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

by

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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.

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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.