	1.805	1.821	1.833
±SD	*0.076*	*0.090*	*0.062*	*0.055*	*0.063*	*0.054*	*0.061*	*0.047*	*0.041*	*0.036*	*0.049*	*0.048*	*0.046*	*0.040*
12	1.468	1.556	1.663	1.716	1.725	1.752	1.765	1.770	1.779	1.788	1.794	1.797	1.802	1.821
±SD	*0.014*	*0.040*	*0.045*	*0.013*	*0.008*	*0.018*	*0.002*	*0.007*	*0.016*	*0.017*	*0.016*	*0.018*	*0.012*	*0.012*

Table 4.5. Mean body weight of birds over time (kg). P = 0.7624

Treatment	Ca inclusion in water (mg/l)	P inclusion in water (mg/l)	Body weight	SD
1	0	0	1.730	0.228
2	100	0	1.763	0.024
3	200	0	1.726	0.036
4	300	0	1.736	0.041
5	0	150	1.724	0.024
6	100	150	1.721	0.012
7	200	150	1.746	0.025
8	300	150	1.753	0.018
9	0	300	1.717	0.04
10	100	300	1.710	0.044
11	200	300	1.729	0.052
12	300	300	1.728	0.01

Ca and P treatment had a significant influence on egg production in terms of eggs/hen/week or % (Table 4.6, P = 0.0004), but no significant influence on egg mass (Table 4.7, P = 0.4175). Interactions between Ca and P levels and exposure time to the treatments did not affect egg production (P = 0.8838) and egg weight (P = 0.4747) significantly. Mean egg production and egg weight over the trial period were not affected by Ca and P administration (Table 4.8).

Dietary phosphorus appears to have a biphasic effect on eggshell quality. An inadequate level of P in the diet reduces eggshell quality; high dietary P also has detrimental effects. The mechanism by which a high level of dietary P adversely affects eggshell quality has not yet been determined.

Possible mechanisms have been suggested (Keshavarz and Austic 1990). Calcium absorption may be reduced because of the formation of insoluble calcium phosphate in the gastrointestinal tract. An increased level of P may reduce the mobilization of Ca from the bones for shell formation. P ions could inhibit normal precipitation of calcium carbonate under physiological conditions.

There was a significant (P = 0.0001) interaction between P levels in the eggshells and exposure time to P administration (Table 4.9). The P levels in the shells decreased as the P levels in the water were increased. The Ca content of the shells was not significantly influenced by Ca and P addition to the drinking water (Table 4.10).

As age advances, proportion of yolk increases, whereas proportions of albumen and shell thickness decrease (Akbar et al. 1983, Fletcher et al. 1983).

There was no significant (P = 0.2261) interaction between eggshell thickness and the exposure time to the Ca and P treatments (Table 4.11).

Although Ca and P are two major macro-minerals involved in bone formation (Frost and Roland 1991), strength or weakness of eggshell is more directly related to carbonic anhydrase activity than to Ca-ATPase, calcium-binding protein in shell gland +2 (Balnave et al. 1992) and serum Ca concentration (Lennards et al. 1981).

In the case of alkalosis, decreased concentration of ionized Ca in serum negatively affects shell formation (Odom et al. 1986). Lower solubility of dietary Ca and slower rate of passage limit the formation of eggshell (Gordon and Roland 1997). Skeletal and urinary Ca metabolism does not affect eggshell quality (Buss et al. 1980).

Eggshell strength depends on its thickness, weight and structure. The mineral content of the diet influences those parameters more than the breed does (Lennards et al. 1981, Junqueira et al. 1984, Clunies and Leeson 1995). Eggshell is a relatively constant proportion of egg weight (Djader 1982).

In this experiment there was a significant (P = 0.0268) interaction between eggshell breaking strength and the exposure time to the Ca and P administration (Table 4.12). There was no significant (P = 0.1963) interaction between the Roché colour score of egg yolks and the exposure time to the treatments. The average score was between 8 and 9 during the first 6 weeks, and between 7 and 8 during the second 6 weeks (Table 4.13).

Table 4.6. LS Means of egg production (eggs /hen/week) of hens receiving different levels of Ca and P in the drinking water (SD± 0.2127).

Treatment	Wk 20	Wk 21	Wk 22	Wk 23	Wk 24	Wk 25	Wk 26	Wk 27	Wk 28	Wk 29	Wk 30	Wk 31	Wk 32
1	0.33	1.87	4.30	5.77	6.20	6.38	6.40	6.60	6.37	6.75	6.45	6.62	6.67
±*SD*	*0.225*	*0.928*	*1.146*	*0.153*	*0.278*	*0.058*	*0.050*	*0.259*	*0.340*	*0.350*	*0.346*	*0.231*	*0.115*
2	0.15	1.70	4.28	5.38	5.87	6.3	6.57	6.63	6.45	6.60	6.45	6.5	6.58
±*SD*	*0.132*	*0.950*	*0.711*	*0.500*	*0.520*	*0.450*	*0.208*	*0.231*	*0.278*	*0.346*	*0.436*	*0.132*	*0.333*
3	0.25	1.72	3.92	5.57	5.76	6.27	6.38	6.28	6.65	6.58	6.52	6.62	6.25
±*SD*	*0.312*	*0.725*	*0.448*	*0.535*	*0.577*	*0.501*	*0.548*	*0.375*	*0.265*	*0.765*	*0.231*	*0.513*	*0.841*
4	0.52	3.00	4.75	5.05	5.95	6.32	6.60	6.23	6.60	6.77	6.60	6.65	6.83
±*SD*	*0.369*	*0.737*	*0.180*	*0.477*	*0.391*	*0.104*	*0.229*	*0.473*	*0.458*	*0.126*	*0.180*	*0.100*	*0.189*
5	0.22	1.95	4.07	5.93	5.85	6.38	6.47	6.62	6.68	6.78	6.62	6.43	6.75
±*SD*	*0.029*	*0.650*	*0.454*	*0.454*	*0.695*	*0.369*	*0.126*	*0.379*	*0.202*	*0.115*	*0.318*	*0.225*	*0.132*
6	0.10	1.95	4.53	6.02	5.80	6.43	6.50	6.41	6.69	6.89	6.65	6.60	6.95
±*SD*	*0.132*	*0.300*	*0.284*	*0.306*	*0.577*	*0.161*	*0.350*	*0.429*	*0.056*	*0.367*	*0.342*	*0.266*	*0.087*

Table 4.6. LS Means of egg production (eggs /hen/week) of hens receiving different levels of Ca and P in the drinking water (SD± 0.2127) (continued).

Treatment	Wk 20	Wk 21	Wk 22	Wk 23	Wk 24	Wk 25	Wk 26	Wk 27	Wk 28	Wk 29	Wk 30	Wk 31	Wk 32
7	0.30	2.45	3.95	5.32	5.47	6.15	6.37	6.35	6.42	6.70	6.52	6.58	6.80
±SD	*0.361*	*1.117*	*0.650*	*0.675*	*0.597*	*0.132*	*0.318*	*0.278*	*0.293*	*0.312*	*0.351*	*0.208*	*0.477*
8	0.30	2.38	4.52	5.62	5.85	6.08	6.47	6.63	6.57	6.65	6.48	6.48	6.77
±SD	*0.229*	*0.225*	*0.843*	*0.076*	*0.265*	*0.525*	*0.225*	*0.104*	*0.153*	*0.100*	*0.275*	*0.251*	*0.202*
9	0.25	2.10	4.08	5.37	6.07	6.22	6.35	6.45	6.55	6.62	6.55	6.67	7.05
±SD	*0.304*	*0.901*	*0.575*	*0.551*	*0.633*	*0.104*	*0.132*	*0.350*	*0.563*	*0.375*	*0.200*	*0.153*	*0.278*
10	0.22	2.07	4.42	5.22	5.98	6.48	6.52	6.37	6.48	6.88	6.68	6.58	6.85
±SD	*0.333*	*0.551*	*0.592*	*0.750*	*0.635*	*0.076*	*0.355*	*0.480*	*0.553*	*0.104*	*0.340*	*0.379*	*0.173*
11	0.27	2.22	4.35	6.13	5.75	6.15	6.52	6.43	6.53	6.67	6.45	6.64	6.81
±SD	*0.202*	*0.729*	*0.608*	*0.231*	*0.444*	*0.377*	*0.257*	*0.437*	*0.437*	*0.407*	*0.225*	*0.295*	*0.185*
12	0.35	2.65	5.10	6.13	6.05	6.57	6.73	6.67	6.77	6.95	6.75	6.48	6.88
±SD	*0.132*	*0.229*	*0.132*	*0.231*	*0.312*	*0.189*	*0.340*	*0.058*	*0.289*	*0.100*	*0.100*	*0.104*	*0.404*

Table 4.7. LS Means of egg weight (g) of eggs produced by hens receiving different levels of Ca and P in the drinking water (SD±2.3615).

Treatment	Wk 20	Wk 21	Wk 22	Wk 23	Wk 24	Wk 25	Wk 26	Wk 27	Wk 28	Wk 29	Wk 30	Wk 31	Wk 32
1	37.94	47.62	53.77	48.61	50.80	52.27	53.37	54.60	54.71	55.70	56.10	56.67	56.53
±SD	*1.257*	*1.852*	*15.95*	*0.896*	*1.05*	*0.607*	*0.226*	*0.809*	*0.537*	*0.546*	*0.404*	*0.283*	*0.238*
2	23.58	49.44	46.18	48.22	50.77	54.22	54.34	55.01	54.82	55.91	56.35	57.14	56.55
±SD	*20.44*	*3.149*	*2.170*	*1.104*	*0.044*	*0.614*	*0.839*	*1.066*	*0.759*	*0.706*	*0.687*	*0.683*	*1.153*
3	23.55	44.99	45.59	48.41	51.39	52.60	54.08	54.43	54.59	55.40	56.09	56.33	58.31
±SD	*20.40*	*2.501*	*1.429*	*1.493*	*0.838*	*0.452*	*0.264*	*1.036*	*0.857*	*0.571*	*0.706*	*0.837*	*2.989*
4	37.68	43.93	44.95	47.53	50.05	51.68	52.43	53.05	53.59	54.75	55.47	55.53	56.42
±SD	*1.477*	*1.823*	*2.486*	*1.076*	*1.014*	*0.849*	*1.262*	*0.833*	*1.487*	*0.946*	*1.062*	*1.458*	*0.814*
5	35.99	44.45	44.44	47.97	50.57	52.05	53.28	53.70	54.02	55.13	55.44	55.93	56.16
±SD	*2.267*	*1.822*	*0.709*	*0.740*	*1.277*	*0.704*	*1.189*	*1.006*	*0.418*	*0.571*	*1.119*	*0.833*	*0.347*
6	20.50	46.57	44.94	48.08	51.75	53.23	54.22	54.52	54.76	56.45	56.51	56.85	57.12
±SD	*19.25*	*1.002*	*1.636*	*2.687*	*0.277*	*0.494*	*0.358*	*0.453*	*0.916*	*0.978*	*0.978*	*0.716*	*0.762*

Table 4.7. LS Means of egg weight (g) of eggs produced by hens receiving different levels of Ca and P in the drinking water (SD±2.3615) (continued).

Treatment	Wk 20	Wk 21	Wk 22	Wk 23	Wk 24	Wk 25	Wk 26	Wk 27	Wk 28	Wk 29	Wk 30	Wk 31	Wk 32
7	25.79	46.25	44.75	48.33	50.38	52.42	52.97	53.69	53.74	55.04	55.65	55.96	56.34
±SD	*22.40*	*2.579*	*0.503*	*0.832*	*1.331*	*1.741*	*1.119*	*1.036*	*1.593*	*0.712*	*1.158*	*1.616*	*1.550*
8	36.28	46.17	44.70	47.83	50.22	52.24	52.97	54.12	54.40	54.91	55.50	55.86	56.26
±SD	*2.362*	*1.583*	*0.905*	*0.624*	*0.724*	*0.657*	*0.841*	*0.856*	*0.322*	*0.375*	*0.654*	*0.460*	*0.635*
9	39.66	47.86	45.13	48.10	50.42	52.21	54.38	53.58	53.94	54.61	55.00	54.32	55.79
±SD	*4.969*	*0.758*	*1.994*	*0.787*	*0.918*	*1.026*	*1.938*	*1.131*	*1.832*	*1.515*	*1.389*	*3.247*	*1.346*
10	24.79	48.51	45.02	48.64	50.73	53.12	53.45	54.19	54.48	55.31	54.34	56.58	56.88
±SD	*21.52*	*0.625*	*0.547*	*0.775*	*0.723*	*0.739*	*1.086*	*0.809*	*0.904*	*1.400*	*3.574*	*1.335*	*1.117*
11	39.54	47.87	45.91	49.38	52.00	53.43	54.10	55.09	55.03	55.67	56.64	56.60	57.04
±SD	*5.537*	*3.209*	*4.401*	*0.133*	*0.434*	*0.493*	*0.365*	*0.912*	*0.785*	*1.243*	*1.020*	*0.959*	*0.856*
12	40.16	46.81	42.40	48.63	51.54	52.44	53.09	53.50	54.04	55.31	55.14	55.57	55.90
±SD	*0.370*	*1.125*	*2.013*	*0.734*	*1.494*	*0.445*	*0.423*	*0.428*	*1.059*	*1.178*	*1.431*	*1.056*	*0.814*

Ca and P treatment had a significant influence (P = 0.0004) on egg production (eggs/hen/week or %) but no significant influence on egg mass (P = 0.4175). There were no significant interactions between Ca and P administered and exposure time to the treatments on egg production (P = 0.8838) and egg weight (P = 0.4747).

Table 4.8. Mean egg production and egg weight per treatment over weeks.

Treatment	Ca inclusion in water (mg/l)	P inclusion in water (mg/l)	Egg Production (Eggs/hen/week) P = 0.7496	Egg production (%) P = 0.7761	Egg weight (g) P = 0.6842
1	0	0	5.438	77.563	52.206
2	100	0	5.344	76.337	50.964
3	200	0	5.289	75.549	50.443
4	300	0	5.528	78.718	50.544
5	0	150	5.442	77.747	50.702
6	100	150	5.502	77.754	50.424
7	200	150	5.336	76.099	50.099
8	300	150	5.446	77.802	50.88
9	0	300	5.409	77.271	51.155
10	100	300	5.442	77.747	50.464
11	200	300	5.455	77.817	52.176
12	300	300	5.699	81.41	51.118

Table 4.9. P contents of the egg shells (%)

Treatment	Ca inclusion in water (mg/l)	P inclusion in water (mg/l)	Mean P content (%) after 6 weeks.	SD	Mean P contents (%) after 12 weeks.	SD
1	0	0	0.119a	0.005	0.115a	0.005
2	100	0	0.123a	0.007	0.120ab	0.004
3	200	0	0.120a	0.007	0.116ab	0.009
4	300	0	0.130a	0.009	0.126ab	0.002
5	0	150	0.122a	0.011	0.115ab	0.005
6	100	150	0.123a	0.001	0.116ab	0.001
7	200	150	0.120a	0.01	0.111ab	0.006
8	300	150	0.125a	0.007	0.108ab	0.006
9	0	300	0.126a	0.005	0.123ab	0.003
10	100	300	0.113a	0.009	0.113ab	0.006
11	200	300	0.129a	0.008	0.119ab	0.005
12	300	300	0.123a	0.006	0.114b	0.002

Table 4.10. Ca contents of the egg shells (%)

Treatment	Ca inclusion in water (mg/l)	P inclusion in water (mg/l)	Mean Ca content (%) after 6 weeks	± SD	Mean Ca contents (%) after 12 weeks.	± SD
1	0	0	30.947	1.167	31.053	1.372
2	100	0	30.79	0.79	29.213	2.298
3	200	0	31.333	0.577	31.23	0.488
4	300	0	31.06	0.567	30.897	0.179
5	0	150	31.35	0.488	30.163	0.545
6	100	150	29.833	0.951	30.493	0.43
7	200	150	30.793	0.845	30.503	0.775
8	300	150	29.567	2.072	30.497	0.556
9	0	300	29.403	0.438	29.473	0.607
10	100	300	30.067	0.634	29.833	0.951
11	200	300	30.43	1.444	30.69	0.1
12	300	300	29.803	0.195	29.733	0.94

Table 4.11. Eggshell thickness of hens receiving different levels and combinations of Ca and P (mm) P = 0.4213

Treatment	Ca inclusion in water (mg/l)	P inclusion in water (mg/l)	Mean shell thickness (mm) after 6 weeks.	± SD	Mean shell thickness (mm) after 12 weeks.	± SD
1	0	0	0.423a	0.035	0.369a	0.034
2	100	0	0.424a	0.03	0.391ab	0.018
3	200	0	0.429a	0.036	0.381ab	0.035
4	300	0	0.419a	0.037	0.381ab	0.027
5	0	150	0.422a	0.037	0.379ab	0.037
6	100	150	0.426a	0.035	0.379ab	0.029
7	200	150	0.447a	0.042	0.374ab	0.03
8	300	150	0.447a	0.033	0.379ab	0.034
9	0	300	0.419a	0.036	0.361ab	0.025
10	100	300	0.432a	0.044	0.368ab	0.036
11	200	300	0.419a	0.041	0.355ab	0.032
12	300	300	0.436a	0.037	0.373b	0.027

Table 4.12. Eggshell breaking strength of hens receiving different levels and combinations of Ca and P (N) P = 0.4213

Treatment	Ca inclusion in water (mg/l)	P inclusion in water (mg/l)	Mean shell breaking strength (N) after 6 weeks. P = 0.5254	± SD	Mean shell breaking strength (N) after 12 weeks. P = 0.0820	± SD
1	0	0	36.898a	9.884	38.934a	6.988
2	100	0	36.145a	8.046	39.993a	6.211
3	200	0	37.998a	10.671	38.232a	8.635
4	300	0	38.492a	8.57	34.977a	7.899
5	0	150	43.532a	12.283	35.545a	11.579
6	100	150	35.789a	8.572	41.181a	6.634
7	200	150	38.771a	12.669	42.642a	8.999
8	300	150	38.610a	8.803	37.165a	8.784
9	0	300	40.605a	7.794	34.088a	11.673
10	100	300	36.183a	9.271	38.184a	11.066
11	200	300	39.487a	9.446	34.686a	9.054
12	300	300	38.175a	7.263	39.038a	6.583

Images from the scanning electron microscope taken from eggs in the control group, the treatment with the lowest (Treatment 7) and highest (Treatment 9) eggshell breaking strengths are presented in Figures 4.2, 4.3 and 4.4 below. As can be seen, the shell of Treatment 7 is much more crystalline and the higher breaking strength is explained.

Figure 4.2. Lateral view of the eggshell from an egg of Treatment 1 (control) (x200).

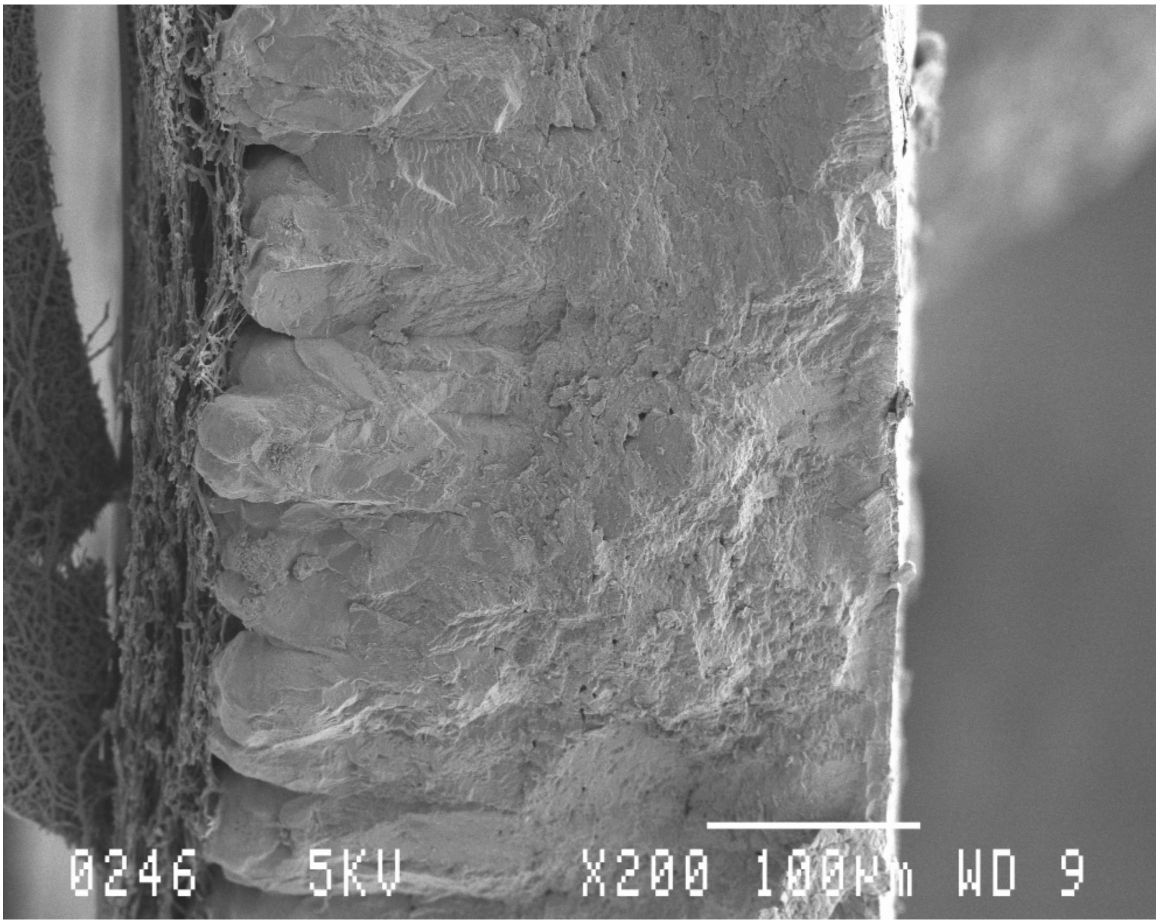


Figure 4.3 Lateral view of the eggshell of an egg from Treatment 7 (x200).

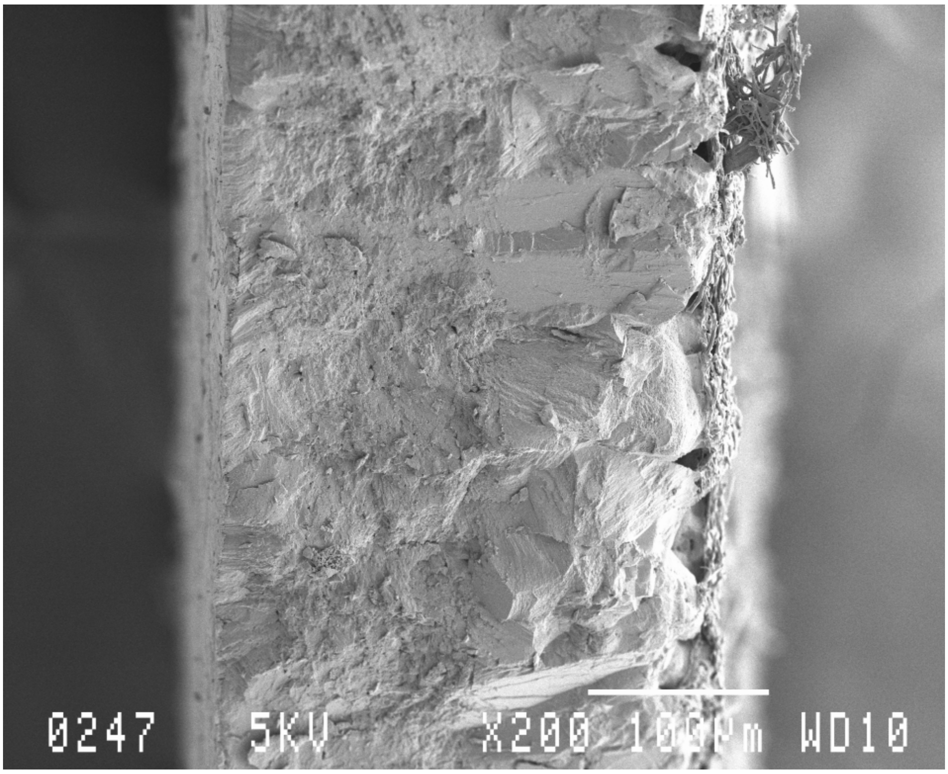


Figure 4.4. Lateral view of the eggshell of an egg from Treatment 9 (x200)

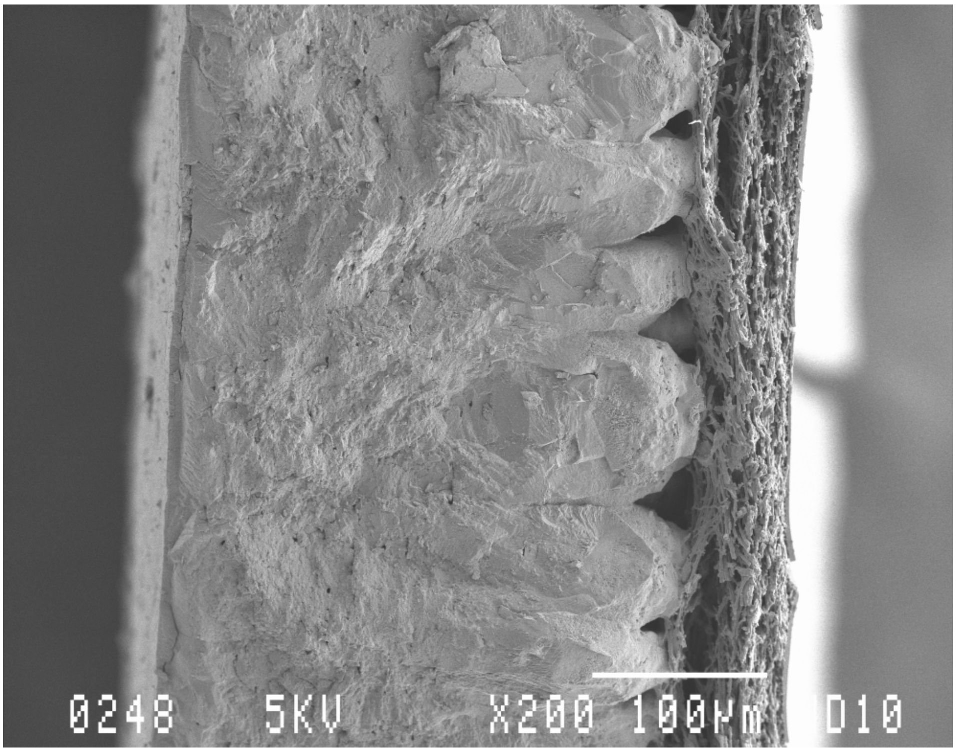


Figure 4.5 Outer shell of Treatment 1. (x 10 000)

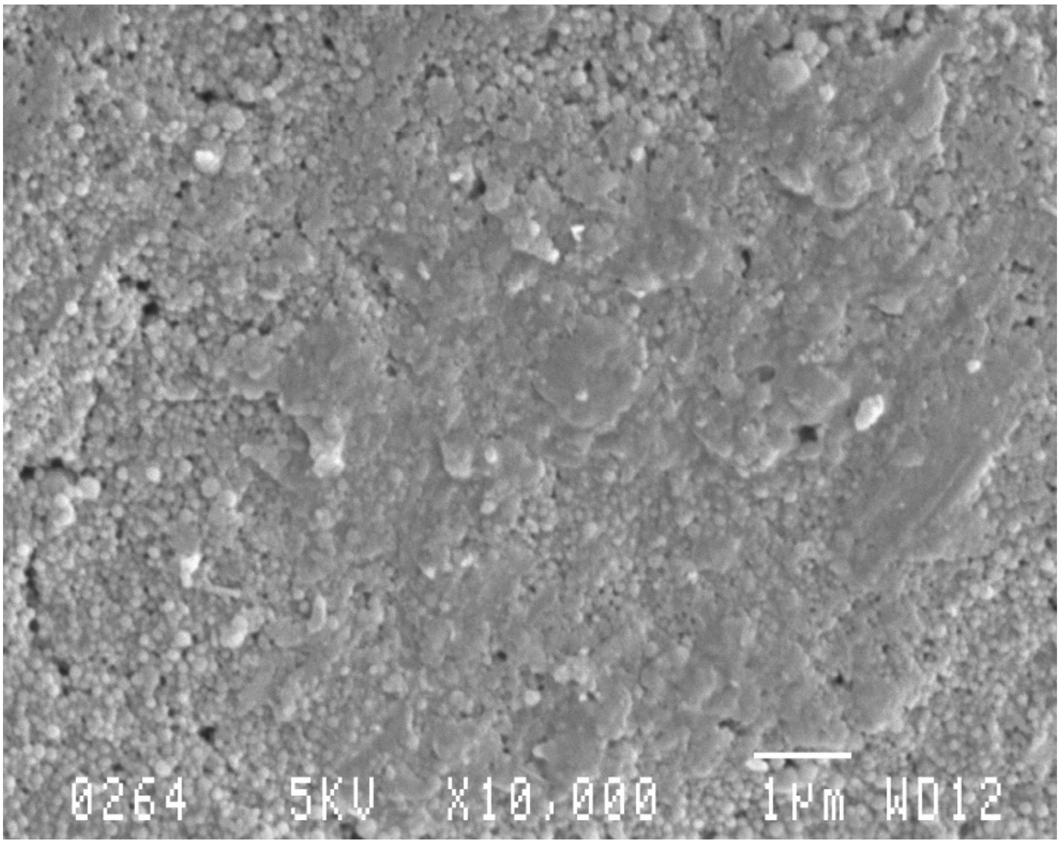


Figure 4.6. Outer shell of Treatment 7. (x 10 000)

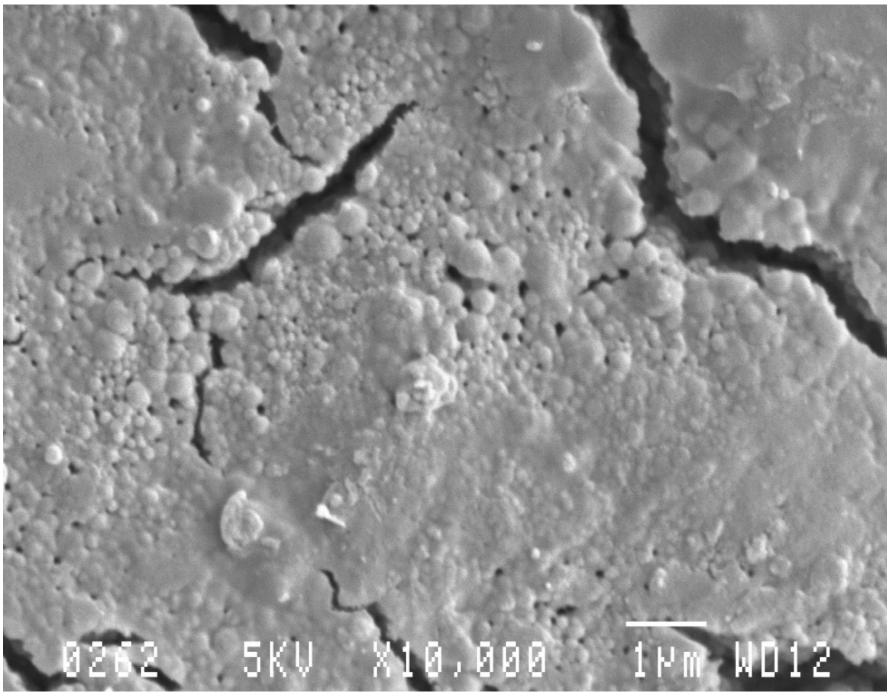
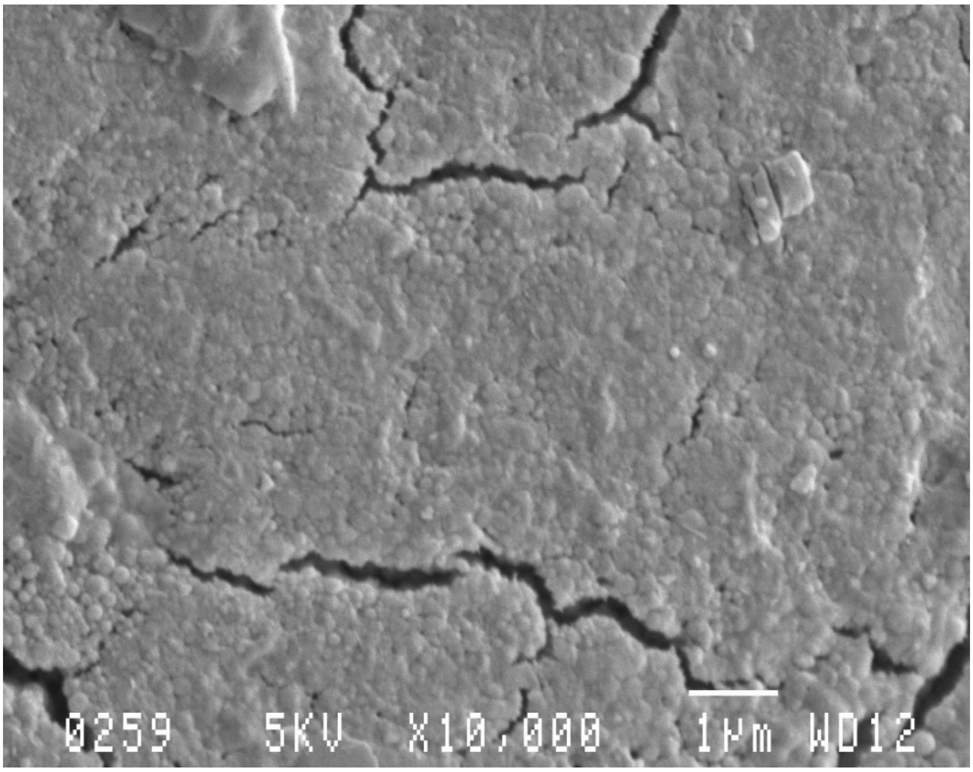


Figure 4.7. Outer shell of Treatment 9. (x 10 000)

Looking at the outer surface of the eggs the shells in Treatments 1, 7 and 9, a marked difference in the



outer shell appearance and structural soundness can be observed (Figures 4.5, 4.6, and 4.7, above). This corresponds to the treatments administered.

Table 4.13. Roché egg yolk colour score of hens receiving different levels and combinations of Ca and P (P = 0.4213)

Treatment	Ca inclusion in water (mg/l)	P inclusion in water (mg/l)	Mean Roché colour score after 6 weeks. P = 0.1111	± SD	Mean Roché colour score after 12 weeks. P = 0.0190	± SD
1	0	0	9.222a	0.808	8.500a	0.924
2	100	0	9.000a	0.686	7.722a	1.018
3	200	0	9.222a	0.732	8.556a	0.984
4	300	0	8.556a	0.783	7.889a	1.079
5	0	150	9.000a	0.594	8.056a	0.802
6	100	150	9.056a	0.539	8.167a	1.043
7	200	150	9.000a	0.594	8.722a	0.669
8	300	150	9.056a	0.416	7.778a	1.166
9	0	300	8.833a	0.618	8.111a	0.963
10	100	300	9.056a	0.416	8.389a	0.85
11	200	300	9.111a	0.583	7.944a	0.802
12	300	300	9.111a	0.583	8.000a	1.085

Ca and P treatment had a significant influence (P = 0.0001) on feed intake (Table 4.14). There was however no significant interaction between Ca and P administered and exposure time to the treatments on feed intake (P = 0.7835).

Table 4.14. LS Means of daily food intake (g) of hens receiving different levels of Ca and P in the drinking water

Treatment	Wk 20	Wk 21	Wk 22	Wk 23	Wk 24	Wk 25	Wk 26	Wk 27	Wk 28	Wk 29	Wk 30	Wk 31	Wk 32
1	96	135	134	141	149	146	151	155	156	155	159	167	170
±SD	10.46	1.74	10.25	10.30	4.91	2.70	4.04	1.08	3.91	3.62	3.50	10.97	4.91
2	98	132	129	135	145	140	144	148	143	144	150	154	150
±SD	6.71	4.19	6.98	2.50	6.50	3.69	5.81	1.71	8.14	9.39	5.20	6.88	0.44
3	99	133	131	137	147	148	150	151	156	152	151	158	156
±SD	4.43	1.93	2.77	1.62	3.18	2.62	4.96	6.69	6.40	1.85	2.21	5.47	3.12
4	97	131	137	140	149	151	150	153	153	152	153	157	157
±SD	9.39	6.97	7.74	13.31	11.54	14.57	15.21	14.25	11.33	8.08	13.26	14.72	10.60
5	99	130	133	140	144	150	145	149	147	150	149	154	153
±SD	11.61	3.97	9.64	7.45	6.36	10.37	7.30	4.72	6.03	8.43	2.23	2.66	3.57
6	96	129	131	145	152	152	141	154	157	159	163	168	166
±SD	9.815	12.74	9.32	9.47	13.80	11.74	1.08	14.52	17.30	16.91	19.91	19.75	17.38
7	100	126	129	135	142	144	142	146	151	150	151	156	154
±SD	12.27	4.30	4.53	3.84	2.74	3.68	7.90	9.12	7.07	6.90	6.81	11.08	8.90

Table 4.14. LS Means of daily food intake (g) of hens receiving different levels of Ca and P in the drinking water (continued).

Treatment	Wk 20	Wk 21	Wk 22	Wk 23	Wk 24	Wk 25	Wk 26	Wk 27	Wk 28	Wk 29	Wk 30	Wk 31	Wk 32
8 ±*SD*	106 *10.11*	139 *6.19*	136 *4.96*	147 *8.54*	148 *5.80*	151 *10.09*	149 *12.51*	152 *11.57*	156 *10.83*	155 *12.18*	162 *10.01*	164 *6.33*	164 *10.19*
9 ±*SD*	99 *5.93*	126 *2.76*	129 *8.98*	133 *7.08*	138 *7.20*	139 *10.61*	142 *8.63*	142 *12.97*	145 *11.82*	145 *12.48*	148 *13.52*	155 *13.93*	155 *9.27*
10 ±*SD*	101 *9.17*	135 *10.74*	136 *12.62*	131 *10.57*	144 *13.68*	141 *11.36*	139 *7.56*	144 *8.15*	146 *6.00*	149 *5.31*	151 *7.59*	150 *7.27*	155 *11.57*
11 ±*SD*	100 *15.99*	133 *8.59*	129 *10.93*	133 *10.49*	146 *11.73*	145 *10.93*	140 *8.36*	146 *9.23*	148 *5.13*	147 *6.36*	153 *5.19*	156 *7.18*	157 *8.37*
12 ±*SD*	103 *1.46*	130 *7.00*	134 *5.09*	143 *7.79*	150 *6.94*	150 *5.97*	149 *7.68*	153 *11.03*	152 *6.90*	152 *2.27*	152 *4.17*	154 *2.91*	154 *2.26*

Schedeler et al. (1995) found that excessive Ca intake decreases growth and feed efficiency in broiler chickens. In this experiment Ca and P treatment (P = 0.7351) and exposure time to the treatments (P = 0.7835) both had no significant influence on feed intake (Table 4.15).

Table 4.15. Mean food intake of birds over time (g/hen/day). P = 0.7351

Treatment	Ca inclusion in water (mg/l)	P inclusion in water (mg/l)	Food intake	±SD
1	0	0	147a	3
2	100	0	139a	3
3	200	0	144a	2
4	300	0	145a	11
5	0	150	142a	5
6	100	150	147a	11
7	200	150	140a	6
8	300	150	148a	9
9	0	300	138a	9
10	100	300	140a	7
11	200	300	141a	8
12	300	300	144a	3

Ca and P treatment had no significant influence (P = 0.8833) on water intake (Table 4.16) and exposure time to the treatments on water intake (P = 0.9992) (Table 4.17).

Table 4.16. LS Means for daily water intake (ml/hen/day) (SD ±0.004)

Treatment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
1	149	177	203	192	189	193	188	214	208	211	202	195	251
±SD	*10.87*	*3.38*	*21.97*	*21.90*	*13.07*	*9.10*	*15.75*	*19.91*	*9.25*	*4.96*	*8.43*	*11.54*	*12.10*
2	147	179	199	188	185	191	188	210	204	220	204	198	252
±SD	*14.17*	*3.79*	*0.41*	*1.22*	*7.58*	*7.95*	*8.44*	*2.30*	*8.50*	*10.82*	*5.76*	*6.82*	*9.97*
3	154	180	196	194	190	191	191	210	205	213	206	200	254
±SD	*4.32*	*4.29*	*7.03*	*9.91*	*9.96*	*5.00*	*6.48*	*12.82*	*10.83*	*12.17*	*12.04*	*12.36*	*15.48*
4	148	182	205	194	188	188	186	205	205	209	202	198	250
±SD	*7.88*	*5.00*	*11.69*	*6.29*	*6.61*	*3.65*	*3.38*	*8.57*	*8.67*	*6.29*	*4.45*	*2.07*	*2.29*
5	144	177	198	192	185	189	187	200	201	204	197	193	237
±SD	*11.84*	*3.24*	*8.03*	*4.26*	*2.18*	*4.85*	*6.16*	*7.06*	*10.52*	*6.28*	*8.36*	*4.99*	*11.32*
6	155	181	201	190	186	193	188	212	212	221	209	203	257
±SD	*5.42*	*3.41*	*7.68*	*9.76*	*6.60*	*1.15*	*7.25*	*8.16*	*8.40*	*5.83*	*10.54*	*9.62*	*9.23*
7	151	178	203	197	193	191	189	213	213	216	210	204	255
±SD	*12.61*	*1.97*	*5.39*	*10.14*	*4.83*	*1.44*	*2.17*	*1.29*	*2.53*	*2.73*	*2.15*	*3.51*	*1.86*

Table 4.16. LS Means for daily water intake (ml/hen/day)(SD ±0.004) (continued)

Treatment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
8 ±SD	152 *11.12*	179 *4.34*	190 *5.57*	188 *7.22*	183 *6.51*	188 *5.04*	186 *4.59*	204 *11.81*	205 *18.41*	210 *19.27*	203 *20.29*	197 *18.82*	251 *27.92*
9 *±SD*	152 *9.96*	180 *3.78*	203 *8.44*	193 *12.74*	191 *9.80*	190 *2.58*	192 *2.61*	211 *7.84*	209 *12.45*	215 *13.38*	205 *11.63*	204 *12.64*	258 *17.30*
10 *±SD*	152 *9.70*	179 *2.30*	201 *6.07*	192 *4.76*	190 *8.37*	192 *5.07*	191 *6.95*	210 *13.93*	210 *9.51*	228 *8.07*	213 *10.69*	202 *10.32*	255 *17.18*
11 *±SD*	149 *21.11*	179 *1.97*	201 *4.88*	198 *5.56*	194 *5.42*	191 *6.70*	194 *6.59*	208 *11.51*	203 *8.69*	214 *8.07*	205 *9.69*	201 *6.62*	254 *6.66*
12 *±SD*	157 *7.90*	177 *6.07*	207 *18.74*	198 *12.48*	191 *5.20*	191 *3.40*	197 *2.38*	216 *4.95*	214 *11.84*	212 *5.49*	204 *0.48*	199 *0.72*	256 *2.65*

Table 4.17. Mean water intake of birds over time (ml/hen/day). P = 0.8833

Treatment	Ca inclusion in water (mg/l)	P inclusion in water (mg/l)	Water intake	± SD
1	0	0	198a	12
2	100	0	197a	7
3	200	0	199a	9
4	300	0	197a	3
5	0	150	193a	6
6	100	150	201a	3
7	200	150	201a	3
8	300	150	195a	9
9	0	300	200a	8
10	100	300	201a	7
11	200	300	199a	6
12	300	300	202a	5

In the poultry industry, processing of spent hens, especially caged birds, often results in many broken and shattered bones. Downgrading is so severe that in some cases the processors refuse to buy the hens because of the danger of bone fragments in their products. The breaking strength of bones is used as a criterion for assessing the value of both diet and cage design for preventing bone breakage (Wilson 1991). In this experiment the breaking strength of the femora increased to a maximum (279.067 N) in Treatment 4 (maximum Ca addition, no P). The lowest breaking strength was found in treatment 1 (68.427 N) where no Ca or P was added to the water (Table 4.18).

Table 4.18. Mean breaking strength of femora (N). P = 0.0615

Treatment	Ca inclusion in water (mg/l)	P inclusion in water (mg/l)	Breaking strength	± SD
1	0	0	68.427	±42.860
2	100	0	199.6	±42.860
3	200	0	102.3	±42.860
4	300	0	279.067	±42.860
5	0	150	107.8	±42.860
6	100	150	255.9	±42.860
7	200	150	191.2	±42.860
8	300	150	134.967	±42.860
9	0	300	172.183	±42.860
10	100	300	146.407	±42.860
11	200	300	132.683	±42.860
12	300	300	137.04	±42.860

No histological abnormalities were evident in the gizzards, spleens, proventriculi and spleens examined. One or more lymphoid foci were present in the hearts of samples from treatments 2, 4 and 8. Scattered lymphoid foci were noted in the kidneys of treatments 1, 3, 4, 5, 6, 7, 8 and 9. In the kidney of treatment 11 there was a large, diffuse area of lymphocyte infiltration into the renal parenchyma. This lesion was interpreted as neoplastic (cancerous), ie renal lymphoma.

Egg yolk peritonitis was noted in a few of the specimens. Judged to be mild in treatments 3 and 11; it was regarded to be moderate in numbers 1, 8, 9 and 10. One or more lymphoid foci were found in the eggshell glands in treatments 4, 9 and 11.

The lymphoid foci found in various organs are indicative of an immune response to a persistent antigen. Most probably the antigen is a virus or mycoplasma of low pathogenicity; one that does not cause overt clinically recognizable disease. The histopathological lesions found in the tissue samples were therefore not linked to the addition of Ca and P in the drinking water.

Ninety-seven percent of the eggshell consists of calcium carbonate. The shell weighs approximately 6.0 g, so almost 6.0 g of calcium carbonate must be synthesized and deposited on the shell each time the hen produces an egg. For many hens, this is almost daily for long sequences. Calcium carbonate is 40% calcium, thus about 2.5 g of elemental calcium must be found and transported to the shell gland in the 18-20 hours it takes to form the eggshell. The calcium content of blood at any given time is no more than 30 mg. Thus the shell contains over 80 times more calcium than the content of the blood.

Calcium is obtained by the hen for shell formation from two sources (Hunton 2005) :

- Firstly, from the feed, via the intestine and the blood stream.
- Secondly, from reserves stored in the medullary bone. These reserves are replenished during the time eggshells are not being formed.

Mueller et al. (1964) found that of the calcium intake of laying hens, 78% was absorbed, 8% was excreted as endogenous calcium and 70% was retained. From 4.3 to 4.9 g of the skeletal calcium participated in eggshell formation, of which 1 g was turned over daily. The size of the exchangeable bone calcium pool was related to the quantity of shell produced and was larger in pullets with a negative calcium balance than in pullets with a positive balance.

Changes in the calcium source or its particle size have been tested as ways of improving shell quality

(Makled and Charles 1987). Guenter (1980) reported data from two long-term experiments, which indicated that continuous feeding of low levels of dietary phosphorus were more beneficial to egg shell quality, than the continuous feeding of higher levels of phosphorus. Although differences between the Ca and P treatments in this experiment did occur, both egg shell thickness and egg shell breaking strengths were not significantly increased by increased Ca or P administration.

The plasma calcium contents of hens receiving different levels of both Ca and P in the water did not differ significantly. This confined the findings of Hester et al. (1980) that hens which laid soft shelled eggs had plasma calcium and magnesium concentrations comparable to hens which produced hard shelled eggs. Lennards and Roland (1981) also found no relationship between serum calcium and shell weight or egg weight.

In 1961 Taylor reported that a substantial increase in eggshell thickness occurred when hens were transferred from a high phosphorus (0,8% P) to a low phosphorus (0.1% P) diet.

If the sole source of calcium is from the diet, then it is apparent that not only is the bird limited by the time taken to consume the mineral for direct use, but that substantial amounts are taken in when shell demands are non-existent. Fortunately, the long bones may act as a depot during this relatively short period of abundance until the dietary source later proves inadequate for shell formation (Hurwitz and Bar 1969). Bone breaking strengths were significantly lower in treatments receiving no Ca in the water.

Connor et al. (1969) reported reduced growth and increased mortality in chickens given $CaCl_2$ in the water. In this experiment levels of up to 300 mg/l of $CaCl_2$ did not adversely affect body weights, feed intake or water intake.

Reddy et al. (1968) found that the amount of calcium in the laying ration has a marked effect on shell quality and egg production. Ca and P treatment had a significant influence on egg production but no significant influence on egg mass.

Conclusion

The results show that water can be a valuable asset to increase eggshell integrity, but waterline maintenance may be increased because of the tendency of calcium to precipitate. Although calcium is one of the most studied minerals involved in laying hen nutrition, it does not seem to have been used to any extent as a drinking water supplement. This may be the result of a universal feeling that waterborne minerals are detrimental to equipment operation. Water should be seen as a dietary source of minerals (Ca + P) and should be taken into consideration when nutrient specifications are set for feed formulations to be used in the various poultry production systems.

Chapter 5

Theoretical Modelling Approach

Published in:

- *Casey, N.H., Meyer, J.A. & Coetzee C.B. 1998. An investigation into the quality of water for livestock production with the emphasis on subterranean water and the development of a water quality guideline index system. Volumes 1 - Development and modeling. Report to the Water Research Commission. WRC Report No: 644/1/98. ISBN No:1 86845 739 0*
- *Casey, N.H., Meyer, J.A. & Coetzee C.B. 1998. An investigation into the quality of water for livestock production with the emphasis on subterranean water and the development of a water quality guideline index system. Volumes 3 - Appendix. Report to the Water Research*
- *Casey, N.H., Meyer, J.A. & Coetzee C.B. 2001. 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. Volume 2. Report to the Water Research Commission. WRC Report No: 857/2/01. ISBN No: 1 86845 714 1*

Introduction

Since poultry consume approximately twice as much water as feed on a weight basis, it would seem logical that water content and quality should be considered in nutrition. Water of poor quality affects poultry performance in two ways. First, high concentrations of bacteria or toxic elements in the water affect the normal physiological processes of the body, resulting in inferior performance. Second, high concentrations of minerals in the water may clog the water system and subject the birds to water deprivation. Alternatively, faulty drinkers may flood the litter, causing leg problems and breast blisters in broilers raised on the floor. The management of laying hens in cages may be compromised.

It is imperative to have a set of Water Quality Guidelines (WQG) applicable to subterranean and other water sources. The need for, and importance of ground water, as a source of drinking water is increasing. Casey *et al*. (1993, 1994, 1996, 1998a, 1998b and 2000) questioned the validity of guidelines presently in use in southern Africa for assessing the quality of water for livestock production.

Some of the shortcomings of presenting a guideline on a mg/l basis are that they do not :

- offer any solution for areas which have inherently saline waters with high concentrations of potentially adverse Water Quality Constituents (WQC).
- take into account, to a large enough extent, the differing water quality requirements, in terms of quality and quantity of animals due to :
    - animal specific factors;
    - site-specific environmental factors;
    - nutritional factors;
    - livestock production system factors.
- take into account the effect of short-term exposure to WQC's.

- cater for differences in probable carry-over effects of potentially toxic substances to the user of the animal product after a limited exposure.
- cater for synergistic and antagonistic interactions between WQC's and the environment.
- base recommendations on the actual ingestion of a WQC for all sources (Casey *et al*. 1998a).

Prior to this work, international guidelines and levels for specific variables differed, and highlighted the need for each country to have its own relevant guidelines.

The aim of this project was to develop a process of determining acceptable levels for WQC taking into account ingestion rates, exposure time and species tolerance to constituents in poultry production systems in South Africa.

Establishing guidelines for water quality for poultry is difficult as growth and health depend on a multitude of factors. These factors have been shown to interact; a certain level of a water contaminant may not affect a bird's performance in one environment, while it could cause a problem in another. The only way to attempt the evaluation of the influence of water quality on poultry production is to base the research on flock performance under existing commercial conditions.

In Chapter 1 data on the different levels of minerals and metals found in groundwater of poultry farms across South Africa was presented. This data confirmed the need to develop a Water Quality Guideline Index System (WQGIS) for South African conditions. The range between the minimum and maximum levels of a specific constituent present in the water varied markedly. Constituent levels far in excess of the existing guidelines were prevalent. Constituents identified to be of concern in these results were investigated further and their effect on poultry production established.

An index system to assess the suitability of water for livestock production was required, as the present system does not fulfill this role. The index system should be based on the assessment of water intake for potentially hazardous variables, to determine the levels of ingestion of the variable concerned and, for palatability variables, to assess the impact of the variables on the water requirements and feed intake. These will be combined to form a water quality index (WQI) (Casey *et al*. 1996).

The results obtained in the experiments, detailed in previous chapters, served as motivation for a new approach to assessing water quality guidelines for poultry.

One objective in establishing a new set of water quality guidelines for poultry production systems was to provide producers with a system that is not as contradictory and static as those of Table 1.1. These guidelines will be presented in the form of an index system, incorporating all the influences of specific sites on water intake in a specific production system.

The only way to arrive at such a solution is through a modeling approach, in which the relationship between biological responses and their causes are predicted within site-specific factors.

Objectives of the Water Quality Guideline Index System (WQGIS):

- Provide a flexible management tool to make decisions about water quality for poultry.
- Provide a means for incorporating site-specific information in risk assessment for poultry watering.
- Provide supporting information to make decisions on the various components and their interactions in biological systems.
- Provide a water quality guideline index system that can be updated, as new research information becomes available (Casey *et al*. 1998a).

These objectives were achieved by:

- Modeling 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 :
    1. Generic WQGIS
    2. Specific WQGIS (Casey *et al*. 1998a)

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

Generic WQGIS

Introduction

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

Generic Guidelines within incidence categories

A total of 20 water quality constituents are addressed in the Generic Guidelines within three incidence categories, based on local research set out in Table 5.1. (Casey *et al*. 1994; 1998).

Table 5.1 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 Sulphate 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 indicates the probable effects that can be expected with increasing concentrations (available via the Results Screen, Types of Effects button). The second provides only cut-off Single Trigger Value Guidelines.

Definitions used for the Generic Guidelines (Casey *et al*. 1998a)

Potentially hazardous water quality constituents have either a:

- **High Incidence** of occurrence in the poultry aquatic environment;
- **Medium incidence** of occurrence in the poultry aquatic environment;
- **Low incidence** of occurrence in the poultry aquatic environment.

Symbols used (Casey *et al*. 1998a)

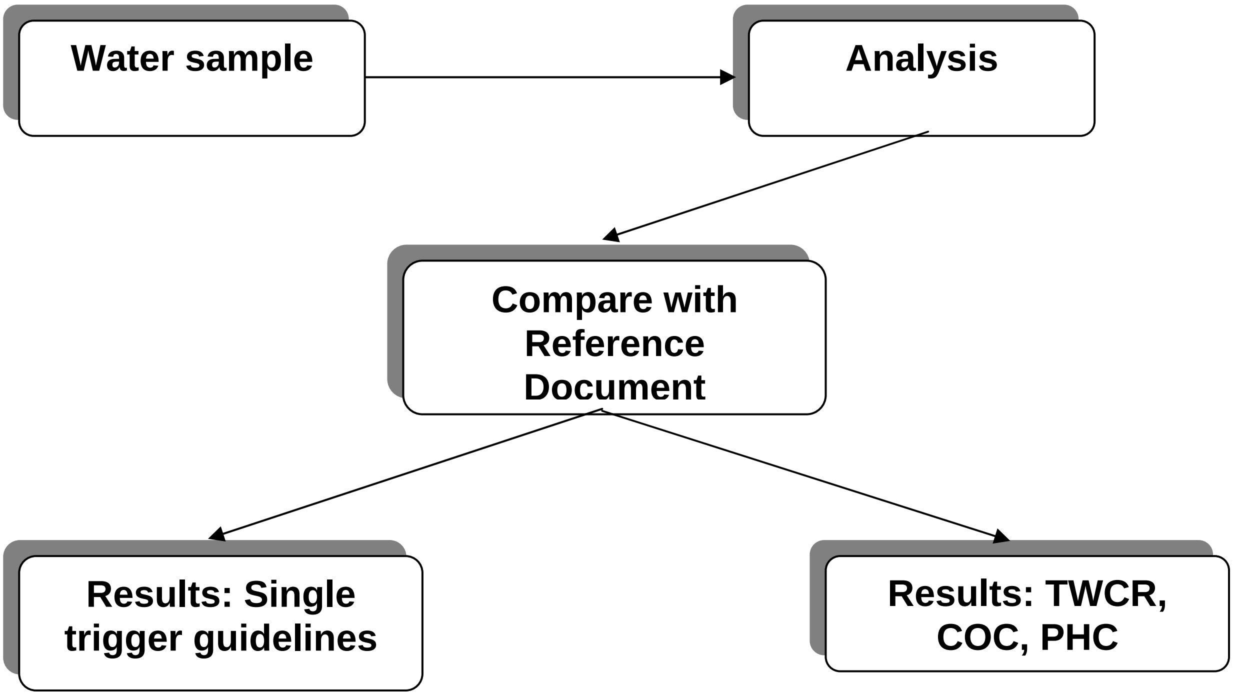
TWQR Target Water Quality Range. This is the range where adverse effects are ***unlikely*** to occur.

➢ The range in question, although ***likely*** to result in adverse effects, may be tolerated in either the short or long term, dependent on the site-specific factors. There may be synergistic and / or antagonistic interactions between constituents in the feed and the water; the design of the poultry production system and actual water ingestion rate.

PHC ***Potentially Hazardous Constituent (constituents in excess of the recommended guidelines).***

COC ***Constituent of Concern and COC (constituents within 10% of the recommended upper limit).***

Figure 5.1. Systems diagram of the Generic application level**.**



Listed below are tables showing water quality constituents in alphabetic order and the generic guidelines that apply to that constituent.

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, diarrhoea, 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 sulphate 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 anaemia. - 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.

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 condemned carcases can occur. This may be correlated with a negative effect on vaccines given in drinking water. Excessive scale may form and deposit in water pipes. Dietary Ca:P ratio (1.1-2.0:1) is 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	**There may be adverse chronic effects. 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 faeces, 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 are 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, diarrhoea, anaemia, 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 diarrhoea, intestinal irritation, watery droppings and lethargy may occur, but are unlikely if: - the sulphate 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 faeces 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 (µg/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 there 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 are 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. Condemned carcases may increase.

Selenium - Low incidence

Selenium Range	**Effects - Poultry**

(µg/l)	
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 sulphate 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>.

Sulphate - High incidence

Sulphate 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 sulphate is more toxic than Na sulphate. 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 tolerated.
> 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>.

Generic Guidelines – Single Trigger Values

Constituents are labelled as single trigger guidelines when there is insufficient information available for formulating generic guidelines (Casey *et al*. 1998a).

Table 5.2 WQC addressed as Single Trigger Guidelines for the Generic System.

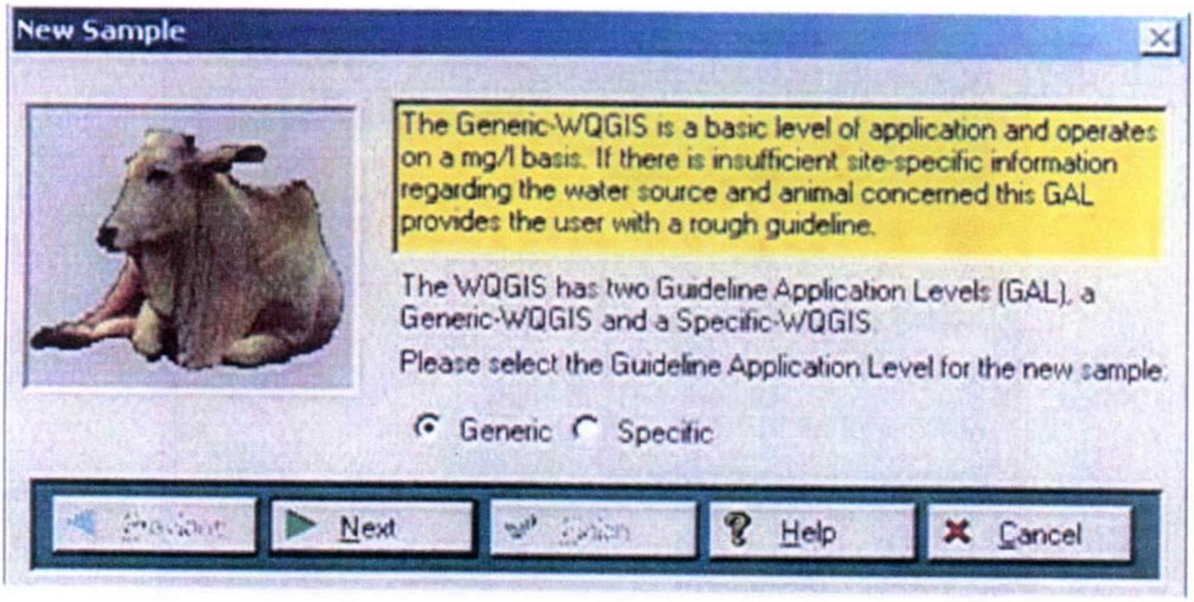
CONSTITUENT	TWQR
Aluminium	0 - 5 mg/l
Ammonium	0 - 2 mg/l
Antimony	0 - 0.006 mg/l
Bacteria	Total = 0 - 100 colonies / ml
	Coliform = 0 - 50 colonies / ml
Barium	0 - 2 mg/l
Beryllium	0 - 0.004 mg/l
Bismuth	0 - 0.001 mg/l
Boron	0 - 5 mg/l
Bromide	0 - 3 mg/l
Cesium	0 - 50 000 µg/l
Carbonate	0 - 500 mg/l
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 – 5µg/l
Hardness (CaCO3)	> 180 mg/l = hard
	< 60 mg/l = soft
Herbicides:	0 - 100 µg/l
2,4-D	0 - 100 µg/l
2,4,5-T	0 - 10 µg/l
2,4,5-TP	
Hydrogen Sulfide	0 - 0.3 mg/l
Indium	0 - 1 µg/l
Iodide	0 -1 mg/l
Lanthanum	0 - 1 µg/l
Lithium	0 - 5 mg/l
Magnesium sulphate	200 mg/l
Molybdenum	0 - 10 mg/l
Nickel	0 - 1 mg/l
Odour	0 - 3 threshold odour number
Pesticides:	
Aldrin	0 - 0.03 µg/l
Chlordane	0 - 0.3 µg/l
DDT	0 - 1 µg/l
Dieldrin	0 - 0.03 µg/l
Endrin	0 - 0.2 µg/l
Heptachlor	0 - 0.1 µg/l
Lindane	0 - 4 µg/l
Methoxychlor	0 - 30 µg/l
Toxaphene	0 - 5 µg/l
Parathion	0 - 500 µg/l
Malathion	0 - 500 µg/l

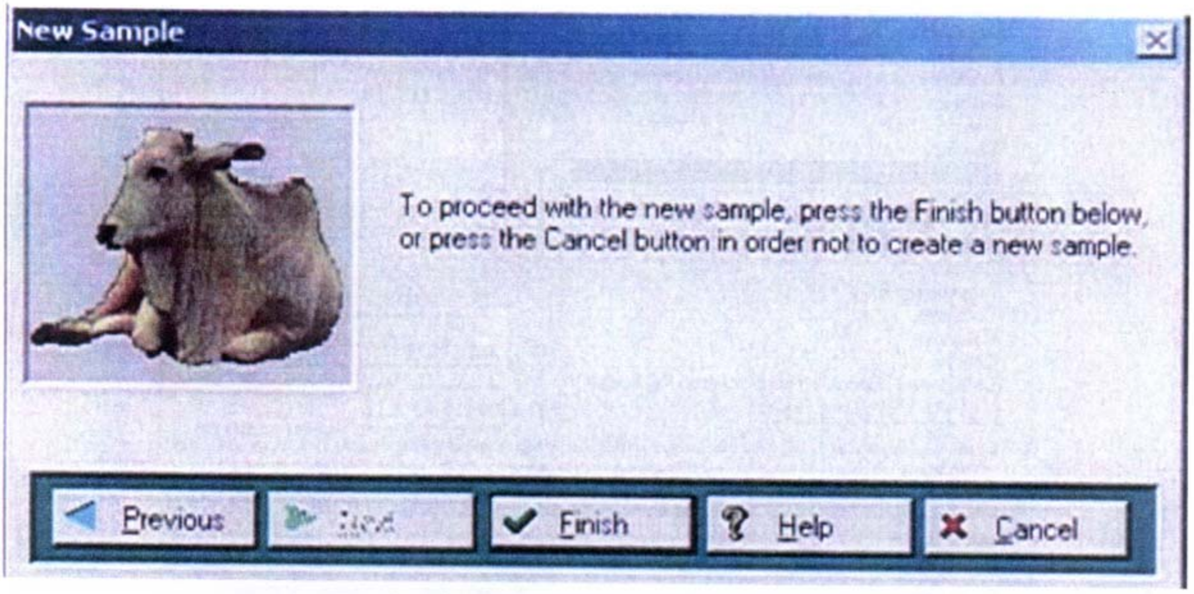
CONSTITUENT	TWQR
PH	6.4 – 9
Phosphate	0 - 2 mg/l
Potassium	0 - 2000 mg/l
Radio-activity	0 - 3 picocurie/l
Gross alpha	0 - 30 picocurie/l
Gross beta	0 - 1000 picocurie/l
^{3}H (tritium)	
Radium	0 - l µg/l
Rubidium	0 - 5 mg/l
Scandium	0 - 1 µg/l
Silver	0 - 0.05 mg/l
Sodium Bicarbonate	0 - 1000 mg/l
Sodium sulphate	0 - 1200 mg/l
Sodium chloride	0 - 1500 mg/l
Strontium	0 - 10 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 µg/l

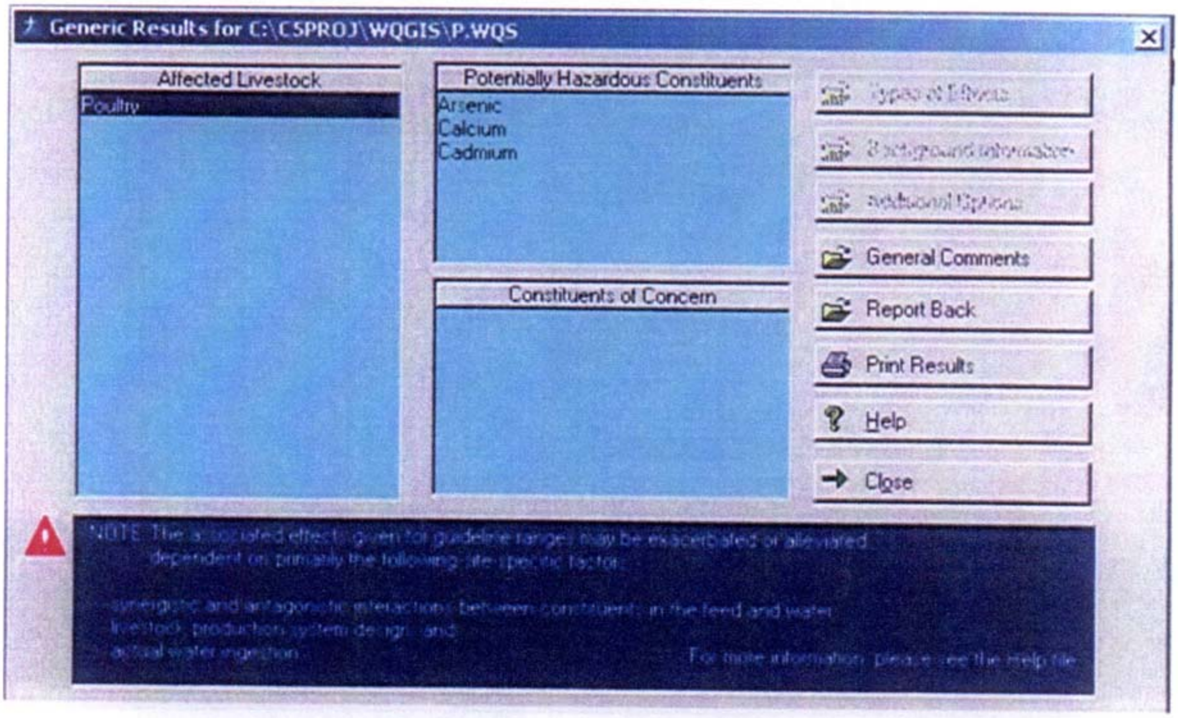
Generic WQGIS – Software Environment

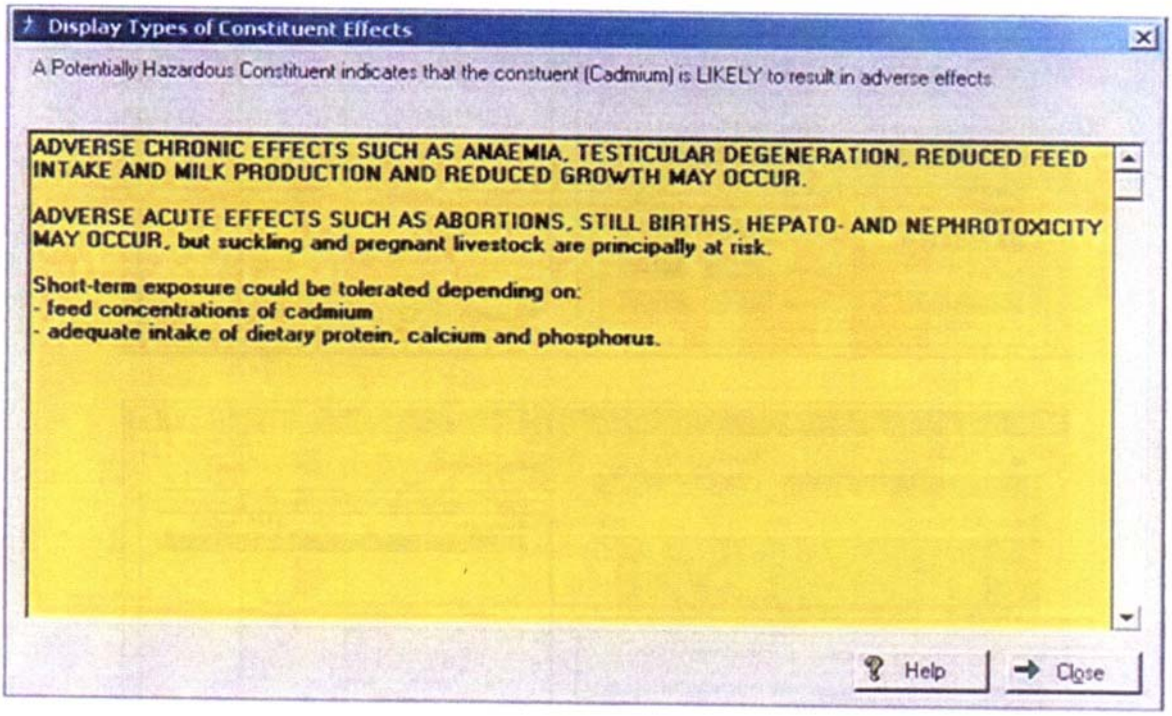
Some of the screens found in the Generic GAL are shown below in sequence of appearance.

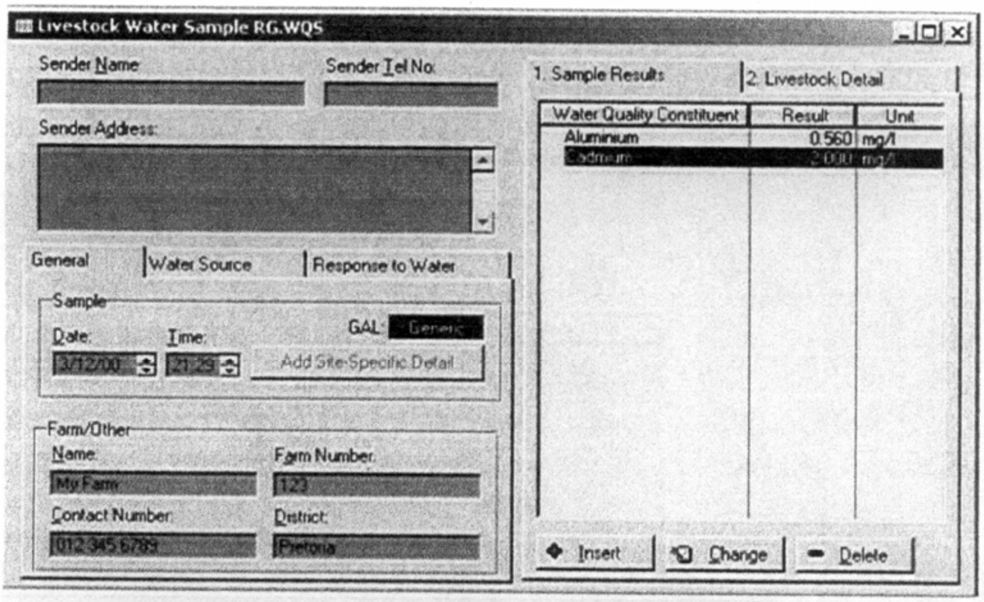
Screens 5.1 Generic WQGIS – Software environment

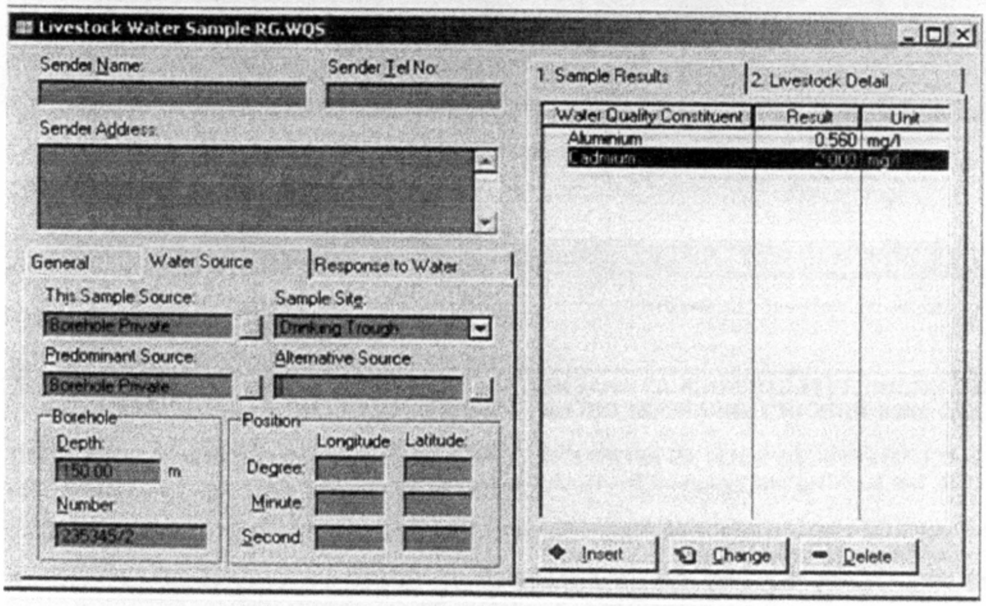


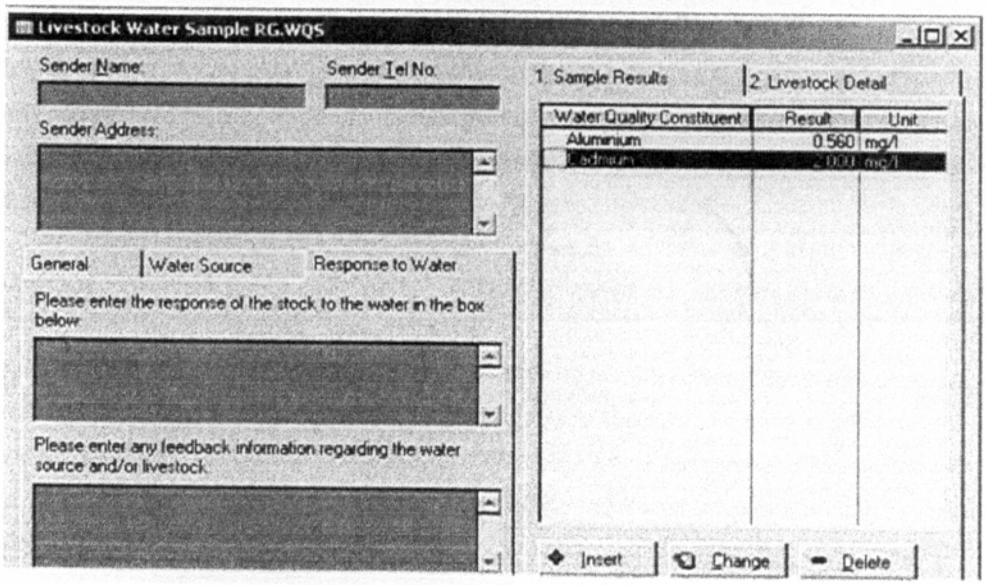


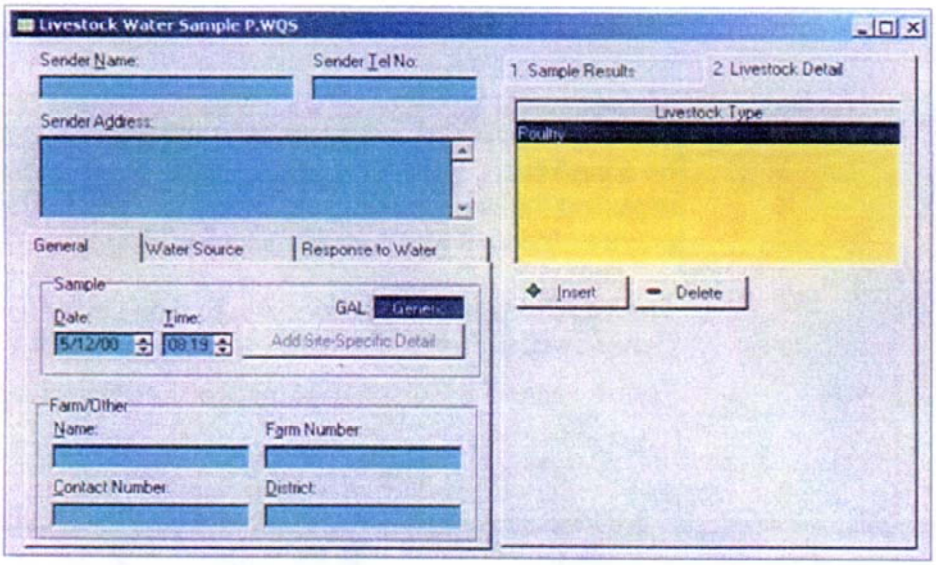

Generic Results for C:\C5PROJ\WQGIS\P.WQS
Affected Livestock
Poultry
Potentially Hazardous Constituents
Arsenic
Calcium
Cadmium
Constituents of Concern
General Comments
Report Back
Print Results
Help
Close

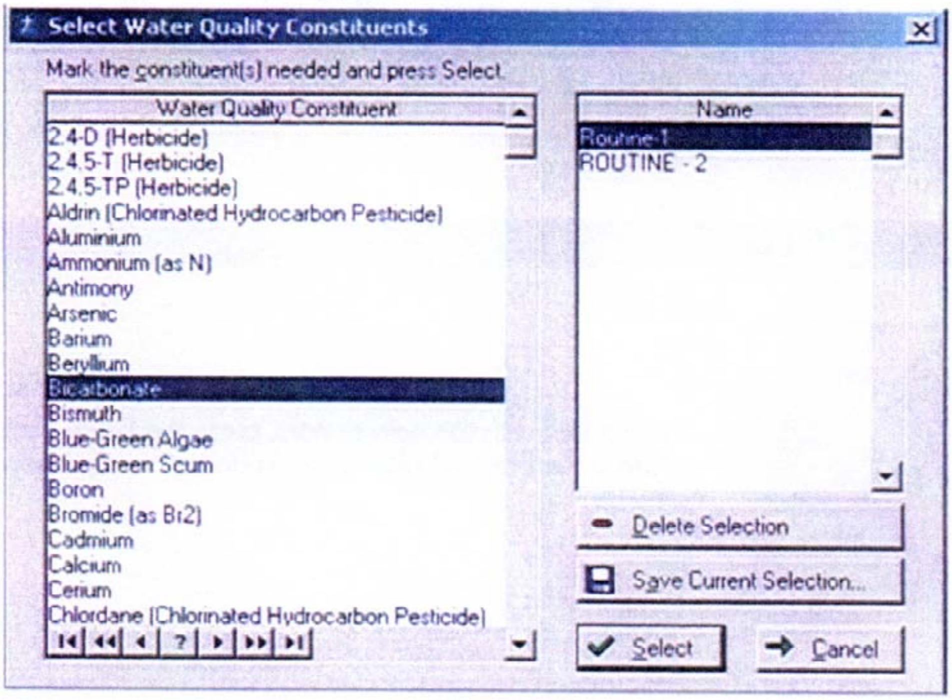

Display Types of Constituent Effects
A Potentially Hazardous Constituent indicates that the constuent (Cadmium) is LIKELY to result in adverse effects
ADVERSE CHRONIC EFFECTS SUCH AS ANAEMIA, TESTICULAR DEGENERATION, REDUCED FEED INTAKE AND MILK PRODUCTION AND REDUCED GROWTH MAY OCCUR.
ADVERSE ACUTE 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

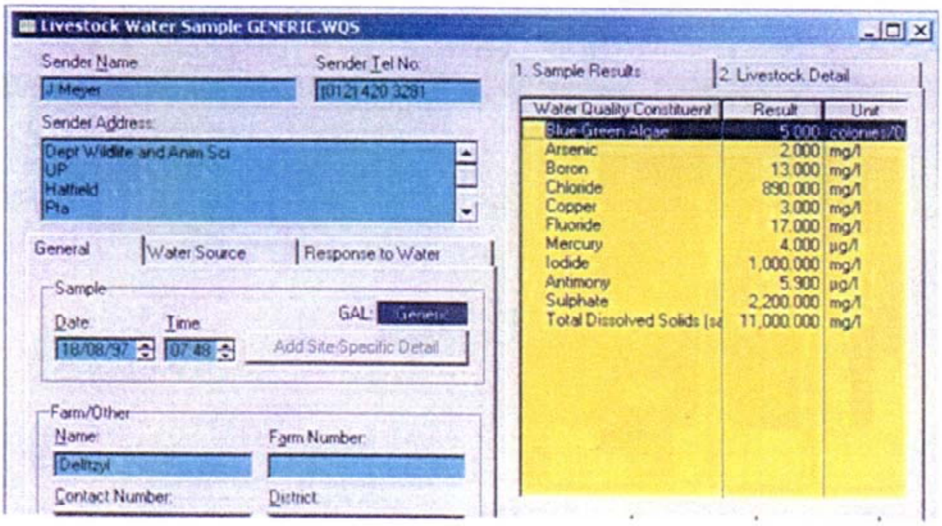

Livestock Water Sample RG.WQS
Sender Name:
Sender Tel No:
Sender Address:
General
Water Source
Response to Water
Sample
Date:
Time:
3/12/00
21:29
GAL:
Generic
Add Site-Specific Detail
Farm/Other
Name:
Farm Number:
My Farm
123
Contact Number:
District:
012 345 6789
Pretoria
1. Sample Results
2. Livestock Detail
Water Quality Constituent
Result
Unit
Aluminium
0.560
mg/l
Cadmium
2.000
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:
Borehole Private
Drinking Trough
Predominant Source:
Alternative Source:
Borehole Private
Borehole
Depth:
150.00
m
Number:
235345/2
Position
Longitude
Latitude:
Degree:
Minute:
Second:
1. Sample Results
2. Livestock Detail
Water Quality Constituent
Result
Unit
Aluminium
0.560
mg/l
Cadmium
2.000
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
Cadmium
2.000
mg/l
Insert
Change
Delete


Livestock Water Sample P.WQS
Sender Name:
Sender Tel No:
Sender Address:
General
Water Source
Response to Water
Sample
Date:
Time:
GAL:
Generic
5/12/00
08:19
Add Site-Specific Detail
Farm/Other
Name:
Farm Number:
Contact Number:
District:
1. Sample Results
2. Livestock Detail
Livestock Type
Poultry
Insert
Delete


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
Bicarbonate
Bismuth
Blue-Green Algae
Blue-Green Scum
Boron
Bromide (as Br2)
Cadmium
Calcium
Cerium
Chlordane (Chlorinated Hydrocarbon Pesticide)
Name
Routine-1
ROUTINE - 2
Delete Selection
Save Current Selection...
Select
Cancel


Livestock Water Sample GENERIC.WQS
Sender Name:
J Meyer
Sender Tel No:
(012) 420 3281
Sender Address:
Dept Wildlife and Anim Sci
UP
Hatfield
Pta
General
Water Source
Response to Water
Sample
Date:
Time:
GAL:
Generic
18/08/97
07:48
Add Site-Specific Detail
Farm/Other
Name:
Delftzyl
Farm Number:
Contact Number:
District:
1. Sample Results
2. Livestock Detail
Water Quality Constituent
Result
Unit
Blue-Green Algae 5.000 colonies/0
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 (s 11,000.000 mg/l

Specific WQGIS

The specific Guideline Application Level (GAL) incorporates the site-specific influences on water ingestion as well. This is achieved by making use of simulation modelling

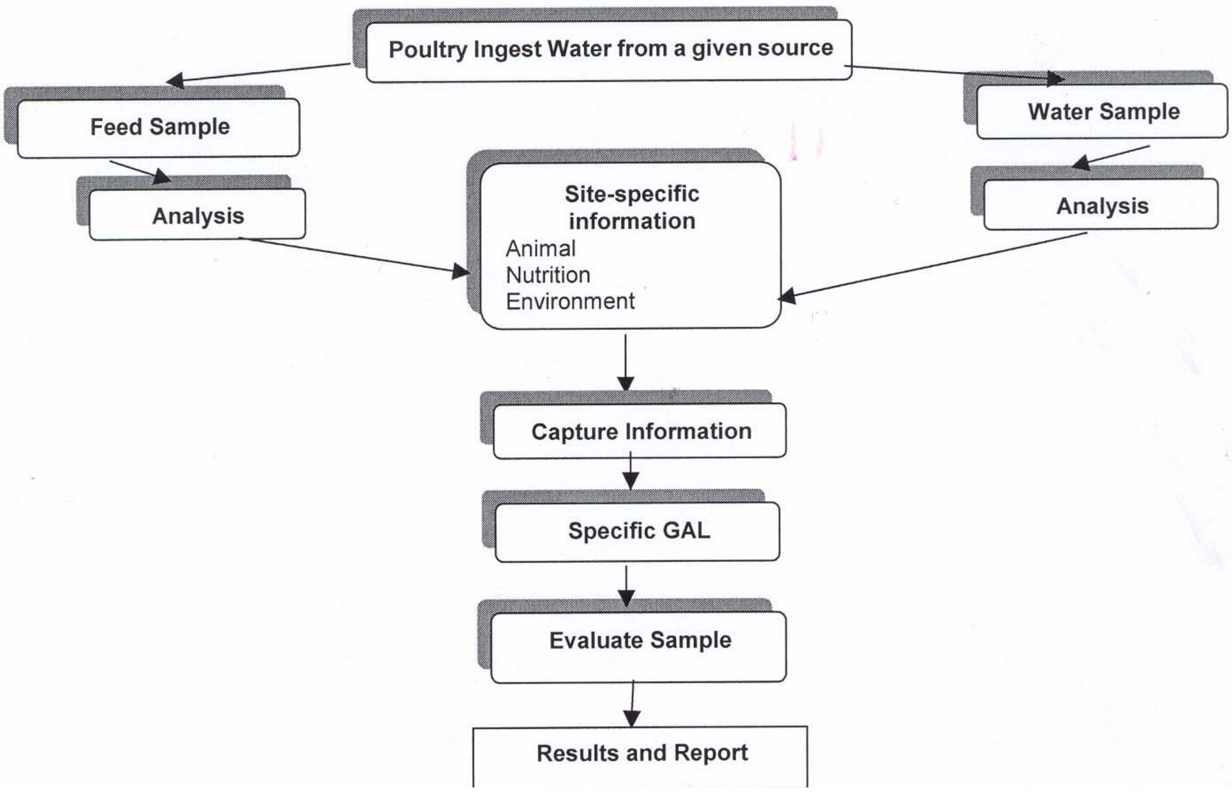
The specific GAL can:

- 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 (Casey *et al*. 1998a).

The specific Guideline Application Level (GAL) incorporates the site-specific influences on water ingestion as well. This is achieved by making use of simulation modelling.

Figure 5.2. represents a brief schematic outline of the primary procedures applied in the Specific WQGIS for poultry.

Figure 5.2. Schematic demonstration of the specific model.



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 Casey *et al*. 1998 for a detailed description and supporting information on the WIRRD concept. This section describes the modifications made to the WIRRD used for modelling of risk assessment for cattle, sheep, goats, horses and pigs, as employed by the software program CIRRA (Constituent Ingestion Rate Risk Assessment) (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) (BW);
- Feed intakes (FI);
- Egg production (layers);
- Moisture content of the feed;
- Total water intakes (TWI) and
- Constituent ingestion rates (IR).

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 (WI) derived from the formulae or the input is then converted to a total water intake (TWI) (Casey *et al*. 1998a).

TWI = WI + % moisture in the feed

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

An example of a typical WIRRD will then look as follows:

Arsenic:

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

Modifying system factors:
Each of the site-specific factors will affect the WIR and consequently the results of the risk assessment. Site-specific factors alter the water concentration at which a given constituent will cause an adverse effect (Casey *et al*. 1998a). A risk assessment cannot 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 (Casey *et al*. 1998a).

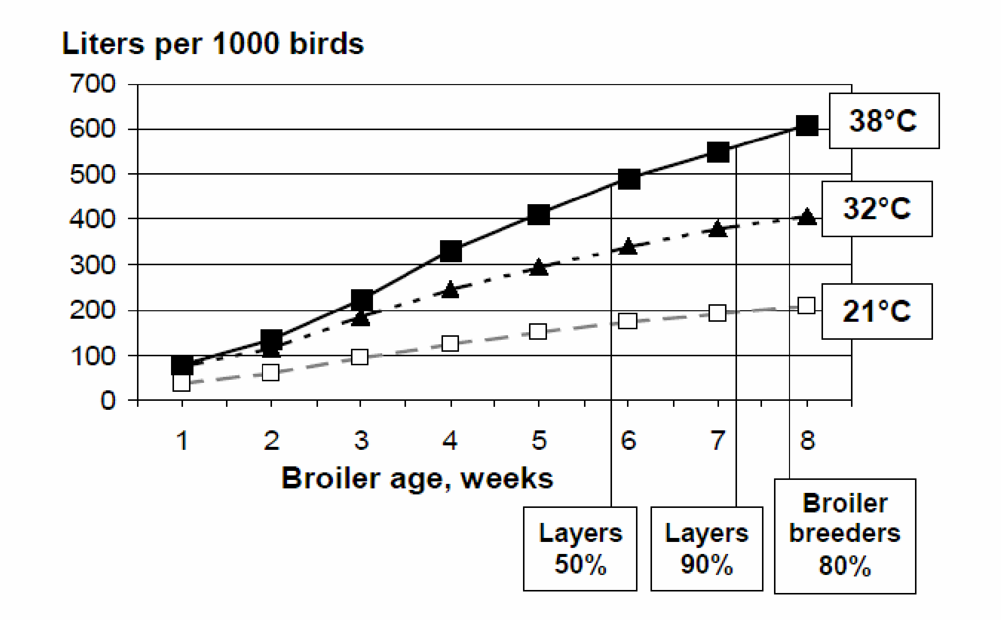
The "factor" system (Casey *et al*. 1998a) is applied by calculating the cumulative effect of all factors either increasing or decreasing the WIR. Factor values assigned to the relevant variables depend on whether they increase or decrease the WIR. The reason for using factor values is that many livestock, livestock production and site-specific factors have an effect on water intake and water turnover, but due to their high variability cannot be accommodated in an equation format. However, to exclude them would be to ignore significant effects. Therefore, in the interests of providing a risk assessment that is a managerial decision making tool, these factors are brought in where appropriate and are presented to the user in two result formats, namely, with and without system factors (Casey *et al*. 1998a). The factors attributing to the modification of the WIR are presented in Appendix 1 and 2 to Chapter 5.

The factors influencing broiler breeder performance, as well as broiler progeny performance, may be divided into two main categories : 1) genetics or inheritance; and 2) environment which includes temperature, humidity, disease, nutrition, feed quality, ventilation, stocking density, beak trimming, and so on. It has been estimated that live performance is determined about 30% by genetics and 70% by non-genetic or environmental factors (Hooge 2002).

Under normal conditions, it is generally assumed that birds will drink around twice as much water by weight as the amount of feed they consume. Water intake increases with age but decreases as a percent of body weight. Water intake varies considerably with air and water temperature. Water consumption increases by approximately 7% for each 1°C above 21°C. This will be greater if the water is cooler than the air and less if the water is warmer than the air. Excess minerals in feed or water above the nutritional requirement will cause increased water consumption and may result in wet manure. Feeds containing more minerals than are anticipated, such as sodium chloride from fishmeal, potassium and ash from molasses or magnesium from calcium or phosphate sources all increase water consumption.

Weight and feed conversion are usually not affected unless water is limiting or if the water contains an excess of the particular mineral that is high in the diet. Average figures for water consumption in broilers and layers are given in Figure 5.3. These should be used as a guideline only. It is recommended that data on water consumption be kept for individual flocks of birds at various points over the course of the year and include both cool and warm weather. The data can then be used later should the need for medication through drinking water arise (Swick 2000).

Figure 5.3 Effect of Temperature on consumption of water in poultry (Swick, 2000)



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

<u>The production systems addressed are the following:</u>

- Broiler
- Layer
- 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

Environment:

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 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 an * and are the minimum information required to run the model.

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 (Casey *et al*. 1998a).

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 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 5.3 below.

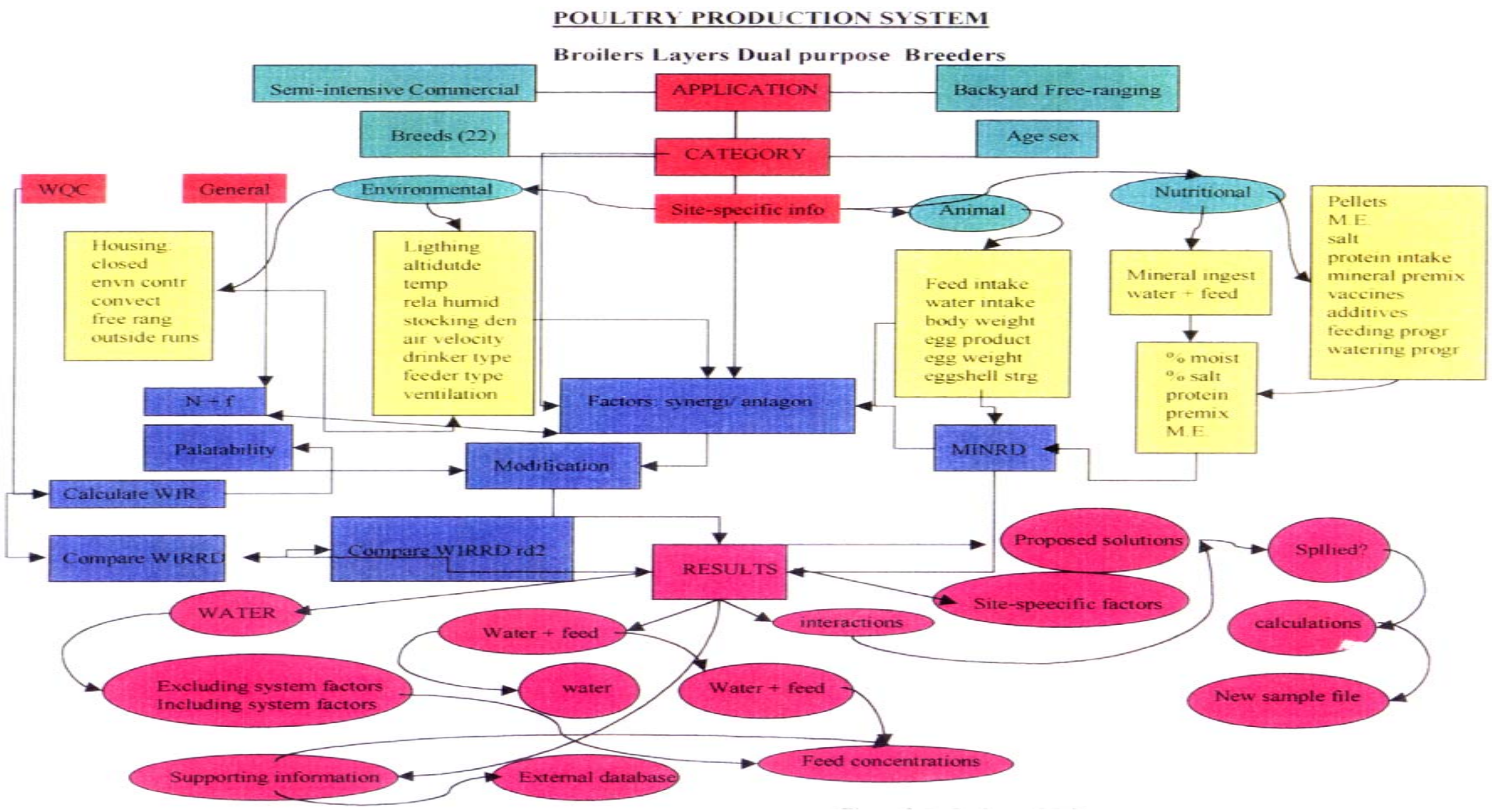
Table 5.3. Water quality constituents with a WIRRD

Arsenic
Bicarbonates
Calcium ,Cadmium, Chloride, Chromium, Copper
Fluoride
Iron
Lead
Magnesium, Manganese, Mercury
Nitrate, Nitrite
Selenium, Sodium, Sulphate
Total Dissolved Solids
Zinc

The specific model:

The basic model used for poultry in the Specific-WQGIS 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.

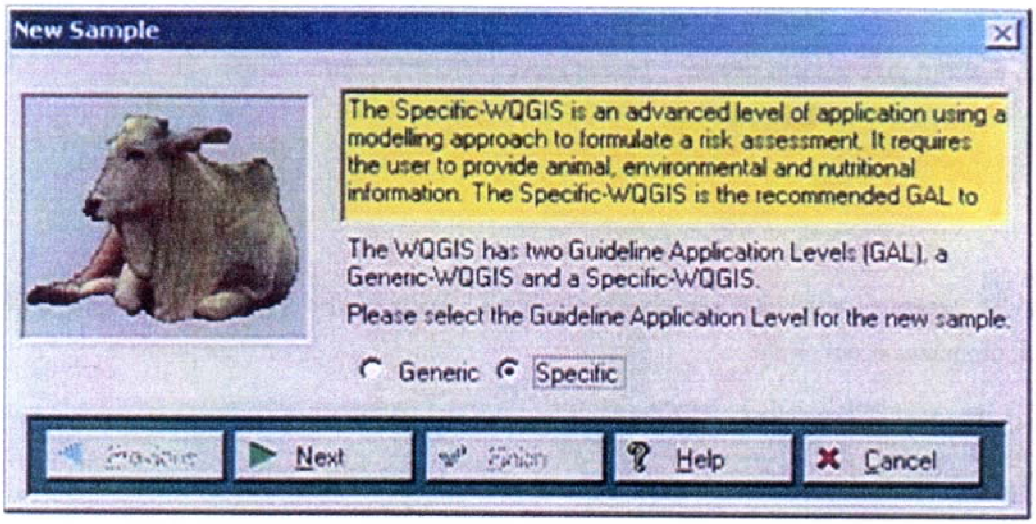
Figure 5.4 Basic model for the Specific application for poultry

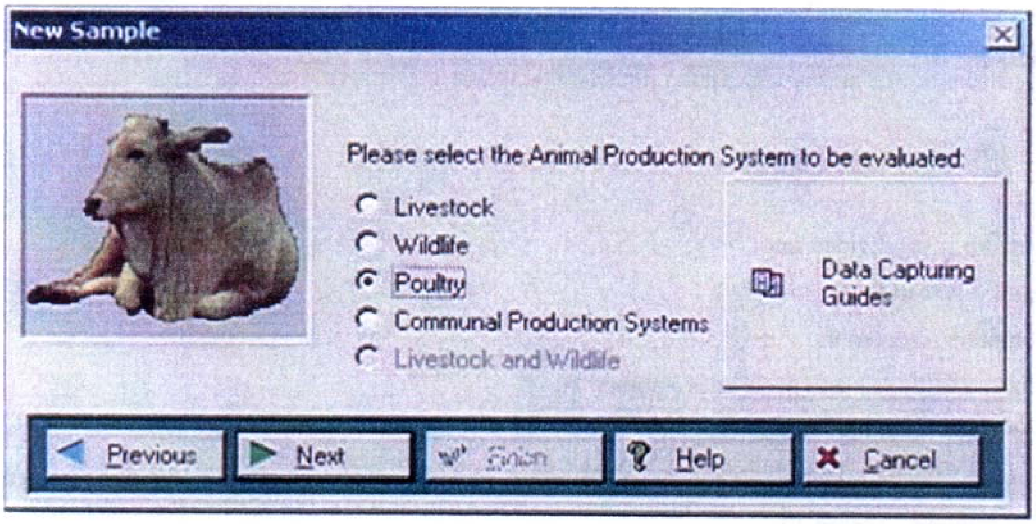


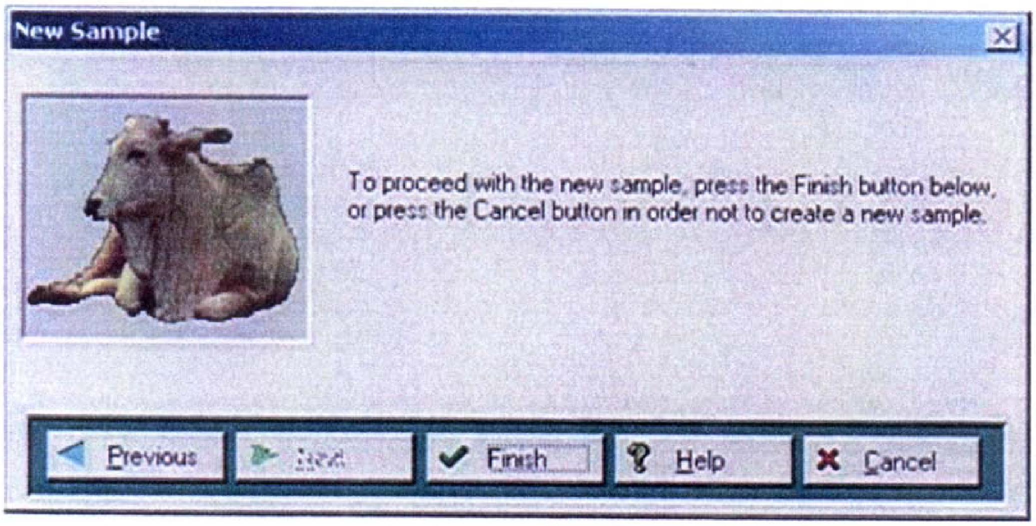
User interface of the Specific WQGIS

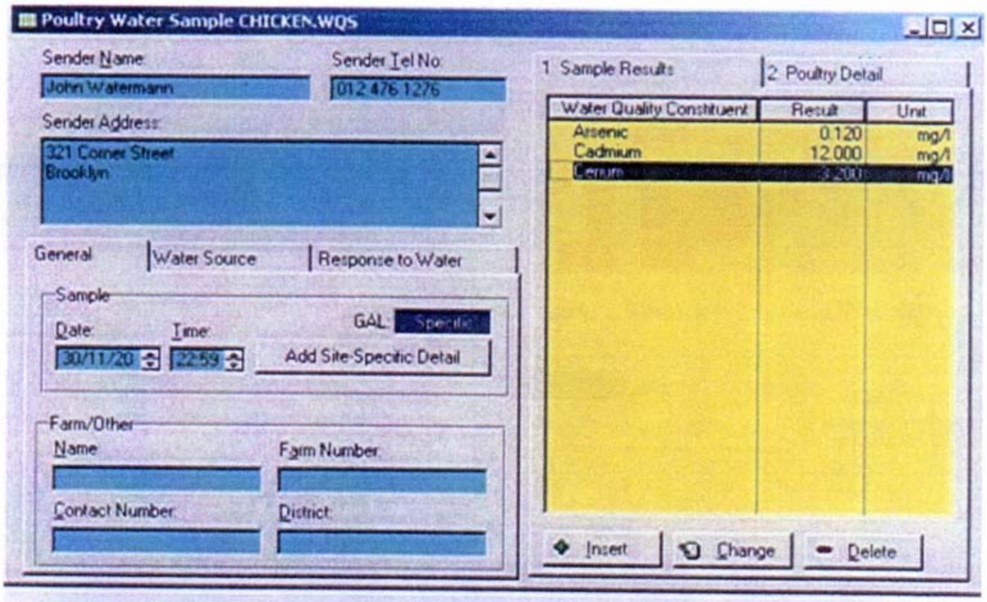
Examples of the general sequence of screens encountered by the user are shown in Screens 5.2

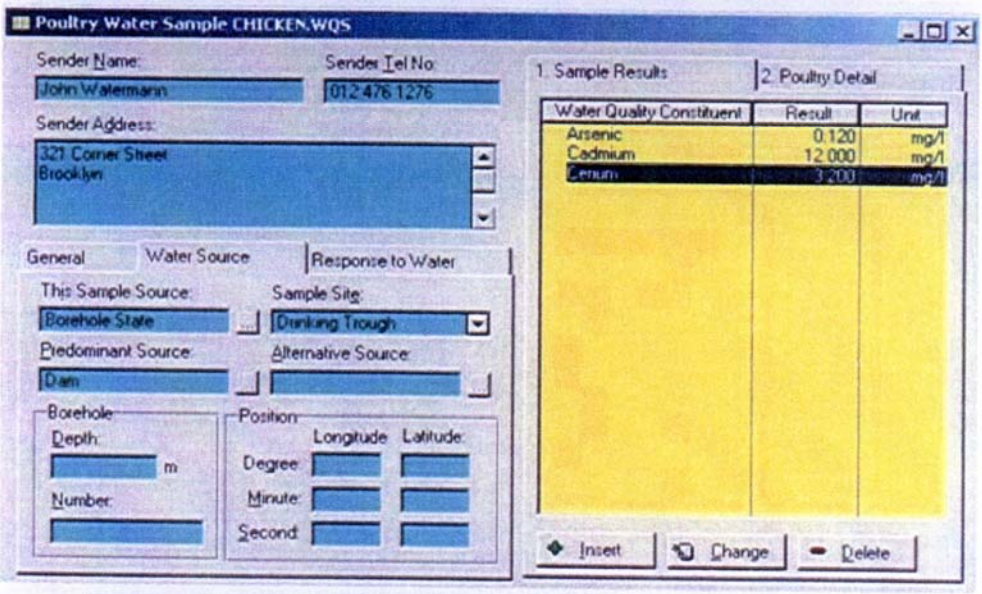
Screens 5.2 Specific WQGIS – software environment

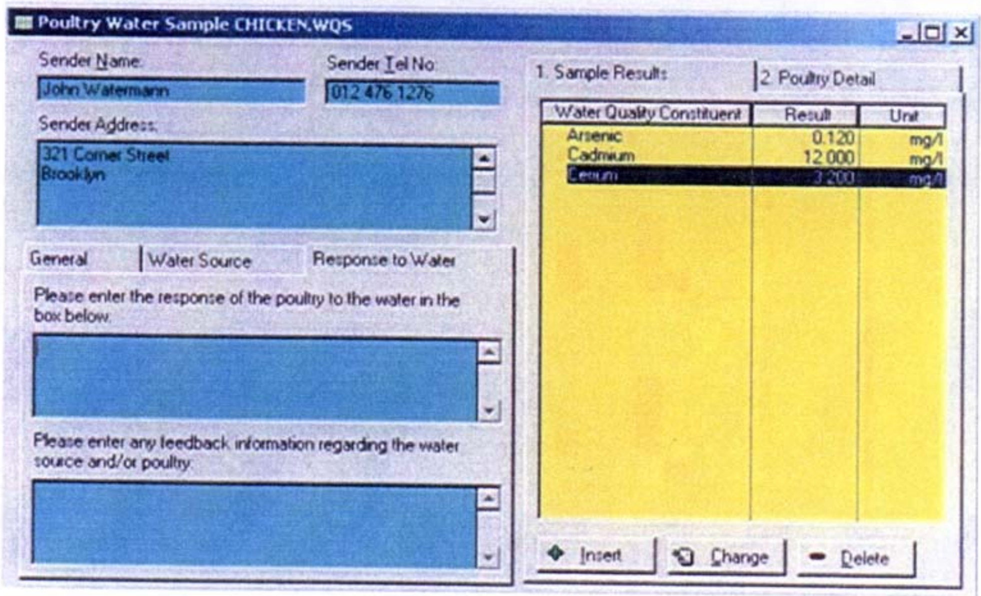


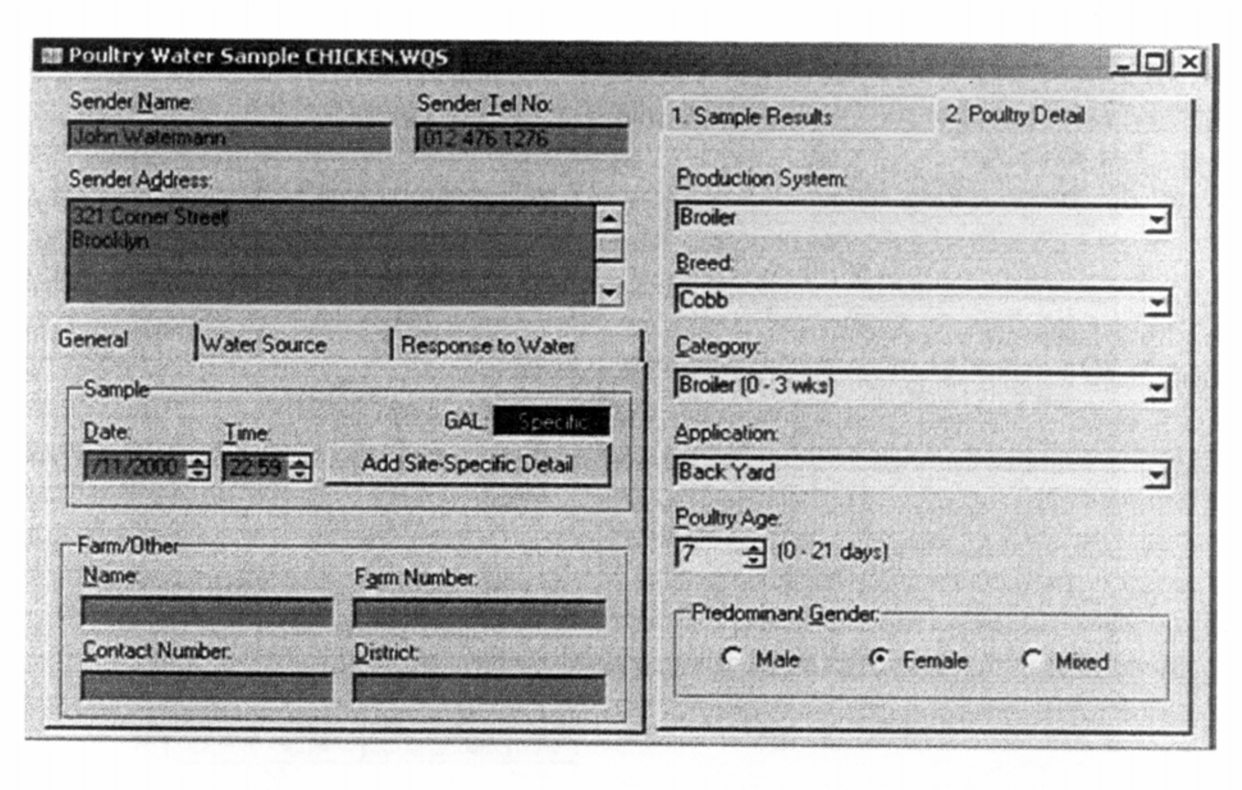


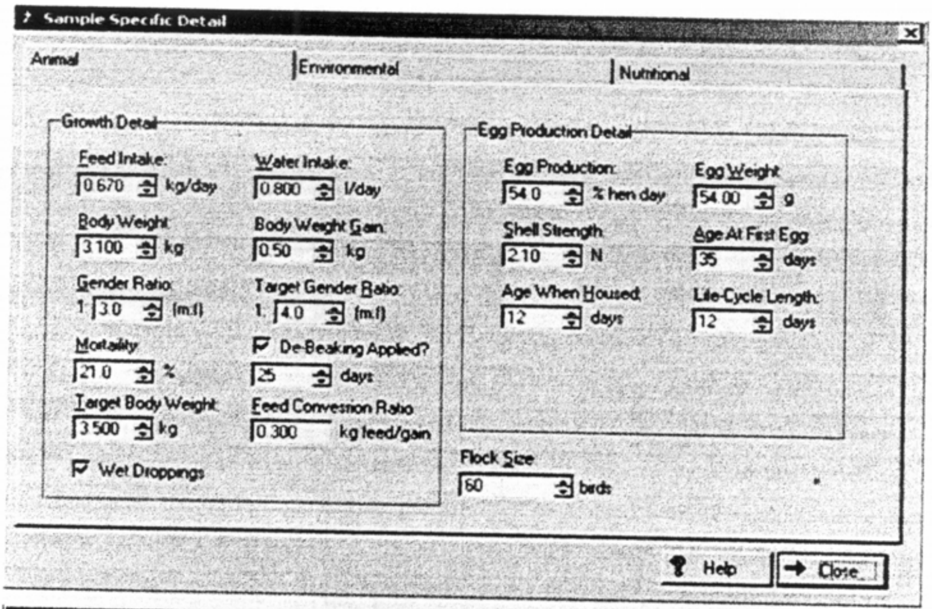


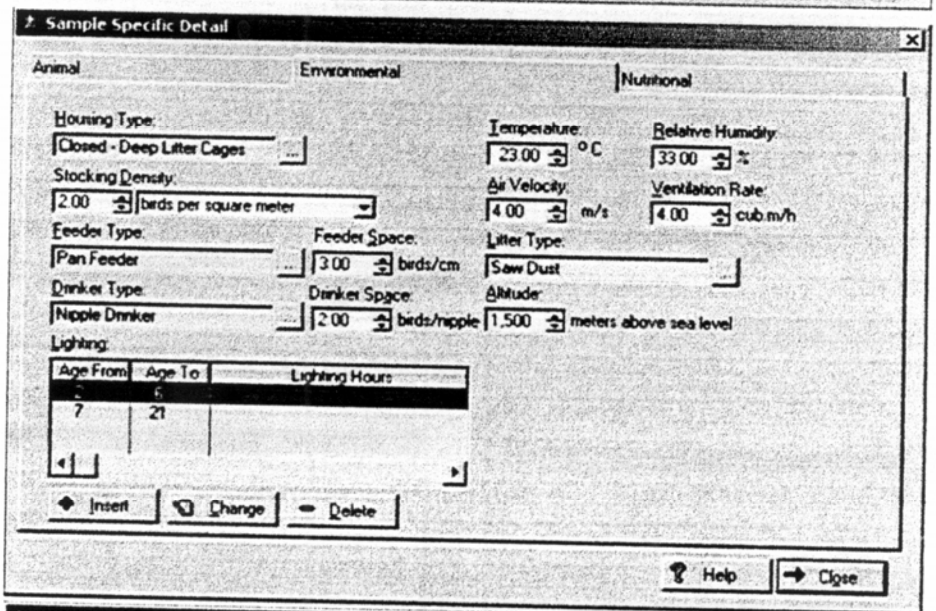

Poultry Water Sample CHICKEN.WQS
Sender Name:
John Watermann
Sender Tel No:
012 476 1276
Sender Address:
321 Corner Street
Brooklyn
General
Water Source
Response to Water
Sample
Date:
30/11/20
Time:
22:59
GAL:
Specific
Add Site-Specific Detail
Farm/Other
Name:
Farm Number:
Contact Number:
District:
1. Sample Results
2. Poultry Detail
Water Quality Constituent
Result
Unit
Arsenic 0.120 mg/l
Cadmium 12.000 mg/l
Cerium 3.200 mg/l
Insert
Change
Delete

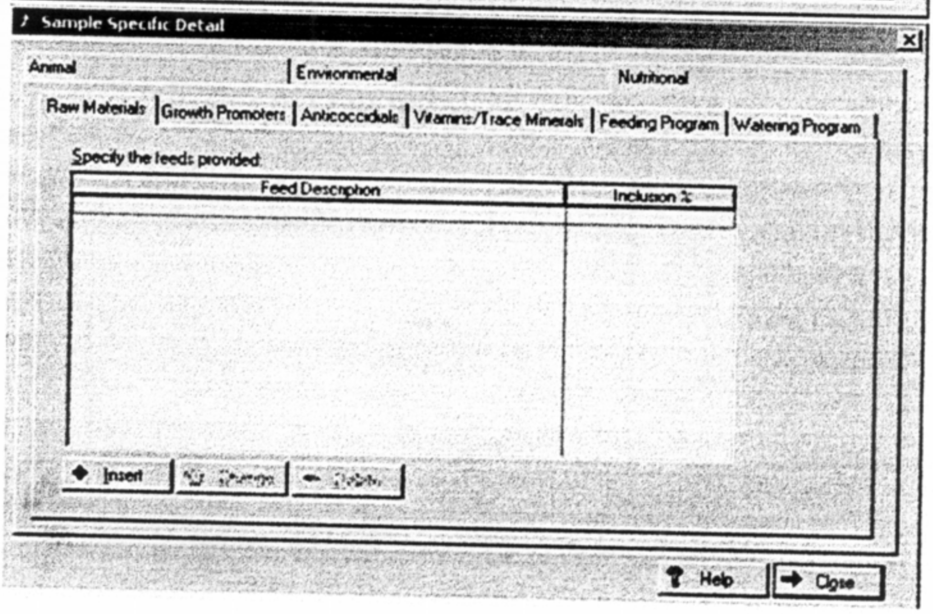

Poultry Water Sample CHICKEN.WQS
Sender Name:
John Watermann
Sender Tel No:
012 476 1276
Sender Address:
321 Corner Street
Brooklyn
General
Water Source
Response to Water
This Sample Source:
Borehole State
Sample Site:
Drinking Trough
Predominant Source:
Dam
Alternative Source:
Borehole
Depth:
m
Number:
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
Cerium 3.200 mg/l
Insert
Change
Delete

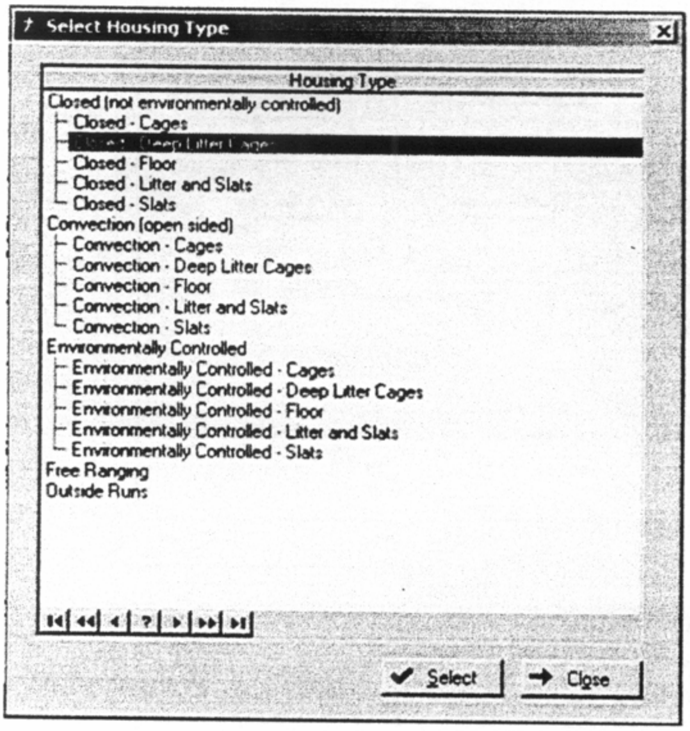

Poultry Water Sample CHICKEN.WQS
Sender Name:
John Watermann
Sender Tel No:
012 476 1276
Sender Address:
321 Corner Street
Brooklyn
General
Water Source
Response to Water
Please enter the response of the poultry to the water in the box below:
Please enter any feedback information regarding the water 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
Cerium 3.200 mg/l
Insert
Change
Delete

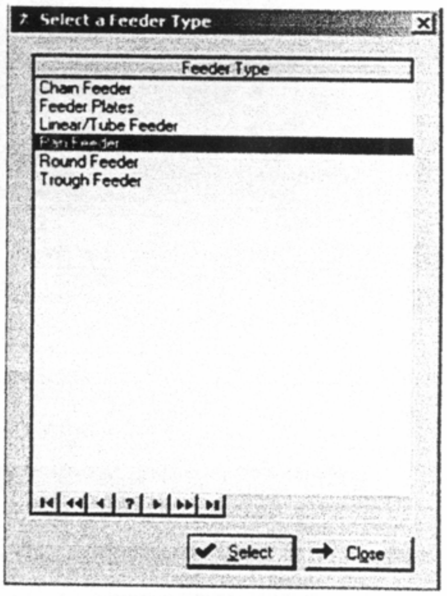

Poultry Water Sample CHICKEN.WQS
Sender Name:
John Watermann
Sender Tel No:
012 476 1276
Sender Address:
321 Corner Street
Brooklyn
General
Water Source
Response to Water
Sample
Date:
7/11/2000
Time:
22:59
GAL:
Specific
Add Site-Specific Detail
Farm/Other
Name:
Farm Number:
Contact Number:
District:
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

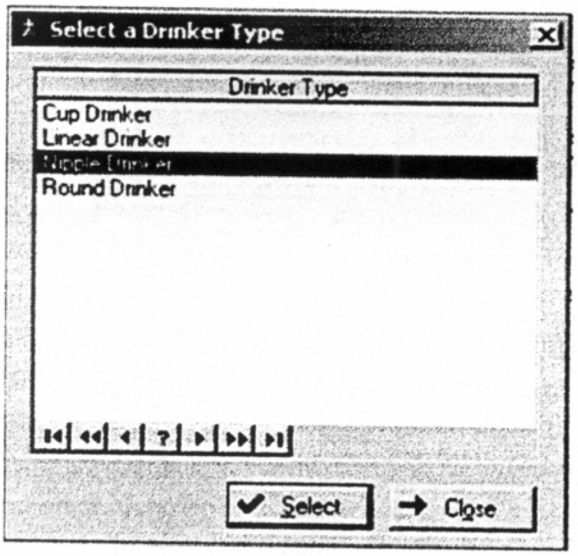

Sample Specific Detail
Animal
Environmental
Nutritional
Growth Detail
Feed Intake:
0.670 kg/day
Water Intake:
0.800 l/day
Body Weight:
3.100 kg
Body Weight Gain:
0.50 kg
Gender Ratio:
1: 3.0 (m:f)
Target Gender Ratio:
1: 4.0 (m:f)
Mortality:
21.0 %
De-Beaking Applied?
25 days
Target Body Weight:
3.500 kg
Feed Conversion Ratio:
0.300 kg feed/gain
Wet Droppings
Egg Production Detail
Egg Production:
54.0 % hen day
Egg Weight:
54.00 g
Shell Strength:
2.10 N
Age At First Egg:
35 days
Age When Housed:
12 days
Life-Cycle Length:
12 days
Flock Size:
60 birds
Help
Close

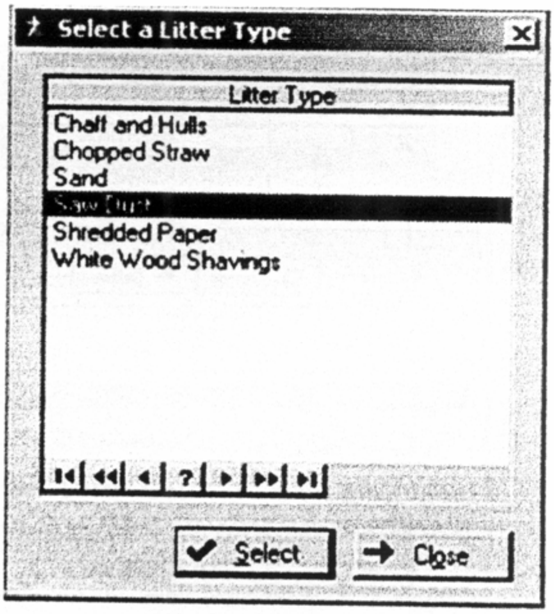

Sample Specific Detail
Animal
Environmental
Nutritional
Housing Type:
Closed - Deep Litter Cages
Stocking Density:
2.00 birds per square meter
Feeder Type:
Pan Feeder
Feeder Space:
3.00 birds/cm
Drinker Type:
Nipple Drinker
Drinker Space:
2.00 birds/nipple
Temperature:
23.00 °C
Relative Humidity:
33.00 %
Air Velocity:
4.00 m/s
Ventilation Rate:
4.00 cub.m/h
Litter Type:
Saw Dust
Altitude:
1,500 meters above sea level
Lighting:
Age From
Age To
Lighting Hours
7
21
Insert
Change
Delete
Help
Close

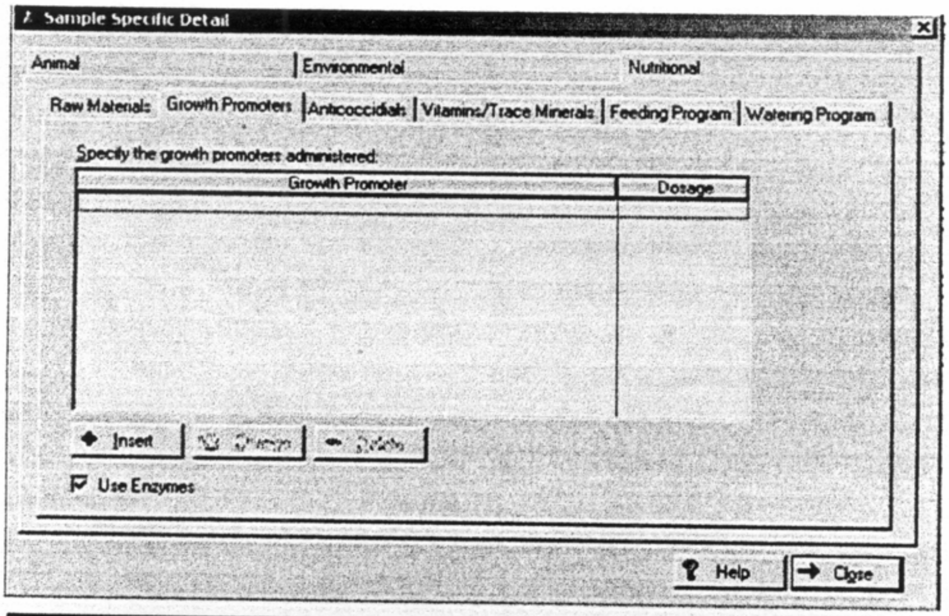

Sample Specific Detail
Animal
Environmental
Nutritional
Raw Materials
Growth Promoters
Anticoccidials
Vitamins/Trace Minerals
Feeding Program
Watering Program
Specify the feeds provided:
Feed Description
Inclusion %
Insert
Help
Close

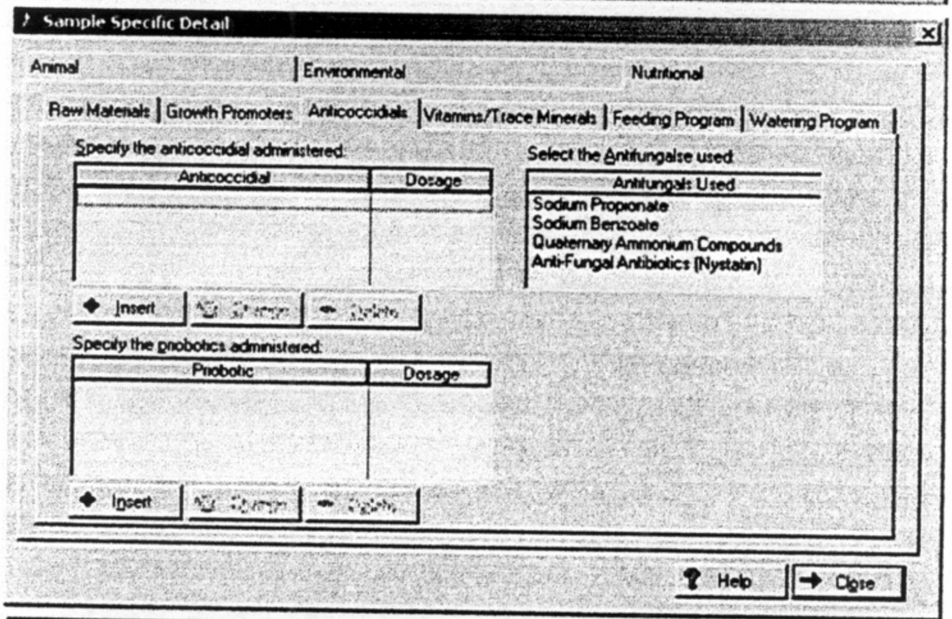

Select Housing Type
Housing Type
Closed (not environmentally controlled)
Closed - Cages
Closed - Deep Litter Cages
Closed - Floor
Closed - Litter and Slats
Closed - Slats
Convection (open sided)
Convection - Cages
Convection - Deep Litter Cages
Convection - Floor
Convection - Litter and Slats
Convection - 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

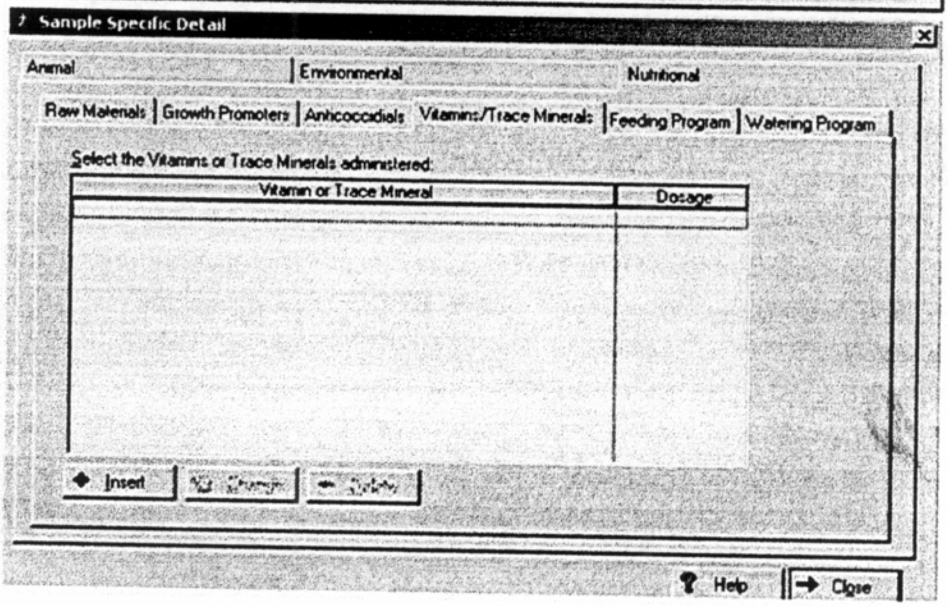

Select a Feeder Type
Feeder Type
Chain Feeder
Feeder Plates
Linear/Tube Feeder
Pan Feeder
Round Feeder
Trough Feeder
Select
Close

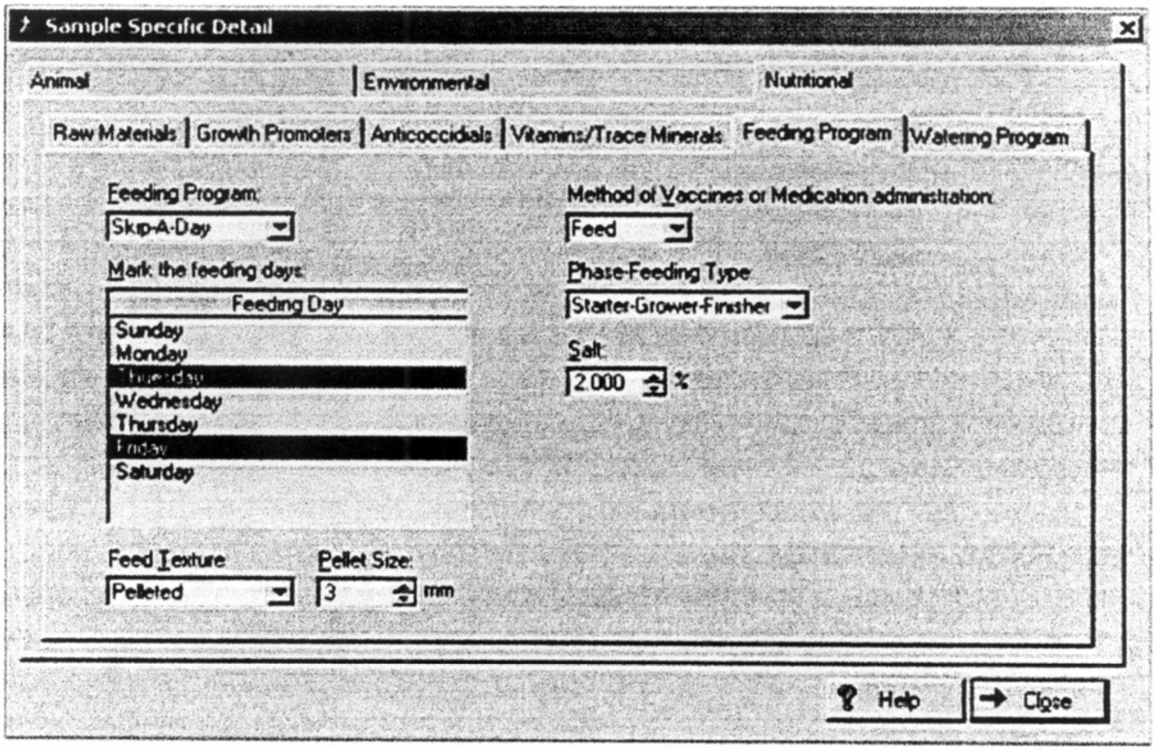

Select a Drinker Type
Drinker Type
Cup Drinker
Linear Drinker
Nipple Drinker
Round Drinker
Select
Close

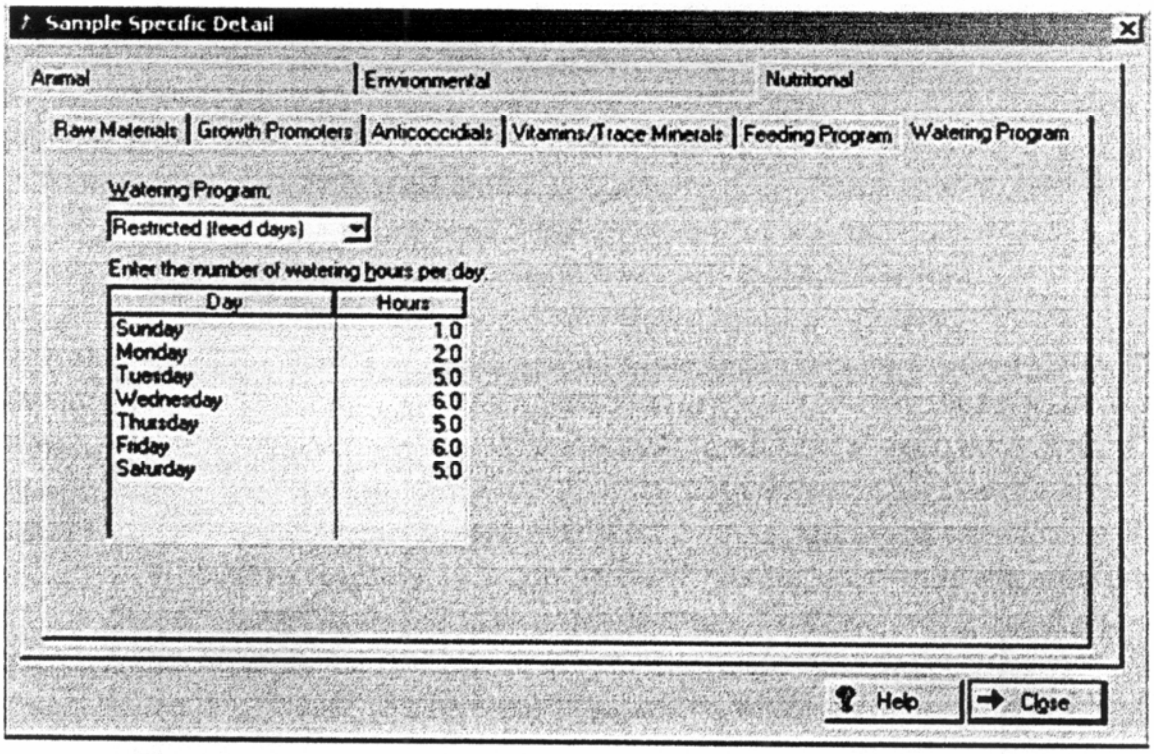

Select a Litter Type
Litter Type
Chaff and Hulls
Chopped Straw
Sand
Saw Dust
Shredded Paper
White Wood Shavings
Select
Close


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 probotics administered:
Probotic
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

Help files

A comprehensive help file 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 (Source: Puls, 1994. Mineral levels in animal health, diagnostic data). A problem solving Reference Document (RD) is also included into the Help file. This document enables the user to do on-the-spot problem solving, provides possible causes for problems and suggests actions to take in case of a specific problem.

Conclusion

Only 10% of South Africa receives an annual rainfall of more than 750 mm. The rainfall pattern is extremely irregular and varies considerably from the average. Water is therefore a valuable commodity in the country and any tool that increases or fine-tunes its use and application holds merit. This thesis highlights the fact that many poultry producers in South Africa have to use water with water quality constituent concentrations way above the norm. The effect of some of these constituents on poultry production has also been addressed. Previously established water quality guidelines recommend much lower maximum levels of water quality constituent concentrations. It is now clear that poultry can tolerate far higher levels without negative effects on production. Developing a water quality assessment tool was therefore a natural progression from the results obtained in the experiments.

For large, intensive commercial production systems a WQC that has a negative influence on nutrient bioavailability or feed intake 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, must be taken into account if feed formulation is to be accurate and representative of the true requirements.

The use of both the Generic and Specific GAL should allow for a more accurate observation and assessment of site-specific factors and will also prevent the incorrect classification of water sources as being potentially hazardous based on rudimentary guidelines. It will 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 for poultry production.

Appendix 1 to Chapter 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 on the literature cited and research conducted. Each of the mentioned factors are incorporated into the model since they all effect water intake, and hence the dose ingestion of a PHC.

ANIMAL

- **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).

- **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, litres 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 (Casey *et al*., 1998).

Table 5.4 shows the water intake of different type of poultry at different ages and at moderate and hot temperatures.

Table. 5.4. Daily ad-libitum water consumption of poultry (l/1000 birds) (Leeson and Summers, 1997)

Poultry type	Age	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**	**28**	**50**
	4wk	**120**	**230**
	8wk	**300**	**600**
Duck breeder		**240**	**500**
Goose	**1wk**	**28**	**50**
	4wk	**250**	**450**
	12wk	**350**	**600**
Goose breeder		**350**	**600**

- **Body weight**

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

$$LBW = 48 + 3.64D + 0.636D^2 + 9.63 \times 10^{-3}D^3$$

$$(1 < D < 28)$$

$$LBW = -1004 + 65.8D$$

$$(28 < D < 56)$$

- **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, and Berry, 1994).

- **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).

- **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. 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, B.R., 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 and Horne, 1970). Approximate water requirements at varying percentages of egg production is shown in Table 5.5 (North and Bell, 1990).

Table 5.5. 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**

- Gender ratio

Too many males in the breeding pen reduces 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 and Bell, 1990) (Table 5.6).

Table 5.6. 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**

- **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 a decline in feeding motivation. (Gentle *et al* 1982, Table 5.7, 5.8 and 5.9).

Table 5.7. 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 5.8. 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 5.9. 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, broilers fed firm pellets with essentially no fines experienced feed consumption and weight gain depressions from 50 to 70 days of age, compared with the corresponding values for controls. When birds were changed from mash to pellet diets at 42 days of age, there was a significant initial increase in feed intake and body weight gain in broilers receiving the pelleted diet, compared with broilers receiving the mash diet (Deaton *et al*. 1988, Table 5.10).

Table 5.10. Effect of beak trimming on body weight gain and feed consumption of broilers 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**

Environmental detail:

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

Humidity rises with cooling. Reducing the temperature of the incoming air by 10° will cause humidity to go up 20%. Reducing it by 20° will result in the relative humidity of the incoming air increasing 40%. In a study by Lacy and Czarick (1992) daily temperatures averaged 36°C. Typically, temperatures were reduced by 1 - 2°C in conventional housing and 4 - 7°C in tunnel-ventilated housing. 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, air movements can easily and quickly chill the birds, particularly young birds. 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% of body weight at 22 days to 12% at 48 days. Usage was 17% of body weight at 34 days. Air velocities had no effect before 30 days. After 34 days usage was 15.7% at 120 m/min. The average usage from 35 to 49 days was 14.3% in still air and 12.4% at 120 m/min. These results illustrate the relationship between age and tunnel ventilation (May and Lott 2000).

Wind Chill is the term used to describe the combined effect of low temperature and wind rate on heat loss from the body. As air velocity increases, heat is carried away from the body at a faster rate, driving down both skin temperature and eventually internal body temperature.

The following equation is used to determine the Wind Chill Index (K) for poultry but is applicable only at air velocities higher than 1.79 m/s.

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

Where 41 = the body temperature of a chicken.

4. Lighting

The duration of the adaptation period to continuous light is an important factor in determining feeding behaviour. Two important factors must be adhered to when choosing a lighting program for growing and laying pullets (North and Bell 1990): (1) The length of the light day should never increase for growing pullets and (2) the length of the light day should never decrease for laying pullets (Table 5.11).

Table 5.11 Influence of lighting 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 and Bell 1990, Table 5.12).

Table 5.12. 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 and 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 (Tables 5.13, 5.14).

Table 5.13. Improvements with various lighting programs (North and Bell 1990)

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

Table 5.14. Effect of short day length on male broiler performance (Leeson and 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 of higher density broiler production are significant and must be considered. With increased density, access to feed and water is more difficult, reducing the performance of each normal bird. Furthermore, birds that have only a marginal disability become less able to compete. With increased stocking density the demand for vital oxygen rises, adding to pressure on the bird's pulmonary and cardiovascular systems. Poorer litter conditions, with higher moisture content, result when stocking densities are greater. Coupled with the greater likelihood of a bird being scratched, this promotes 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 to disease.

Increased stocking densities and stress go hand in hand. Increased stress will manifest itself in many ways, most commonly as a reduction in overall performance. Greater stress increases susceptibility to the common broiler diseases of a given geographical area and may open the door for new and re-emerging diseases (Ritchie 1999, Table 5.15).

Table 5.15. Stocking densities for broilers

Liveweight (kg)	Birds/m^2
1	34.2
1.2	28.5
1.25	27.2
1.4	24.4
1.5	22.7
1.6	21.4
1.75	19.4
1.8	19.0
2	17.1
2.2	15.6
2.25	15.1
2.4	14.3
2.5	13.6
2.6	13.2
2.75	12.4
2.8	12.2
3	11.4
3.2	10.7
3.4	10.0
3.5	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:

Cage system	*Week 0 – 5* 200 cm^2/bird	*Week 5 – 18* 300 cm^2/bird	*Week18 - 72* 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 was higher, but return on estimated capital outlay was lower, with 102 mm than with 76 mm feeding space/bird, at a constant Colony size and floor area/bird. (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 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 3.5:1 and 7:1 hens per nipple.

Body weight and water intake was significantly influenced by the number of nipples per hen. 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.

1. 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 in Figure**

Figure 5.5. The relationship between dry bulb temperature, wet bulb temperature, equivalent temperature, vapour pressure and dew point.

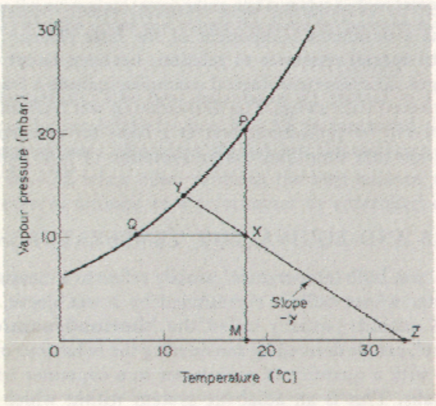


Fig. 11.1 The relation between dry bulb temperature, wet bulb temperature, equivalent temperature, vapour pressure and dew point. The point X represents air at 18°C and 10 mbar vapour pressure. The line YXZ with a slope of −γ gives the wet bulb temperature from Y (12°C) and the equivalent temperature 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.

Table 5.16 gives the optimum temperature and relative humidity for broilers.

Table 5.16. 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 high 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 ratio 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 800 g and the effect of temperature increased as body weight increased.

The following regression equations were developed in this study.

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

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

At moderate temperatures animals will consume, by weight, twice as much water 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 5.17, 5.18).

Table 5.17. % 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 5.18. % 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**

- **Floor type**

Poor litter conditions reduce access to feed and water. An increased demand for fresh air may increase the incidence of pulmonary/cardiovascular disease (Table 5.19).

Table 5.19. 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**

NUTRITION

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 chicks selected for high body weights, when fed a restricted diet. (Marks, 1980, Tables 5.20, 5.21, 5.22)

Table 5.20. 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**

Watering program

Table 5.21. Mean feed and water consumption and egg production of hens during and after a 6-week period with water supply restricted to 90% of *ad libitum* intake.

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 5.22. Effect of water restriction on weekly feed consumption of broilers (Leeson and 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**

2. Feed texture/Pellet size

The form of the feedstuffs plays a role in the consumption of water, although it is largely due to the relationship between feed and water rather than the actual physical form of the feed (Table 5.23).

Table 5.23 Mean body weights, feed intake and water intake by dietary treatment and age. (Marks and Pesti 1984)

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 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:

<u>Growth and production promoters</u>

A. Antibiotics cause a 1% increase in feed intake

1. Penicillin
2. Chlortetracycline
3. Oxytetracycline
4. Bacitracin
5. Streptomycin

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

1. Arsanilic acid (para – amino – hydroxyphenylarsonic acid)
2. Sodium arsanilate
3. 3 – nitro – 4 – hydroxyphenylarsonic

C. Hormonal preparations

1. Thyro – active have no effect on feed intake
   a) Iodinated casein
   b) Desiccated thyroid glands
   c) Thyroxine
2. Estrogenics cause 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

Anticoccidials

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)

Chapter 5 Antioxidants

Chapter 6 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

Vitamin and trace mineral premixes

Recommended vitamin and mineral specifications are presented in Table 5.24.

Table 5.24 Recommended Vitamin and Trace Mineral levels

		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
Chapter 7 it 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	0.03	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
Choline 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
Zn	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. Interrelationships

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 recognized as essential. 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, a standard methodology has been followed for the determination of the requirements of a specific nutrient. Graded amounts of the nutrient under study are added to a purified diet containing all the nutrients with the exception of the one being investigated. The minimum amount of a nutrient which produces the maximum benefit to, for example, growth, development, egg production or feed efficiency in a normal healthy flock, was tabled as the requirement for that function.

Although is 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 : that the requirements and functions were independent and isolated. During the last thirty years the concept of interdependence and interrelationships of various nutrients has been recognized and given due emphasis.

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

- The energy-protein relationship.
- The interrelationship between calcium, phosphorus and Vitamin D_3.
- Nicotinic acid and tryptophan.
- Choline, methionine, folic acid and Vitamin B_{12}.
- Vitamin E, Selenium and Cystine.
- Copper and zinc, zinc and cadmium, molybdenum and tungsten, selenium and arsenic.
- 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 5.25).

Table 5.25. ME/P ratios for varying caloric and protein content of the diet.

ME	Protein %													
Kcal per0.45 kg	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**

Sodium Chloride

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 (Tables 5.26, 5.27).

Table 5.26 Diet salt and litter moisture (Leeson and 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 5.27. 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

9. Protein

Protein sources such as soybean and meat and bone meal tend to increase water consumption compared to other protein sources. Certain fish meals contain higher sodium concentrations, depending on the age and type of fish used and the time of the year it was processed, which increases water consumption. Any nutrient that increases mineral excretion by the kidney will influence water intake (Table 5.28).

A comparison of the amount of oxidative water produced with the amount of water lost through evaporation and other routes allows for 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 and Cade 1963).

Table 5.28. Growth, feed and water consumption of birds on different levels of soybean oil meal (44%) in the diet over 8 weeks. (Glista and 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

10. Energy

High-energy diets tend to decrease water consumption compared to low energy diets (Table 5.29).

Table 5.29. Performance of broilers fed diets of variable energy content (Leeson and 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 5.30 Effect of energy dilution of finisher diet on growth of broilers. (Leeson and 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

APPENDIX 2 to Chapter 5

Site Specific Factors used in the model:

As explained in the section on modifying the WIRRD the following section deals with the modifying factors used to accommodate changes from the factors mentioned in APPENDIX 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 reference document.

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, litres 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

1. Egg production

The following factors apply to layers. If hen-day egg production (%) is the following and water intakes 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**

2. Gender Ratio

If the recommendations for gender ratio are not adhered to, the following rule applies:

Gender ratio > recommendation, then apply factor 0.9

Gender ratio < recommendation, then apply factor 1.1

3. 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 plant	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
Chapter 8	**All mash diet**
None	1.1
1/3 top	1
½ top	9.5
½ block	8
Chapter 9	**Pelleted Feed**
None	1.1
1/3 top	7.5
½ top	4.5
½ block	4.5

Environmental factors

1. Housing factors

The following housing water turnover rate factors apply:

Housing type	Broilers	Layers	Breeders	Dual purpose
Convection with floor with litter	0.9	0.9	1	1
Convection with slats	0.9	1	0.9	1
Convection with cages	0.9	1	0.9	1
Environmentally controlled 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 slats	0.9	1	1	1
Closed house (not environmentally controlled) with cages	0.9	0.9	0.9	1
Closed house (not environmentally controlled) with floor with litter	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 Celcius.

$K = 41 – ((10.4 + 10*(\sqrt{\text{Air velocity}}) – \text{Air velocity})*(41 – \text{Temperature})/22.04$

Where 41 = the body temperature of a chicken.

Chapter 10 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**

Broilers: 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**

4. Stocking density for broilers: If stocking densities are exceeded, apply the factor 0.9.

Liveweight (kg)	**Birds/m^2**
1.0	34.2
1.2	28.5
1.25	27.2
1.4	24.4

Liveweight (kg)	Birds/m^2
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

Open side houses for broilers: 25 kg/m^2

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

Stocking density for 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	-

Stocking density for layers:

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

5. Feeder space/type

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

Feeder Type	**Feeder Space**
<u>Manually filled:</u>	
Feeder plates	1 plate/70 – 100 chicks
Metal pen troughs (2cm)	4 cm space/chicken
Round suspended feeders (tube 38cm)	1 tube/70 birds
<u>Automatically filled:</u>	
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)

6. 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 - 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.

7. Relative humidity

If the RH exceeds the standards provided apply factor 1.1.

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

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.

8. 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 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

9. Floor type

Apply the following factors:

Floor type	Factor
Litter floor	**1.1**
Wire floor	**1**

Nutrition factors:

1. Feeding programme

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 program

The water intakes are adjusted by the watering programme detail stipulated below.

	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

Water intake (g/bird/day)

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

Chapter 11 If the following additives are present in the diet, apply the following factors :

Chapter 12 **<u>Growth and production promoters</u>**

Chapter 13 A Antibiotics cause a 1% increase in feed intake

- Penicillin
- Chlortetracycline
- Oxytetracycline
- Bacitracin
- Streptomycin

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

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

C. Hormonal preparations

Thyro – active No effect on feed intake

- Iodinated casein
- Desiccated thyroid glands
- Thyroxine

Estrogenic - 2% increase in feed intake

- Diethylstilbestrol (DES)
- 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.

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 below 0, 7.5, 15 or 30%

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

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

Diet energy **ME (kcal/kg)**	Factor	
	42d	49d
3200	1.250	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

Chapter 6

Summary, Application and Recommendations

As discussed in the Introduction to this thesis, the disparities and constraints of existing water quality guidelines for poultry production called for a new approach to their formulation. This study has highlighted the need to fine-tune Water Quality Guidelines in South Africa for specific species under specific conditions. Investigation of water quality on poultry farms in South Africa revealed that Bicarbonates, Chlorides, Fluoride, Nitrates, Phosphates, Sodium, Cadmium, Iron, Lanthanum, Lead, Manganese, Mercury, Titanium, Zirconium, Bromine, Chromium and Selenium occurred at levels higher than the recommended maximums established by Kempster *et al*. (1981), Waggoner *et al*. (1994) and Vohra (1980). The consequences of elevated levels of water quality constituents on poultry production are shown in Table 6.1.

Table 6.1 Water quality constituents and effects on poultry production found in water analysed.

Variable	PHC	COC	
	>	= / <	Adverse effects of excess #
Bicarbonate	98	88.2	Non-toxic.
Calcium	600	540	Non-toxic, clog up pipes.
Chloride	250	225	Reduced growth immature chickens, but effect largely overcome by adding Na and K.
Fluoride	6	5.4	Lower feed intakes and growth rates.
Magnesium	350	315	Laxative effect. Reduced growth and bone mineralization in immature chickens. Magnesium form part of the hardness of water.
Nitrate	10	9	Reduced growth, increase mortality rate. Impaired the oxygen carrying capacity of blood.
Nitrite	1	0.9	Thyroid enlargement methaemoglobinaemia.
Phosphate	2	1.8	Indicator of sewage contamination.
Sodium	50	45	Diuretic, reduced egg production and growth.
Sulphate	125	112.5	Laxative effect, reduced egg production.
TDS	3000	2700	Indication of excessive mineral content.
Bromine	3000	2700	Reduced growth rate.
Cadmium	5	4.5	Excess has severe health effects.
Chromium	100	90	Contributes to hardness, low toxicity, essential nutrient; absence causes diabetes.
Iron	10	9	Causes odour, bad taste & precipitate. Can encourage iron bacteria growth.
Lanthanum	1	0.9	Low to moderate acute toxicity rating.
Lead	20	18	A toxic element
Manganese	1000	900	Contributes to hardness and turbidity, deposits in pipes and bitterness of water.
Mercury	2	1.8	A toxic element with no beneficial physiological function.
Selenium	50	45	Reduced growth.
Titanium	100	90	Soluble salts potentially toxic.
Zirconium	1	0.9	Low toxicity.

Kempster et al. (1981); Waggoner et al. (1994); Vohra (1980) and Zimmerman (1995); Carter (1985); Phillips et al. (1935); Ralph (1989); Puls (1994) and Zimmerman (1995).

Because of their documented effects on poultry production and the interactions between some of them, Magnesium, Chlorides, Sodium, Nitrates, Sulphates, Calcium and Phosphorus were isolated for further experimental investigation.

The literature surveyed recommended the following allowable constituent levels (Table 6.2). In the subsequent studies the maximum allowed levels were sometimes exceeded.

Table 6.2. Maximum allowed levels of constituents investigated and the maximum levels administered in the subsequent trials.

Constituent	Maximum allowed level (mg/l)	Author	Maximum inclusions in experiments (mg/l)
Magnesium	125	Schwartz, 1994	250
Sodium	75	Keshavarz, 1987	250
Sulphate	60	Keshavarz, 1987	500
Calcium	200	Vohra, 1980	300
Phosphate	5	Kempster et.al., 1981	300
Chloride	250	Schwartz, 1994	500
Nitrate	10	Zimmerman, 1995	300

This study revealed that:

1. Twelve different combinations of Mg, Na, Cl and SO_4 had no significant effect on growth, food and water intake, and egg production or egg quality. Poultry producers in areas with naturally high levels of these minerals in their ground water can therefore continue to function successfully if the concentrations present are up to 250 mg/l of Mg, 500 mg/l of Cl, 500 mg/l of SO_4 and 250 mg/l of Na. At these levels the minerals manifested themselves in the egg contents and the effect thereof on the consumer needs to be investigated further. Since artificially enriched eggs are the order of the day in this century, creating a niche market for “mineral enriched eggs” is a possibility.
2. Hens receiving up to 300 mg/l of nitrate in the drinking water showed no significant differences in egg production or egg weight over a 12 week period. This indicates that intensive commercial egg production units, with naturally elevated levels of nitrate in the drinking water up to a level of 300 mg/l, do not run the risk of lowered egg production or weight.
3. Broilers receiving up to 300 mg/l of nitrate in the drinking water showed increased body weights in some weeks. The addition of Vitamin A to the nitrate treated water further increased body weights of chicks. The increase in body weight was not due to increased food intakes, as food intakes decreased in chicks receiving elevated levels of nitrate in the drinking water. No negative effects on broiler production and growth were observed.
4. Ca and P in the water up to levels of 300 mg/l can be a valuable asset to increase eggshell integrity. Waterline management may be increased because Ca tends to precipitate.

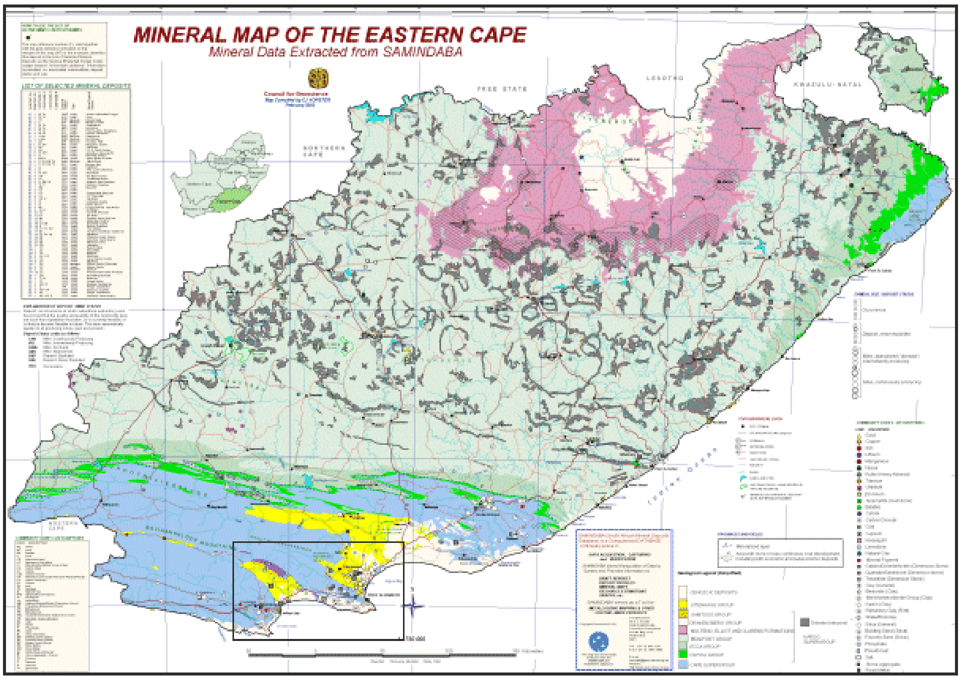
The results obtained in the experiments motivated a new approach to assessing water quality guidelines for poultry. This was addressed in the previous chapter. The practical implementation and workability of the academically correct approach might be considered questionable. Little of the information needed is usually on hand for the farmer with a potential water quality problem. Implementing at least some of the principles will, however, have a substantial effect on the usability of the water source. The main criteria for developing this system was to capitalise on water sources that were previously considered potentially hazardous or un-useable while avoiding potentially hazardous effects.

The development of this theoretical model (Chapter 5) highlighted the complex concepts required for water quality guidelines and the many factors influencing them. Unfortunately the academic approach is not always feasible. In this light it was decided to present a workable case study to demonstrate how the information gathered in the previous chapters could be applied to an on-farm situation.

Case study

1. A water sample was received from a farmer situated in the coastal areas of the Eastern Cape. The farmer is a poultry farmer and is home mixing his feed.

Map 6.1 Mineral map of the Eastern Cape



Source:http://www.geoscience.org.za/samindaba/maps/easterncape.htm

The Eastern Cape's coastal area receives abundant rainfall, but the interior is much drier and has had chronic drought problems. The city of East London, located on the coast, receives an average annual rainfall of 900 mm (36 in), while Cradock, in the interior, receives an average annual rainfall of 310 mm (10 in). Most rain falls during the warmer months of October through April. Average temperatures range from 18° to 27° C (from 64° to 80° F) in the summer and from 8° to 20° C (46° to 68° F) in the winter.

The province consists of the subtropical coast along the Indian Ocean and the semi-arid plains of the Karoo. Inland, the predominant vegetation is dense indigenous forests in the region near the coast and succulents and hardy plants in the Karoo (http://www.places.co.za/html).

Unlike the mineral rich provinces in the rest of South Africa, the Eastern Cape is without large, valuable mineral deposits. In particular the age of the rocks and strata are much younger than in provinces to the north. Notwithstanding this, several mineral deposits are located in the province but remain unexploited. Most are not precious metal deposits but minerals with industrial applications. Deposits that have value are stone quarried for export and building industry minerals, such as sand, aggregate, limestone and heavy mineral sands. (http://www.geoscience.org.za/samindaba/maps/easterncape.htm)

2. The sample was submitted for analysis to an accredited laboratory.
3. The water quality analysis results are presented in Table 6.3.

Table 6.3 Analysis results obtained from water sample taken in the Eastern Cape Province.

Mineral analysis results				
ELEMENT	**Borehole "Diptenk"**	**Borehole "Stal"**	**Borehole "Oom Dirk"**	**Max Allowed**
pH	6.41	6.5	6.69	6 to 9 *c*
Electrical conductivity	374 mS/m 25°C	686 mS/m 25°C	311 mS/m 25°C	370 *c*
Carbonate	None	None	None	0
Bicarbonate (mg/l)	658.91	812.53	646.71	98 *a*
Chloride (mg/l)	1290.74	>1773	1028.34	250 *b*
Sulphate (mg/l)	50.2	69.4	47.8	60 *e*
Calcium (mg/l)	177.4	234.4	142.8	200 *d*
Magnesium (mg/l)	703.9	1643.8	1004	125 *b*
Sodium (mg/l)	625	1171	482	75 *e*
Potassium (mg/l)	39.2	48.9	172.8	2000 *b*
Iron (mg/l)	0.067	0.088	0.071	0.2 *c*

a)Kempster et al., 1981, b)Schwarz, 1994, c)Carter, 1985, d)Vohra, 1980, e)Kehavarz, 1987.

4. The implications for poultry production using this water source.

Only the Borehole "Stal" will be discussed here, but it is obvious from the analysis above that boreholes on the same farm can differ in quality. When taking a water sample at a specific production facility, it is important to ensure a representative sample. To achieve this and to minimize cost, multiple samples from each borehole or watering site should be pooled and a sample taken of that.

In the "Borehole Stal" water analysis, elevated levels of almost all the constituents analysed occurred and the high electrical conductivity (686mS/m) is indicative of this. In Chapter 2 the interactions between Cl, Mg, Na and SO_4 were investigated. According to Schwartz *et al*. (1984) Cl levels as low as 14 mg/l may be detrimental to chickens if the Na level is higher than 50 mg/l and levels greater than 50 mg/l of Mg or Na may be detrimental if the $^{-}SO_4$ or Cl levels are high. Keshavarz (1987) found the permissible levels of Mg, SO_4, Na and Cl for poultry production to be Mg 10 mg/l, SO_4 50 mg/l, Na 50 mg/l, and Cl 20 mg/l. If the these levels are exceeded, the water is considered toxic.

The outcome of the work done in Chapter 2 showed that 12 different combinations of Mg, Na, Cl and SO_4 had no significant effect on growth, food and water intake, and egg production or egg quality. Poultry producers in areas with naturally high levels of these minerals in their ground water can therefore continue to function successfully if the concentrations present are up to 250 mg/l of Mg, 500 mg/l of Cl, 500 mg/l of SO_4 and 250 mg/l of Na.

If the Generic Application Level of the model (Figure 5.1) were applied to the analysed results, the outcome would be that this water source is not suitable for poultry drinking since the inclusions are much higher than the maximum levels allowed. When the same set of data is interpreted by the Specific Application Level of the model (Figure 5.2), this water source can be identified as a useable one, provided that all site-specific information is considered.

Exposure time to elevated levels of constituents is important in assessing water quality. This particular water source is suitable for broilers rather than layers because of the shorter period of exposure.

Table 6.4 shows the Ingestion rate (mg) of each constituent, assuming a worst case scenario of water intake determined when the environmental temperature is 32°C. The importance of determining ingestion rates instead of working with constituent levels present in the water can be seen. Sulphate no longer qualifies as a Potentially Hazardous Constituent.

Table 6.4 Ingestion rates (mg) of constituents present in the water.

Constituent	Level present in water (mg/l)	Water intake (l)	Ingestion rate (mg)	Max Allowed
Chloride	1773	0.5	886.5	250
Sulphate	69.4	0.5	34.7	60
Magnesium	1643.8	0.5	821.9	125
Sodium	1171	0.5	585.5	75

The vitamin and mineral premixes and diets used are shown in Tables 6.5 and Table 6.7.

Table 6.5 Vitamin and mineral premixes used in the broiler diets.

		STANDARD BROILER STARTER	STANDARD BROILER FINISHER
Vitamin A	iu	12 000 000	10 000 000
Vitamin D3	iu	3 000 000	2 000 000
Vitamin E	iu	40 000	30 000
Vitamin K3	g	2.5	2
Vitamin B1	g	4	2
Vitamin B2	g	6.5	5.5
Niacin	g	42	35
Calpan	g	13	11
Vitamin B12	mg	30	20
Vitamin B6	g	5	4
Choline	g	350	300
Folic Acid	g	1.2	0.8
Biotin	mg	120	100
Vitamin C	g	60	- - -
Zinc Bac. Active	g	22.5	22.5
Manganese Oxide	g	126	144
Zinc Sulphate	g	113.2	141.5
Copper Sulphate	g	23.7	29.6
Potassium Iodate	g	1.6	1.6
Cobalt Sulphate	g	2.3	2.3
Ferrous Sulphate	g	71.2	57.0
Selenium (5%)	g	6	6
Limestone Powder	g	Filler	Filler
UNIT SIZE	**:**	**2.5KG**	**2.5KG**
USAGE RATE	**:**	**ADD 1 UNIT TO 1 TON FINAL FEED**	**ADD 1 UNIT TO 1 TON FINAL FEED**

The premix contribution to the sulphate intake is presented in Table 6.6 and is negligible.

Table 6.6 Sulphate content of water ingested as well as premix ingested.

Mineral	Unit	Level Present Starter	Level Present Finisher	Sulphate contribution (%)	Total Sulphate present Starter	Total Sulphate present Finisher	Sulphate ingestion from water
Zinc Sulphate ($ZnSO_4.H_2O$)	g	113.2	141.5	16.4	18.6	23.2	
Copper Sulphate ($CuO_4S.5H_2O$)	g	23.7	29.6	12.84	3.0	3.8	
Cobalt Sulphate ($CoSO_4.7H_2O$)	g	2.3	2.3	14.77	0.3	0.3	
Ferrous Sulphate ($Fe_2(SO_4)_3.H_2O$)	g	71.2	57	23.02	16.4	13.1	
Total g of sulphate present in premix					**38.3**	**40.5**	
Feed intake of a 3 and 6 week old broiler					95 g/day	180 g/day	
Ingestion of sulphate through feed (premix included at 2.5 kg/ton)					**0.0036421**	**0.007284**	**34.7**
Total Sulphate intake					**34.703642**	**34.70728**	

Table 6.7 Diets fed

Raw materials	Broiler Starter kg	Broiler Grower kg	Broiler Finisher kg
Yellow Maize	548	663	707
Soya Oilcake	324	227	169
Dried Brewers Grain	38	22	32
Extruded Full Fat Soya	60	58	64
Limestone	12	15	17
Monocalcium Phos	11.5	7	4.5
Salt	4.5	4.5	4.5
Natuphos	0.05	0.05	0.05
DL Methionine	2.5	2	1.8
Lysine HCL	1.3	1.5	1.5
Broiler Starter Premix	2.5		
Broiler Finisher Premix		2.5	2.5
VOLUME	100	100	100
	g/kg	**g/kg**	**g/kg**
Dry Matter	886.7	883.1	881.7
ME Poultry	12.7	13.2	13.4
DE Swine	14.1	14.2	14.1
Crude Protein	229.3	189.4	169.5
Lysine	13.5	11.0	9.6
Fat	42.1	43.2	45.6
Fibre	37.6	33.5	34.6
Calcium	9.1	8.9	9.0
Total Phosphorus	7.5	6.2	5.5
Avl Phosphorus	4.5	3.5	3.0
Sodium	1.9	1.9	1.9
Chloride	3.3	3.4	3.4
Potassium	9.5	7.8	6.8
Magnesium	1.7	1.6	1.5

The feed contributes a further 0.342 g of sodium, 0.612 g of chloride and 0.270 g of magnesium, assuming an intake of 180 g of feed. The total intake of these minerals derived from the feed and water is then 0.928 g of sodium, 1.499 g of chloride and 1.092 g of magnesium. These levels are still too high to ensure optimal broiler production.

The diet has 4.5 kg of salt added to it. The contribution of this salt to the sodium and chloride levels ingested are shown in Table 6.8.

Table 6.8 The contribution of salt to the sodium and chloride intake of a 3 week and 6 week old broiler

	Salt %	Na and Cl in 1 ton of feed	Na and Cl in 1 kg of feed	Starter feed intake (g)	Finisher Feed intake (g)
Sodium	39.337	1770.165	1.770165	95	180
Chloride	60.663	2729.835	2.729835	95	180
Salt in feed (g)			4.5	0.427	0.81
Sodium intake from salt in diet				**0.168**	**0.319**
Chloride intake from salt in diet				**0.259**	**0.491**

Removing the salt from the diet would definitely alleviate the effects of Na and Cl in the water. Table 6.9 shows the levels of Na and Cl remaining in the feed after the salt has been removed from the diet. The total Na and Cl intake is now 0.609g Na and 1.007g Cl (Table 6.8) compared to the 0.928g Na and 1.499g Cl before it was removed.

Table 6.9 The effect of removing the salt from the diet.

	Starter g/kg	95g feed intake	Finisher g/kg	180g feed intake	Removing salt from the diet Starter	Removing salt from the diet Finisher
Sodium	1.9	0.1805	1.9	0.342	**0.013**	**0.023**
Chloride	3.3	0.3135	3.4	0.612	**0.054**	**0.121**
Magnesium	1.7	0.1615	1.5	0.27		

Table 6.10 Total Na and Cl intake after the salt was removed from the diet and adding the minerals from the water.

	Water	Starter	Finisher	Total Starter	Total Finisher
Sodium	0.5855	0.013	0.023	0.598	0.609
Chloride	0.886	0.054	0.121	0.940	1.007
Total intakes (g/kg)					

Final recommendations:

- This borehole is not to be used for layer production, as the exposure time to the high levels of Na, Mg and Cl would have the following effects :

Chlorides - High incidence

Chlorides Range (mg/l)	Effects - Poultry
TWQR 0 - 200	*No adverse effects*
200 - 500	**Adverse chronic effects** such as wet faeces, 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. Short and medium term exposure tolerated>.
>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>.

Magnesium - High incidence

Magnesium Range (mg/l)	Effects - Poultry
TWQR 0 - 125	*No adverse effects*
125 - 250	**Adverse chronic effects** such as diarrhoea, intestinal irritation, watery droppings and lethargy may occur, but are unlikely if: - the sulphate 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>.

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 sulphate 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 tolerated>.

- Broilers on a 6-week cycle will be able to produce adequately when drinking this water. Tolerance to these high levels of minerals will increase with age.
- Bedding management would be of utmost importance as the presence of Cl, Mg and Na at such high levels will lead to wet litter and breast blisters if not managed correctly.
- Removing the salt from the diet will greatly lessen the Na and Cl level ingested.

Conclusion:

The case study presented in this Chapter shows the workability of the model described in Chapter 5. The software program will conduct all calculations and a report presenting recommendations on water use will be supplied with each water sample entered.

The hypothesis that international water quality guidelines are adequate as a basis for water quality assessment for poultry production in South Africa is therefore rejected. This work should contribute to the final development of a tool to enable poultry farmers in South Africa to use the water sources on their farms optimally.

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