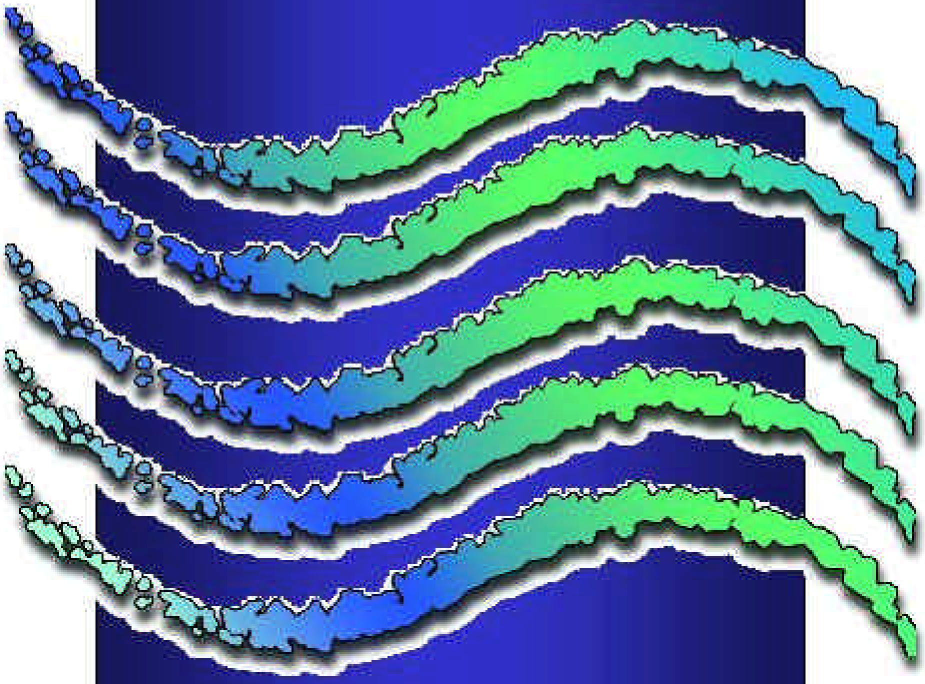
SOUTH AFRICAN

WATER QUALITY GUIDELINES

VOLUME 5

AGRICULTURAL USE: LIVESTOCK WATERING



Department of Water Affairs and Forestry

Second Edition 1996

SOUTH AFRICAN WATER QUALITY GUIDELINES

Volume 5: Agricultural Water Use: Livestock Watering

Second Edition, 1996

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South African Water Quality Guidelines

Volume 5
Agricultural Use: Livestock Watering

Department of Water Affairs
and Forestry

Second Edition
1996

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This volume is the fifth in a series of eight volumes comprising the South African Water Quality Guidelines.

Volume 1: South African Water Quality Guidelines -
Domestic Water Use

Volume 2: South African Water Quality Guidelines -
Recreational Water Use

Volume 3: South African Water Quality Guidelines -
Industrial Water Use

Volume 4: South African Water Quality Guidelines -
Agricultural Water Use: Irrigation

Volume 5: South African Water Quality Guidelines -
Agricultural Water Use: Livestock Watering

Volume 6: South African Water Quality Guidelines -
Agricultural Water Use: Aquaculture

Volume 7: South African Water Quality Guidelines -
Aquatic Ecosystems

Volume 8: South African Water Quality Guidelines -
Field Guide

Foreword

The Department of Water Affairs and Forestry is the custodian of South Africa's water resources. Part of its mission is to ensure that the quality of water resources remains fit for recognised water uses and that the viability of aquatic ecosystems are maintained and protected. These goals are achieved through complex water quality management systems which involve role players from several tiers of government, from the private sector and from civil society.

A common basis from which to derive water quality objectives is an essential requirement that enables all role players involved in such a complex system to act in harmony in order to achieve the overarching goal of maintaining the fitness of water for specific uses and to protect the health of aquatic ecosystems. For these reasons the Department initiated the development of the *South African Water Quality Guidelines*, of which this is the second edition. The *South African Water Quality Guidelines* serve as the primary source of information for determining the water quality requirements of different water uses and for the protection and maintenance of the health of aquatic ecosystems.

The process that followed and the wide variety of organizations and individuals involved in the development of these guidelines ensured the acceptance and use of these guidelines by all significant role players, as the ***South African** Water Quality Guidelines*. These guidelines are technical documents aimed at users with a basic level of expertise concerning water quality management. However, the role players involved in the different water use sectors are expected to use these guidelines as a basis for developing material to inform water users in specific sectors about water quality and to empower them to effectively participate in processes aimed at determining and meeting their water quality requirements.

The Department recognises that water quality guidelines are not static and will therefore update and modify the guidelines on a regular basis, as determined by ongoing research and review of local and international information on the effects of water quality on water uses and aquatic ecosystems. The process of developing water quality guidelines, and the involvement of key role players, is a contining one. The second edition is published in a loose leaf, ring binder format to facilitate the regular updating of the guidelines. All those who want to comment on and make suggestions concerning the *South African Water Quality Guidelines* are invited to do so at any time by contacting the Director: Water Quality Management, Department of Water Affairs and Forestry, Private Bag X313, Pretoria 0001.

Finally I wish to express my sincere appreciation to all those who have been involved in the development of these guidelines. I also look forward to their continued involvement in maintaining one of the corner-stones of the water quality management system in South Africa.

Kader Asmal

Professor Kader Asmal **MP**
Minister Of Water Affairs and Forestry May 1996

Contents

Acknowledgements

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Chapter 1

Introduction

Introduction

Scope and Purpose of the Water Quality Guidelines

Scope

The South African Water Quality Guidelines for Livestock Watering Use is essentially a user needs specification of the quality of water required for different livestock production systems. It provides information to make judgements on the fitness of water for livestock watering purposes, primarily for consumption by livestock, but also for water distribution systems.

The guidelines are applicable to any water that is used for livestock watering purposes, irrespective of its source (municipal supply, borehole, river, etc.) or whether or not it has been treated.

Purpose

The South African Water Quality Guidelines contain similar information to what is available in the international literature. However, the information provided is more detailed and not only provides information on the ideal water quality for water uses, but also provides background information to help users of the guidelines make informed judgements about the fitness of water for use. Where possible the information provided is based on local geohydrological and livestock production factors of relevance to the Southern African context.

Users of the Guidelines

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

Ongoing review

The *South African Water Quality Guidelines* will be periodically reviewed. The purpose of the reviews is to

- add guidelines for constituents not yet included in the guidelines

- update the guidelines for constituents currently included in the guidelines as relevant new information from international and local sources becomes available on the water quality or support information for a particular constituent.

The loose leaf/ring binder format of the guidelines, as well as the footnotes at the bottom of each page, which clearly indicate the exact version of a guideline, have been designed to facilitate regular updating of the guidelines.

Overview

The *South African Water Quality Guidelines for Livestock Watering Use* is divided into six chapters:

- Chapters 1 - 4 provide an introduction to the guidelines, define some important water quality concepts, explain how water used for livestock was characterised for the purpose of developing these guidelines, describe how the guidelines were developed and provide guidance on how they should be used.

- Chapter 5 provides the guidelines for the different water quality constituents.

- Chapter 6 consists of appendices which provide additional support information.

Water Quality

Introduction

To be able to correctly use the *South African Water Quality Guidelines* it is important for users to understand how water quality and some related concepts were defined for the purpose of developing the guidelines.

Definition

The term *water quality* is used to describe the physical, chemical, biological and aesthetic properties of water that determine its fitness for a variety of uses and for protecting the health of aquatic ecosystems. Many of these properties are controlled or influenced by constituents which are either dissolved or suspended in water.

Constituents

The term *constituent* is used generically in this edition of the *South African Water Quality Guidelines* for any of the properties of water and/or the substances suspended or dissolved in it. In the international and local literature, several other terms are also used to define the properties of water or the substances dissolved or suspended in it, for example *water quality variable*; *characteristic* and *determinand*.

Examples of constituents that are used to describe water quality are:

- the temperature of the water is 20 °C.
- the colour of the water is green.
- the concentration of calcium is 60 mg Ca/ℓ.
- 30 % of the surface of the water body is covered with water hyacinth.

Note that none of the statements of water quality in this example says anything about how desirable or acceptable it is for water to have the properties listed. Therefore, in addition to such statements, one also needs to make a judgement about how desirable or acceptable water of such a quality would be for a particular water use or for maintaining the integrity of aquatic ecosystems before the fitness of water for use can be determined.

Water Quality Criteria

Water quality criteria are scientific and technical information provided for a particular water quality constituent in the form of numerical data and/or narrative descriptions of its effects on the fitness of water for a particular use or on the health of aquatic ecosystems.

No Effect Range

For each water quality constituent there is a No Effect Range. This is the range of concentrations or levels at which the presence of that constituent would have no known or anticipated adverse effects on the suitability of water for a particular use. These ranges were determined by assuming long-term continuous use (lifelong exposure) and incorporate a margin of safety.

Target Water Quality Range

As a matter of policy, the Department of Water Affairs and Forestry (DWAF) has decided to strive to maintain the quality of South Africa's water resources within the No Effect Range. The DWAF encourages all stakeholders concerned with the quality of South Africa's water resources to join forces and aim to maintain water quality within the No Effect Range where and whenever possible.

For this reason, the No Effect Range in the *South African Water Quality Guidelines* is referred to as the Target Water Quality Range (TWQR). It is included and highlighted in the water quality criteria provided for each of the constituents in the guidelines.

Users of the *South African Water Quality Guidelines* should note that an important implication of setting the Target Water Quality Range equal to the No Effect Range is that it specifies good or ideal water quality instead of water quality which is merely acceptable.

Water Quality Guidelines

A water quality guideline is a set of information provided for a specific water quality constituent. It consists of the water quality criteria, including the Target Water Quality Range for that constituent, together with other support information such as the occurrence of the constituent in the aquatic environment, the norms used to assess its effects on water uses, how these effects may be mitigated, possible treatment options, etc.

The *South African Water Quality Guidelines* consist of the guidelines for domestic, recreational, industrial and agricultural water uses, guidelines for the protection of the health and integrity of aquatic ecosystems as well as guidelines for the protection of the marine environment.

Fitness for use

Introduction

The Department of Water Affairs and Forestry is the custodian of South Africa's water resources. Part of its mission is to maintain the fitness for use of water on a sustained basis. The concept of fitness for use is therefore central to water quality management in South Africa and to the development and use of these guidelines.

Water Use

Four broad categories of water use are recognised in the South African Water Act, namely

- domestic use;
- industrial use;
- agricultural use; and
- recreational use.

The DWAF's mandate also requires it to protect the health and integrity of aquatic ecosystems. The water quality requirements of these water uses and those for the protection of the health of aquatic ecosystems, form the basis on which the fitness for use of water is judged.

Characterisation of Water Uses

The broad water use categories listed above can each be subdivided into a number of subcategories such as water used for different livestock management practices and production systems. The subcategories of a particular water use can have quite different water quality requirements. Hence the need to characterise water uses into subcategories or components and to specify water quality requirements at a sub-use.

The characterisation of water uses involves determining and describing those characteristics which will help determine their significance as well as those which dictate their water quality requirements, for example:

- The significance of each water use is determined by considering issues such as the volume of water used, the socio-economic benefits and costs associated with the use; the nature of the use, that is, whether it is consumptive or not or whether it is abstractive or not.

- The water quality requirements of a water use is determined by considering:

    - typical water quality problems associated with a particular water use or the role that water quality plays in sustaining the use;
    - the nature of the effects of poor water quality on the use;
    - the norms which are commonly used as yardsticks to measure the effect of water quality on a particular water use;
    - the water quality constituents which are generally of concern; and
    - any other site- or case-specific characteristics of the water use which may influence its water quality requirements.

Fitness For Use

The fitness for use of water is a judgement of how suitable the quality of water is for its intended use or for protecting the health of aquatic ecosystems. The fitness of water use for livestock is largely determined by the type of livestock production system and associated environmental factors. Livestock production systems can range from intensive to extensive. The environments under which livestock can be farmed in Southern Africa also need to be accounted for.

To be able to make judgements about its fitness for use, one needs to :

- characterise the water uses and/or a particular aquatic ecosystem from a water quality perspective;
- determine the quality requirements of the intended uses and/or that of an aquatic ecosystem;
- obtain information on the key constituents which determine the fitness of water for its intended uses and/or which affect the health of aquatic ecosystems;
- establish how, and how much, the intended use or the aquatic ecosystem will be affected by the prevailing water quality; and
- determine whether the undesirable effects of water quality on a particular use can be mitigated for.

The fitness for use of water can range from being completely unfit for use to being 100 % or ideally fit for a specific use. Further, water of a specific quality may be fit for use for a specific livestock production system and environment, even though the water quality criteria may exceed the TWQR. The narrative descriptions commonly used to express judgements about the fitness of water for use are:

- ideal; 100 % fit for use; desirable water quality; target water quality range;
- acceptable;
- tolerable, usually for a limited time period only;
- unacceptable for use; and
- completely unfit for use.

Effects and Norms

Water quality can affect water uses or the health of aquatic ecosystems in many different ways. For example, it can affect the

- health of an individual drinking the water or swimming in it;
- productivity or yield of a crop being irrigated;
- cost of treating water before it can be used in an industrial process;
- sophistication of technology required to treat water to adequate quality;
- biodiversity of aquatic ecosystems.

It is therefore necessary to use different norms, such as health effects; crop quality; cost of treatment; sophistication of treatment technology; and the effects on biodiversity, as yardsticks when making judgements about the fitness for use of water.

Sustained Use

The sustained use of water is generally an important objective for economic growth and development. The long-term sustainability of water uses was an important consideration in the development of the guidelines. For example, the water quality criteria for livestock watering use are based on the assumptions of lifelong and continuous exposure to water of a given quality.

However, many livestock production systems have a predetermined slaughter stage, either in terms of live-weight or age. In these cases criteria may often be exceeded without adverse effects to the animal or product. The assumptions underlying the development of the guidelines must be taken into account, particularly when making judgements about the fitness of water which needs to be used for a short duration only. It is noteworthy that these scenarios form a large proportion of the livestock water user groups.

Chapter 2

Approach to Guideline Development

Approach to Guideline Development

Rationale, Approach and Methodology

Rationale

Many different water quality criteria and guidelines have been published in the international and local literature. Different approaches and methodologies have often been used to derive criteria and guidelines, for example some guidelines specify maximum concentrations for constituents as fit for use, whereas others attempt to define the ideal concentration of a constituent, often with the inclusion of safety factors. Therefore, depending on which guideline or criterion is used to establish water quality requirements, one can arrive at answers which sometimes differ by a factor of a hundred or more.

The rationale for developing the *South African Water Quality Guidelines* was to:

- Develop a single set of guidelines and criteria that is appropriate for South Africa, based on a consensus of South African expertise and other role players in water quality and fitness for use. The intention of this approach is to limit the confusion that often arises from the use of different criteria and guidelines to establish the water quality requirements for a particular water use by the stakeholders of water supply and utilisation in South Africa.

- Modify international guidelines in the light of local research and experience.

Approach

The difficulty of developing water quality guidelines for livestock watering use is partly due to the differences between livestock production systems and the diversity of environments in which livestock are farmed. Given these different factors, a wide range of possible effects for a given water quality constituent concentration exists and fitness for use is significantly affected by several factors not directly related to the intrinsic properties of a particular water.

Further, differences also occur within the same production system, for example from one beef feedlot to another with respect to rations, types of weaners, environmental factors and duration time of the feedlot. The main difficulty with the previous edition of the livestock watering guidelines and several international guidelines was that they provided derived concentrations for a specific water quality constituent which was fit for use during lifetime exposure for all production systems and environments. As such, these guidelines were highly conservative. Moreover, some guidelines were inapplicable to Southern African conditions and no solutions to problems of inherently saline water or water exceeding the recommended limit were given, a scenario which presents itself frequently in the arid zones of Southern Africa.

The approach taken was to

- give an indication of the No Adverse Effects range, that is, the TWQR;
- describe the possible adverse effects that might occur if stock were allowed access to water with concentrations exceeding the TWQR;
- give an indication of the major synergistic and antagonistic factors affecting the onset of possible adverse effects; and
- give an indication of the types of concentrations that might be tolerated, firstly for limited periods of exposure to constituents that have known toxicological effects and secondly, to indicate when adaption factors could be allowed for.

The first edition of the *South African Water Quality Guidelines for Livestock Watering Use* divided the water quality constituents into high and low incidence categories. This division is still valid, but constituents have been alphabetised for easier access.

Due to the importance of total ingestion of a specific water quality constituent and constituents that have synergistic and antagonistic effects, some nutritional factors have been included.

To comprehensively account for all relevant nutritional factors would be beyond the scope of these guidelines and the reader is referred to texts on livestock nutrition for further information.

The approach used to develop the *South African Water Quality Guidelines for Livestock Watering Use* was that the guidelines should, as far as practically possible, serve as a standalone source of information and support base to allow water resource managers to make judgements about the fitness for use of water used for different livestock uses. It is accepted that in many cases the user would have to consult different sources or obtain expert opinion before reaching a final conclusion as to fitness of water for use. However, the guidelines should, in these cases, at least indicate to the users what kinds of information to look for.

Therefore, the guidelines consist not only of the water quality criteria for a specific constituent but also include a substantial amount of information to support the user of the guidelines in making judgements about the fitness of water for livestock use.

In order to decide what information to include in the *South African Water Quality Guidelines,* an analysis was done of the DWAF's different water quality management processes. Those that required the guidelines to be used as a source of information and/or decision support were identified and their typical information needs determined. The product specification of the *South African Water Quality Guidelines*, delineating the information requirements, was provided to the technical teams responsible for the development of the guidelines.

Methodology

The methodology used to develop water quality guidelines for livestock watering in South Africa consisted of:

! Listing the various types of livestock production systems for which water was used.

! Describing, for each water use, the water quality-related problems or issues typically experienced in South Africa.

! Determining for each water quality problem or issue the appropriate norm to be used as a yardstick for assessing the effects of water quality on the purpose the water is used for.

! Determining, for each norm, which water quality constituents in South Africa typically affect the fitness of water for use. A list of constituents for the livestock watering guidelines was developed from this information.

! Accessing international and local sources of information and expertise to develop draft guidelines for each constituent selected.

! Through a process of technical review and stakeholder participation, finalising the guidelines as published in the *South African Water Quality Guidelines*.

- Characterising the main uses and norms for each use by which the fitness of water for livestock watering could be measured;

- Identifying the main water quality constituents involved with the respective uses and norms for the Southern African context.

- Identifying a TWQR based on South African expert experience and opinions and international literature.

- Identifying the primary factors involved in determining the concentration at which adverse effects can be expected and interpreting them in terms of their effects on the fitness for use.

- Identifying the types of adverse effects that could be expected with increasing concentrations of a specific water quality constituent.

Tentative Guidelines

The information available on the effects of some constituents on water uses is either very limited and/or there are unresolved differences in opinion on the effects these constituents may have on water uses. In these cases the guidelines have been included in the *South African Water Quality Guidelines* as Tentative Guidelines, and are clearly indicated as such.

During the ongoing review of the guidelines, it is intended that the status of the tentative guidelines eventually change to regular guidelines, when either sufficient information becomes available or sufficient consensus is reached among experts concerning the effects of these constituents on water uses.

Sources of Information

Introduction

Because the *South African Water Quality Guidelines* are primarily aimed at South African water resources managers and water users, a greater emphasis was given to South African source documents. Opinions of a wide range of South African experts in water quality and related aspects of livestock health and production, and of water suppliers and users, were used to supplement published sources. International literature was used primarily as background material.

Sources of Information

South African experts in water quality and water treatment, as well as water suppliers and users, were consulted during the development of the guidelines. The following criteria and guidelines published in the international literature were used as background and supplementary information in the development of the *South African Water Quality Guidelines for Livestock Watering :*

- AWRC 1982. *Australian Water Quality Criteria for Heavy Metals*. AWRC Technical Paper No. 77. Australian Government Printing Service, Canberra, xv - xxxiv, 5-10.

- CANADIAN GUIDELINES 1987. *Canadian Water Quality Guidelines*. Prepared by the Task Force on Water Quality Guidelines of the Canadian Council of Resource and Environmental Ministries. Canada.

- CANADIAN GUIDELINES 1992. *Update Canadian Water Quality Guidelines*. Prepared by the Task Force on Water Quality Guidelines of the Canadian Council of Resource and Environmental Ministries. Canada.

- ENSMINGER M.E., J.E. Olfield and W.W. Heinemann 1990. *Feeds and Nutrition*, 2nd Edition. The Ensminger Publishing Co., California, 168-169.

- GARDINER and Zabel 1989. *United Kingdom Water Quality Standards arising from European Community Directives - An Update*. Water Research Centre, , Buckinghamshire, UK.

- JOINT RESEARCH CENTRE 1989. *European Community (EC**) *Drinking Water Standards and Standards for Water Abstraction to Potable Supply*.

- HART *et al*. 1974. *Australian Water Quality Guidelines for Domestic Supplies*.

- HART *et al*. 1992. *Australian Water Quality Guidelines*, Draft for Public Comment. Australian and New Zealand Environment and Conservation Council, Australia.

- McKEE J.E. and H.W. Wolf 1963. *Water Quality Criteria*, 2nd Edition, California State Water Resources Control Board, Publication No. 3-A. California.

- US EPA 1976. *Quality Criteria for Water*, Section V. Agricultural Uses for Water. Water for Livestock Enterprises. National Technical Information Service, Washington DC, EPA.

- WHO 1984. *Guidelines for Drinking Water Quality*. World Health Organisation, Geneva, Switzerland.

Note: *The European Community is referred to as the EC when discussed as an economical/political entity. It is referred to as the European Economic Community (EEC) when directly citing a Directive promulgated before the formal change from EEC to EC in 1992.

The following criteria and guidelines published in the South African literature were used in the development of the *South African Water Quality Guidelines for Livestock Watering*:

- ADELAAR T.F. 1974. *Veeartsenykunde Onderstepoort* (Reuter and Gous, 1974).

- BOREHOLE WATER ASSOCIATION OF SOUTHERN AFRICA 1990. *Ground Water - Guidelines for Boreholes*. Compiled by Borehole Water Association of Southern Africa, CSIR (EMATEK), Department of Agricultural Development, Department of Water Affairs and the Geological Society of South Africa. CSIR (EMATEK), Pretoria, 3-27.

- BRIGGS G.M. and B.S. Schweigert 1990. An Overview of Meat in the Diet. In: *Meat and Health - Advances in Meat Sciences*, Volume 6. Ed: Pearson, A.M. and T.R. Dutson. Elsevier Applied Science, 3-19.

- CASEY N.H., J.A. Meyer, C.B. Coetzee and W.A. van Niekerk 1994. *An Investigation into the Quality of Water for Livestock Production*. Report to the Water Research Commission. WRC Report No. 301/01/94.

- DEPARTMENT OF WATER AFFAIRS AND FORESTRY 1993. *South African Water Quality Guidelines*, Volume 4: 1st Edition. Agricultural Use.

- KEMPSTER P., Hattingh and H. van Vliet 1980. Summarised WQC.

- KEMPSTER P. and H. van Vliet 1991. Internal Discussion Document on Draft Fitness-for-use Curves for Domestic Water Use.

- LAWRIE R.A. 1991. *Meat Science*, 5th Edition, 227-234.

- MARICOWITZ G. and W.J. Conradie 1985. *Boorgatwater vir Veesuipings op Soutpanproefplaas*. Department of Agriculture and Water Affairs, Transvaal Region. Agrivaal 7 (4), 1-4 (1985), 1-5.

- NATIONAL INSTITUTE FOR WATER RESEARCH (now Division of Water Technology) *Proposed Drinking Water Criteria* (Kempster and Smith, 1985) and Department of National Health and Population Development Criteria for Drinking-water Quality (Aucamp and Viviers, 1990).

- SINGH K.S. and B. Panda 1988. *Poultry Nutrition*. Kalyani Publishers, New Delhi, 115-137.

- SMITH R. 1988. *Water Quality Criteria for Livestock Watering and Human Consumption*. CSIR, Division of Water Technology. Project No. 670 21709.

- SOUTH AFRICAN BUREAU OF STANDARDS (SABS) 1984. *Specification for Water for Domestic Supplies*.

- WOLFORD J.H. and K. Tanaka 1970. Factors influencing Egg Shell Quality - A Review. *World's Poultry Science Journal*, Volume 26, 763-769.

Chapter 3

Characterisation of Use: Livestock Watering

Characterisation of Water used for Livestock

Background Information

Introduction

Livestock production is defined as using animals and their products in a responsible manner for the benefit of mankind by striving for improved biological and economic efficiency, taking animal comfort into account and without biological, physical or aesthetic degradation of the environment. Basic input commodities such as nutrition, energy and capital are converted with biological and economic efficiency into improved, value-added, user commodities.

The use of water for livestock production depends on several factors, such as the type of production system in use (intensive or extensive), the type of livestock and the type of livestock products.

Since the water needs of livestock differ, it follows that the type of quality requirements represent a synthesis of the needs for the various activities, and a wide spectrum of problems may be encountered where water does not meet requirements.

Production systems

Livestock are produced in extensive systems, semi-extensive/intensive systems or intensive systems. The characteristics of these different systems and the conditions within them vary and can affect the animal's water requirements. In some instances, such as beef, lamb and mutton, the primary phase of production is on extensive rangelands, from which the progeny are transferred to intensive feeding systems. Wool and mohair are produced on extensive rangelands.

The quality and vegetative composition of the range influences the water needs of livestock. The more succulent the feed, the less water supplementation is required and *vice versa*. Intensive systems, such as dairying, may combine grazing on cultivated pastures and a dry-feed supplement. Poultry, pigs and rabbits are all intensive systems and to a large extent are raised under environmentally-controlled conditions where dry rations are fed. Both intensive and extensive systems are set in a diverse range of environments and utilise different livestock species and breeds.

In all production systems, water troughs must be cleaned and serviced regularly to prevent an increase in salt concentration through evaporation, the growth of algae and the accumulation of debris. Overflowing water troughs create marshy conditions which make it difficult for animals to reach the trough and increase the possibility of disease and parasites. Pollution, especially by animal waste, must be avoided.

Sources of Water

Water supplies for livestock can originate from impoundments such as dams, from rivers and streams, or from ground water *via* boreholes. Livestock water sources in South Africa span a wide range, with most farmers relying largely on ground water for livestock watering, specifically in extensive production systems and during dry conditions. Both water quantity and quality may be affected by seasonal droughts or floods.

Water Requirements

The water requirements of animals are influenced by a number of animal physiological factors and the environment. These include conditions such as stage of physiological development, gestation, lactation, physical exertion, type of ration and dry matter intake, inorganic salt intake and ambient temperature-humidity indices.

The potable quality of water for livestock may be defined according to the palatability of the water which would affect intake and hence production, as well as its degree of contamination with pathogenic micro-organisms of a wide variety, algae and/or protozoa, hydrocarbons, pesticides and salts such as nitrates, sulphates, fluoride and the salts of heavy metals.

The following table gives an indication of the average daily water requirements for livestock. This provides a useful indication of water intake although the values may change due to dietary and environmental factors.

Table of Average Daily Water Intakes for Livestock (Ensminger *et al.*, 1990).

Species age (weeks and years)	**Body weight (kg)**	**Condition**	**Water intake (R/day)**
Cattle			**(R/day)**
4 weeks	51	growing	0.3 - 5.7
8 weeks	69	growing	5 - 7
12 weeks	93	growing	8 - 9
16 weeks	119	growing	11 - 13
20 weeks	148	growing	15 - 17
26 weeks	189	growing	17 - 23
60 weeks	354	growing	23 - 30
84 weeks	464	pregnant	30 - 38
1 - 2 years	464 - 545	fattening	30 - 34
2 - 8 years	545 - 726	lactating	38 - 95
2 - 8 years	545 - 726	grazing	17 - 34
			(R/day)
Pigs	14	growing	1 - 4
	27 - 36	growing	2.6 - 4.5
	36 - 57	growing	4 - 7.5
	91 - 180	maintenance	5.7 - 13
	91 - 180	pregnant	15 - 19
	91 - 180	lactating	19 - 25
			(R/day)
Sheep	9	growing	1.9
	23	growing	1.5
	68 - 91	grazing	1.9 - 5.7
	68 - 91	grazing (salty)	8
	68 - 91	hay + grain	0.4 - 3
	68 - 91	good pasture	< 1.9
			(R/100 chickens/d)
Chickens			
1 - 3 weeks		growing	2.7 - 5
3 - 6 weeks		growing	5.7 - 11.3
6 - 10 weeks		growing	11.3 - 15.2
mature		growing	15 - 19
mature		non-laying	19
mature (32EC)		laying	19 - 28
		laying	34
Horses			45

Water Quality Problems

A range of different impacts as a result of changes in water quality may be experienced. These can be categorised as follows:

- **Livestock consumption**
  - Toxicological effects
  - Palatability effects

- **Livestock distribution systems**
  - Economic impacts of the effects of scaling, corrosion or deposition of sediments in the distributing system.

- **Livestock product quality**
  - Consumer health hazards
  - Product quality problems

Constituents

The water quality problems and issues listed above can be identified with the constituents which cause them. Frequently, water quality problems are associated not only with the presence of a constituent, but with the interactions between constituents. Therefore certain constituents, such as total dissolved solids and pathogens, represent aggregates of constituents which interact to cause a particular water quality effect.

Some constituents are often used to characterise a water source and/or are identified a cause of water quality-related problems, whereas other constituents are associated with site-specific water quality problems. Prioritising constituents in terms of toxicity, as done in some international guidelines, can be misleading as constituents with a low order of toxicity typically are responsible for poor water quality-related problems. This is in part due to the geohydrology of Southern Africa and is enhanced by palatability or antagonistic effects (between constituents in feed and water).

The following categories are specifically applicable to Southern African conditions and are aimed at providing the water resource manager, who may not be familiar with livestock production and the typical water quality problems experienced, with an aid to manage a water source by placing emphasis on those constituents which are frequently hazardous. The terminology *potentially hazardous* is used, as adverse effects often occur without producing toxicity. Furthermore, there is often insufficient data to accurately assess the concentration at which a constituent may pose problems. This is due to the complex interacting factors involved with different conditions and types of livestock.

The following table indicates the incidence of occurrence of a particular water quality constituent.

Category A

Water quality constituents that are potentially hazardous, with a high incidence of occurrence

- salinity
- chloride
- sulphate
- arsenic
- copper
- sodium
- calcium
- fluoride
- molybdenum
- magnesium
- nitrate and nitrite
- toxic algae

Category B

Water quality constituents that are potentially hazardous, with a low incidence of occurrence

- cadmium
- chromium
- mercury
- lead
- zinc
- selenium
- boron
- aluminium
- cobalt
- iron
- nickel
- vanadium
- manganese
- pesticides
- pathogens

Site-specific Factors

The following factors need to be considered in establishing water quality guidelines as they influence the concentration/level at which a given constituent will have adversely affect livestock production:

- species tolerances;
- the climatic impact on the animal (macro and microclimates);
- the feed environment;
- the production system;
- the animal's physiology;
- the animal's production phase;
- the effect of time exposure to the potentially hazardous substances;
- the effect of concentrated intake over a short period;
- the physiological impact of exposure to potentially hazardous elements;
- the economic implications of such exposure;
- the probable carry-over effect of potentially toxic substances to the user of the animal product;
- the synergistic and antagonistic interactions between water quality constituents.

Characterisation of Uses

1 Livestock Consumption Norms
  - Toxicological Effects
  - Palatability Effects

2 Livestock Watering Systems Norms
  - Clogging
  - Corrosion
  - Encrustation
  - Scaling
  - Sediment

3 Livestock Product Quality Norms
  - Consumer Health Hazards
  - Product Quality

1 Livestock Consumption: Toxicological Effects

Constituents

Constituents of concern include arsenic, copper, fluoride, molybdenum, nitrite, sodium, toxic algae, cadmium, mercury, lead, selenium, pathogens and pesticides. Constituents that are of concern but **unlikely** to result in toxicosis due to a low order of toxicity **or** a low occurrence in the aquatic environment, are aluminium, calcium, chloride, chromium, cobalt, iron, manganese, nickel, sulphate, vanadium and zinc.

Description

Water quality constituents which, at certain concentrations, under certain conditions, act as a poison, are termed "potentially toxic". This implies that their ingestion or absorption may impair health or cause death. Most toxic constituents are absorbed in the intestine. Two principal factors are the quantity ingested (water and other sources) and the exposure time. The toxicity is not only determined by the toxicity of the constituent, but also the condition of the animal, nutritional status and production system specifics. Although some toxins *are* highly toxic and others have a low order of toxicity, this should not be the deciding factor in assessing the fitness for use of a water source. Although highly toxic constituents do have a given effect over a *smaller concentration range* (and exceedance of the TWQR is therefore more potentially hazardous), more often than not it is the constituents of low order toxicity that present problems in the industry. This is primarily due to their occurrence in the aquatic environment. Furthermore, it is invariably chronic toxicity which is more important than acute toxicity.

Effects

Poisons act locally and systemically, frequently affecting one organ more severely than others, hence references to blood toxins, muscle toxins, etc. The effects from the ingestion of a toxic water quality constituent differ not only between constituents, but also between species and, to a lesser extent, between breeds. Production system specifics are determining factors in terms of their respective synergistic and antagonistic factors. Invariably clinical symptoms, chemical pathological and pathological changes overlap. Chronic intoxication can have a clinical or a subclinical course. Furthermore, secondary infections often complicate diagnosis. Clinical signs often observed in livestock include unthriftiness, inappettance, impaired feed conversion ratio, poor growth, jaundice, harsh wool/hair, listlessness, anorexia and lowered production (milk). Grinding of teeth, abdominal pain, rectal prolapse, diarrhoea and tenesmus are usually terminal symptoms.

Reversibility

Depends largely on constituent implicated, amount ingested and prior condition of the animal. Reversibility may be complete, partial or not at all. Immediate specialist advice should be sought for suspected poisonings.

Mitigation

Prevention or decrease of constituent consumption is the first option. This could be *via* alternative water/feed provision and changes in the production system (housing conditions, production levels). A common practice is to feed, where possible, an antagonist of the constituent, usually to purge it from the system or to decrease its absorption.

However, results are often less than expected, due to "complication" factors. Treatment is usually based on symptoms. Specialist advice must be sought.

Norms

The first norm is the concentration of the constituent in the water and also in animal tissue. The health of the animal is the second norm. This is because many toxic constituents have a subclinical course and the adverse effects are observed too late. Livestock production/performance records serve as a valuable tool for early detection. It is important to positively identify the constituent in any suspected intoxication. Corroborative evidence, such as chemical analysis of animal tissues, is usually required for a specific diagnosis.

Site-specific factors

The total ingestion (from food and water) of the potentially toxic constituent has to be taken into account. High levels of a constituent in the water source are frequently accompanied by high levels in soil/pasture. Synergistic and antagonistic interactions between constituents in the feed and water also influence the concentration at which toxicity occurs. Therefore, all potential sources of contamination and ingestion of the relevant constituent should be examined. It is noteworthy that mineral availability in forage crops vary greatly, hence the importance between fallout contamination or uptake from soil. Specialist advice should be sought.

A most important factor is the water intake and hence ingestion of the constituent by the animal. This varies greatly for a given species/breed between environments and production systems due to varying water requirements. The implications are that lower concentrations can yield toxicity under some conditions, while higher concentrations may be tolerated in others.

Palatability Effects

Constituents

The primary water quality constituents of concern regarding palatability are the total dissolved solids (TDS), chloride and sulphate. Other water quality constituents which may be implicated include nitrates and high concentrations of heavy metals.

Description

The occurrence of certain water quality constituents, singularly or in combinations, can affect the palatability or taste of water for livestock. The acceptability of the water source for the livestock is manifested by a change in the amount of water consumed. A water source yielding suboptimal water intake (for a specific production system, salinity and related water requirements) due to adverse palatability can be assessed as water of poor quality for livestock production.

Effects

Adverse palatability results in an initial reluctance by livestock to consume the water, after which they will either adapt to the water or (if offered no alternative supply) be forced *via* thirst signals to drink from the available source. The resultant consumption of water is usually suboptimal, but may be excessive after a prolonged period of refusal. Due to the direct positive correlation between water and feed intake, suboptimal water intake can cause production and animal health to decline chronically. In extreme cases where livestock refuse to consume water for an extended period (more than 48 hours), the effects may be acute. Stock which have adapted to highly saline waters (often associated with potential palatability problems) tend to increase water intake with increased salinity.

This can result in above-average water intake for an extended period of time, leading to a high intake of other potentially hazardous water quality constituents. Toxic effects can result at normally safe concentrations, primarily due to the increased ingestion. A continuous high intake of saline water can also lead to primary hypertension with mainly the heart, brain, eyes and kidneys affected.

Reversibility The effects are generally reversible, provided suboptimal water intake has not occurred for an extended period of time (weeks) and fresh water can be offered.

Mitigation Livestock can generally adapt to adverse palatability, but this varies markedly between species, palatability constituents and production system specifics. These specifics influence the degree to which the adverse effects can be alleviated. Primary factors include forage moisture percentage and energy content of the ration.

Norms The norm used to assess palatability is the response of the animal primarily in terms of water intake. Deviation of the water intake from the normal level as dictated by the physiological requirement is an indication of adverse palatability. Additionally, any decline in production, health or feed intake may indicate suboptimal water intake.

Site-specific Information The following information regarding the response of the animal to the water source may aid in identifying and alleviating problems associated with palatability:

- initial refusal;
- time taken to drink readily;
- volume consumed compared to fresh water intake;
- general condition of the animals;
- type of ration, specifically protein and fat intake; and
- mineral content of ration/pasture (for possible toxic effects with high salinity waters).

2 Livestock Watering Systems

Norms and Constituents The following norms (characteristics) and water quality constituents are of concern regarding livestock watering systems:

Clogging	usually due to algae, bacteria and products of chemical precipitation such as manganese and iron.
Corrosion	
- Chemical corrosion	usually due to low pH values and high concentrations of total dissolved solids (TDS) and chlorides.
- Biological corrosion	usually due to sediments containing sulphate-reducing bacteria.
Encrustation	usually due to high concentrations of TDS.
Scaling	predominantly due to carbonates and sulphates of calcium and magnesium (polyvalent cations - equivalent quantity of calcium carbonate $CaCO_3$; referred to as hardness), although sulphate, zinc, manganese, aluminium and iron may contribute.
Sediment	predominantly due to manganese.

Description

Livestock watering systems can be adversely affected by the presence of certain water quality constituents. This may occur at levels which are still acceptable for livestock consumption. Previous watering systems that used asbestos and steel components encountered problems, primarily clogging and corrosion, but the current use of PVC and PE components is generally without major problems. Scaling and corrosion are therefore unlikely to be problematic. Problems are largely confined to watering systems with small emitters, such as those found in intensive livestock production systems (swine and poultry), and to deterioration in PVC pipes exposed to direct sunlight, which can lead to bursting. The PE pipes made to SABS specification can be indefinitely exposed to sunlight without fear of deterioration.

Effects

Clogging can occur in drip watering systems with small diameter emitters, such as those found in swine and poultry systems and ball-valves. Predictions of clogging may be calculated using the Langelier saturation index. Effects are usually a decrease in the flow of water and very seldom will clogging occur to a great enough extent to cause a blockage. Scale is formed on heat exchange surfaces and is very difficult to remove once formed. As regards corrosion, chlorides are particularly aggressive towards stainless steel and levels above 50 mg/ℓ may lead to corrosion, whereas SO_4 enhances corrosiveness to concrete and to asbestos cement pipes. For detailed descriptions, see **Industrial Guidelines**.

Reversibility

A certain degree of scaling can inhibit corrosion by forming a protective layer on metal surfaces, and hardness of over 50 mg/ℓ can prevent concrete dissolution. Water temperatures can rise significantly in black PVC pipes exposed to the sand and burying the pipes a short distance underground (10 cm) alleviates the buildup of carbonate encrustation. Removal of $CaCO_3$ formations can be accomplished with acid treatment. Regular cleaning of drinking troughs and reservoirs not only prevents excessive buildup found with high salinity water, but is also beneficial from a health perspective (decreasing evaporative effects and toxic algae, pathogens and parasites). Manganese and iron can be removed by aeration to form a precipitate, followed by filtration to remove the insoluble particles.

For further information on the remaining norms, see **Industrial Guidelines**. Specialist advice should be sought with suspected problems regarding livestock watering systems on a site-specific basis.

3 Livestock Product Quality

Norms

The norms are:

- Consumer Health Hazards
- Product Quality

Description

Livestock products generally include the following:

Meat: Beef, game and veal; lamb and mutton; kid and goat; pork; poultry which includes broilers, layers, ducks, geese, turkeys and ostriches.

Fibre: Wool, mohair and karakul

Dairy: Cows and goats

Eggs: Domestic fowl, ducks, geese and ostrich

Effects

Water quality constituents may adversely affect the quality of a product and/or render the product unsuitable for human/animal consumption. These effects are inevitably associated with a decline in animal health/performance, but may go unnoticed. Alternatively the livestock producer may be aware of the condition but unable to rectify it while production still continues.

Milk is usually well protected against arsenic, cadmium, mercury, and fluoride, but not against lead and selenium, although with very high levels in water and feed, a concurrent increase in milk for more water quality control will occur.

Species differences also occur as is apparent in the case of fluoride, but often analytical techniques to determine these are insufficiently substantiated.

Many metals may accumulate in tissues such as muscle, bone, brain, liver and kidney, although other than mercury and pesticides most are unable to accumulate to an extent where they pose a consumer health risk.

High concentrations and/or interference with calcium and subsequent interactive effects with manganese and zinc may result in lower egg production, decreased hatchability rate and egg shell thickness and in an increased number of small eggs. Further high concentrations of selenium may increase the incidence of embryonic abnormalities.

Chapter 4

Information Contained in the Guidelines

Information Contained in the Guidelines

Overview

The information contained in a guideline for a particular constituent is organised in three sections, namely:

- Background information. This section contains most of the support information required to make judgements about the fitness of water for use;

- Information on the effects of the constituent, including the criteria, on water used by livestock; and

- Information on additional sources of information.

The information in each section of a guideline for a constituent is organised under a series of labels in the left hand margin which identifies the type of information and can assist users of the guidelines to quickly locate the information they require.

Background Information

Introduction The introduction to the guideline for each constituent includes a brief description of the constituent as well as a brief statement of its significance for water used by livestock.

Occurrence Information on the fate and occurrence of a constituent in the aquatic environment, as well as the natural and manmade sources thereof, are provided as background to help the user determine how widely and in what form and under what circumstances the constituent is likely to occur.

Interactions The effects of a water quality constituent on the fitness of water for use can sometimes be significantly modified by synergistic or antagonistic effects caused by the presence or absence of other constituents in the water. These effects, if any, are described in the guideline and should be considered when making judgements about the fitness of water for use.

Measurement The effects of many constituents on water uses depend on the state (dissolved or particulate) and the chemical species (such as oxidised or reduced; inorganic or organic, etc.) in which it occurs. It is important for users of the guidelines to understand how measurement of the concentrations of constituents in water are obtained and which methodologies to use.

Data Interpretation The types of effects of constituents on water uses vary from acute to chronic. It is important that the appropriate statistics, depending on the type of effect that is likely, are estimated from datasets and used for making judgements about the fitness of water for use.

For example, if the type of effect is acute, statistics which estimate extreme values, such as the maximum or the 95th percentile, should be used to compare against the water quality criteria provided. However, if the effects are mostly chronic, estimates of the average situation, such as the median value, should be used.

Treatment Options

There are a large variety of options, or combinations of options, to:

- Improve, with the use of various treatments, the quality of raw water supplied to water users.

- Improve, with the use of various treatments, the quality of water on site by the users themselves. For example, to boil raw water drawn from a river before drinking it.

The cost of, and the ease with which management interventions can be implemented are important factors which can influence judgements about the fitness of water for use. The feasibility of such interventions depends on

- feasibility and availability of technological solutions;
- social acceptability;
- scale of the intervention required;
- institutional capacity to implement and sustain interventions;
- availability of suitably qualified people to implement and maintain the intervention; and
- capital and operating costs of implementing the intervention.

The information provided in the guidelines on treatment is very general and is simply provided to give the user of the guidelines a first indication of whether management intervention in the form of treatment is possible. It is expected that if that option is to be pursued, the user would obtain expert advice on water treatment.

The Effects of the Constituent

Norms

The norms which were used as yardsticks for assessing the effects of a particular water quality constituent on the fitness for use of water are described in this section of the guideline.

Effects

Water quality has different types of effects on specific water uses, for example these effects can range from

- acute to chronic;
- reversible to irreversible; and
- recoverable to irrecoverable.

In order to make informed judgements on the fitness of water for use, it is important that users of the guidelines take into account the information provided on what types of effects can be expected.

As a result of differences in the hydrological characteristics of South African rivers, the water quality from inflow sources can be highly variable. The effects of water quality on water uses often depend on the duration of exposure to water of a given quality. Therefore, users of the guidelines must also consider information on the likely duration of the exposure to water of particular quality when judging the fitness of water for use.

The effect of a given water quality on its fitness for use can be significantly enhanced or suppressed by other factors, such as:

- Adaptation by livestock to water of a certain quality;
- The nutritional status of animals using the water;
- The effects of climate, for example, on water intake by animals.

Users of the guidelines need to take into account the information provided on environmental factors and interactions with other constituents when deciding on the fitness of water for use.

Mitigation

The undesirable effects of water quality on its fitness for a specific use can often be prevented or mitigated through management interventions during the use or at the point of use. These interventions can, for example, include the addition of chemicals to water during use to reduce staining, scaling, corrosion, etc., or taking measures to reduce the consumption of water of poor quality in order to minimise possible negative effects.

The user of the guidelines is provided with relevant information on the availability of options for intervention and the feasibility of implementing such interventions. This information should be considered when making judgements about the fitness of water for use.

The information on mitigation in the guidelines is very general and is simply provided to give the user of the guidelines a first indication of whether management intervention in the form of mitigation is possible. It is expected that, if that option is pursued, the user would obtain expert advice on the different mitigation options.

Criteria

In the guidelines for livestock watering, the water quality criteria for most of the constituents is provided in the form of a table in which the effects of increasing concentrations of the constituent are described using the appropriate norms. The No Effect Range, designated in the *South African Water Quality Guidelines* as the Target Water Quality Range, is highlighted. It must be remembered that the Target Water Quality Range describes essentially what is considered good or ideal water quality and therefore water quality outside of this range may, under certain circumstances, still be acceptable.

Modifications

There are many site and case-specific factors which modify the effects of water quality on specific water uses. Examples of such site or case factors are:

- Ambient temperature and salt content of rations, which greatly influence the water requirement.

- Some chemical forms of a constituent may be much more toxic than others, for example, organic mercury is five to 10 times more toxic than inorganic forms.

It is therefore important that the information on site/case-specific modification of the guidelines be considered when making judgements about the fitness of water for use.

The information on modification provided in the guidelines is very general and is simply provided to give the user of the guidelines a first indication of whether the criteria for a constituent could or should in certain cases be modified. It is expected that, if it appears that the criteria should be modified in a particular case, the user of the guidelines would obtain expert advice on this issue.

Sources of Information

It was simply not possible to either include all the constituents which may possibly affect the fitness of water for livestock use, or to include all the relevant information on the constituents for which guidelines were developed.

The user is therefore referred to additional sources on information on a particular constituent. These same sources of information may in some cases also provide information on constituents which are not yet included in the *South African Water Quality Guidelines*.

Should the user of these guidelines require additional information, it must be remembered that, besides the publications referenced in the guidelines, there is also a wealth of unpublished information available from a number of organisations and individuals in South Africa. The list of acknowledgements of people and organisations who participated in the development of these guidelines is provided in the front of this document and is a good starting point for accessing this information.

How to Interpret the Guidelines

Generally, any water source where the constituent concentration is within the target guideline quality range, can be used with relative safety. Due to the possibility of antagonistic factors being present, either between constituents in the water source or between the constituent and the animal's environment, it is possible that slightly lower levels than the upper limit of the target guideline range may have an adverse effect on livestock. Should levels slightly higher than those recommended occur, it is possible that the level may still be used without an adverse effect on the livestock. This is due to synergistic factors in the water source and environment altering the level at which the constituent has an adverse effect.

Due to the abovementioned possibilities, a single target guideline value is not always indicative of the nature of the effect the level may have on livestock. The guidelines are, however, conservative and in most cases slightly higher levels can be used with caution.

In the event of concentrations being higher than recommended levels, the following course of action may be taken:

! refer the situation to a specialised person in the field of animal science;
! observe the impact of the water source on the animal in question.

Constituents not Included in the Guidelines

Generally, water quality guidelines for livestock are less conservative or less stringent than those for human drinking water standards. **If a constituent does not appear in the guidelines, human standards can be used with reasonable safety, although specialised persons in the field of animal science should be consulted.**

Factors requiring consideration include the ability of the constituent to accumulate in animal products, since this can affect human health.

Chapter 5

Water Quality Constituents

Algae

Background Information

Introduction

Cyanobacteria are fresh water blue-green algae which have been associated with numerous livestock and game deaths in southern Africa. The term blue-green "algae" is a misnomer as the organisms are in fact bacteria. In Southern Africa the most common bloom-forming algae is *Microcystis aeruginosa*, although blooms other *Microcystis spp.*, *Anabaena spp.*, *Oscillatoria spp.* and *Nodularia spumigena* have been reported. At present most poisonings have only been attributed to *Microcystis*, although there are some reported cases of *Nodularia* poisoning. Other toxic species may be implicated to a far lesser degree, but may have escaped attention due to a lack of monitoring.

Occurrence

Algae

Microcystis is widely distributed in southern Africa and indications are that toxicity is possible in any surface waters that can support a toxic *Microcystis* bloom. Most reported stock poisonings are in the south-eastern Transvaal and the north-eastern Free State. Blue-green algal cells may become over-buoyant, leading to thick scum formation during blooms. These scums are easily identified as thick, green, paint-like accumulations of algal cells along the shorelines. Wind direction influences scum movement and higher algal concentrations are often found on the windward verges of dams. Shallow eutrophic water with little turbulence and fine, hot sunny weather are conducive to algal growth. Blue-green algae tend to dominate the summer algal population on many Highveld water bodies. Potentially dangerous levels of toxic algae are very unlikely to occur in drinking troughs, due to a short residence time and subterranean water sources. Likewise they are unlikely to occur in closed water systems typically found in pig and poultry production systems, due to the lack of sunlight.

Repeated occurrences of *Microcystis* blooms on a small holding dam are often attributed to agricultural runoff from the same farm, indicating that management on a site-specific basis of diffuse pollution is required.

Toxin

A bloom can contain both toxic and non-toxic strains. Algal death or disintegration releases the toxin into the water. Release may also occur during digestion or with water treatment by copper sulphate. Conventional water purification may not be sufficient to destroy the poisons. In South Africa toxicity has been recorded on at least 17 large water bodies, situated throughout the country.

Interactions

The growth of algal blooms are governed by all chemical, physical and biological factors that determine their survival in a water body. Factors such as nutrient-rich conditions, lower nitrogen to phosphorus ratios, reduced feeding by zooplankton, the ability to regulate their buoyancy and elevated pH all favour the dominance of blue-green algae.

Blue-green cells

Measurement Blue-green cells are measured in the top meter of water as cells/mℓ and measurement requires the breaking up of colonies. The algae are measured as colonies/strings in a two-minute scan of 0.5 mℓ of the top meter of water under x200 magnification. As a rough guideline more than 2 000 *Microcystis* cells/mℓ, or more than six colonies of blue-green algae/0.5 mℓ can be regarded as a **bloom**. A bloom carries a high risk of **scum** formation (within two weeks). A scum is not measured in terms of cells/mℓ or a colony count, but is identified as an accumulation of algal cells visible with the naked eye.

Toxins

The mouse bio-assay involving intraperitoneal injection of blue-green cell extracts is the most common form of bio-assay. This is a useful technique to detect acute risks to livestock, although extrapolation to *per os* ingestion by livestock may not always be valid (an intraperitoneal injection of 200 μg/kg was lethal within two hours to a vervet monkey, whereas a *per os* dose of 1 000 μg/kg did not result in any detectable pathological effects). Immunoassays and protein phosphatase inhibition tests can also be used to quantify the toxins (detection of levels below 0.8μg/ℓ). Microcystins and nodularin can also be chemically analysed using HPLC, while the neurotoxins anatoxin-a and anatoxin-a(s) are detectable on a GCMS.

Data Interpretaion Single-sample values should be used to compare with the criteria given. If a toxic bloom is detected, a permanent risk of toxicity should be assumed.

Treatment Options Depending on the size and mobility of the algae in the water, their removal will normally require an effective coagulation and flocculation process followed by dissolved air flotation prior to deep-bed or multimedia filtration. Coagulants like aluminium sulphate or ferric chloride are conventionally used, with small doses of polyelectrolytes added to assist in flocculation. With many waters, small doses of polyelectrolytes alone may be sufficient to promote flocculation of the particles for removal by flotation and filtration.

The algae may contain toxic components within their cell contents or produce toxic extracellular excretions. In these cases it is necessary to adsorb the excretions using activated carbon, or to destroy them with a strong oxidising agent such as ozone. The processes require careful design and skilled monitoring and control to operate effectively. Similarly, the grade of activated carbon used should be chosen for its ability to adsorb algal excretions.

Flotation overflow and filter backwash water may cause disposal difficulties.

The Effects of Algae

Norms The norms used in the guideline are based on the toxicological effects associated with the ingestion of toxic algae in water consumed by livestock.

Effects Chronic affects are unlikely to be of importance in livestock as exposure to high toxin concentrations is seldom continuous. Most often acute effects are associated with algal scums.

Three types of cyanobacterial toxins are known: hepatotoxins, neurotoxins and lipopolysaccarides. The lipopolysaccarides are of little importance for livestock. The majority of hepatotoxins are known as microcystins, while the genera *Anabaena* and *Oscillatoria* produce neurotoxins. The former are most frequently responsible for livestock poisonings and the primary adverse effects are liver cell shrinkage, liver haemorrhages and death from circulatory shock due to the pooling of blood in the liver. The primary freshwater neurotoxins are anatoxin-a and anatoxin-a(s). Although anatoxins have not yet been associated with animal poisonings in southern Africa, poisonings are common in Australia. The neurotoxins saxitoxin and neosaxitoxin are more commonly associated with the marine dinoflagellate algae (red tides), although freshwater blue-green algae have been reported to produce these toxins.

For hepatotoxins, symptoms of acute poisoning include weakness, constipation (hard and blood-covered faeces), apathy, icterus, inappetence, ruminal stasis and photosensitivity. Liver haemorrhage is usually evident on *post mortem*. For neurotoxins, symptoms of acute poisoning include paralysis, muscular tremor, staggering and convulsions.

The microcystins are chemically stable, but degradation may be higher in the lower pH range, found in the gut of monogastrics, as opposed to higher pH ranges found in the rumen of ruminants. Ruminants are most commonly affected by poisoning, possibly attributed to reduced selectivity when drinking. Sheep tend also to select far more than cattle and are therefore less likely to be affected than cattle. The possible bacterial degradation of microcystins does not appear to have a significant alleviatory effect in ruminants.

It should be stressed that it is the consumption of scum that is most likely to cause adverse effects. Stock may drink from waters with a blue-green bloom which has values in excess of the TWQR without any adverse effects. However, this is not recommended as the risk of scum formation is high and may occur overnight.

Mitigation

Firstly, stock should not be allowed to drink from or have any contact with algal scum. Stock should rather be forced to drink from a different area (same water body), but care must be taken as wind can shift the scum within a short period of time. Therefore it is preferable to prevent access to the water body until analyses indicate it to be safe. This practice should not present any problems as the scum does not usually persist continuously. Secondly, the scum can be physically broken up and dispersed throughout the water body. Thirdly, a registered algicide can be used to control the bloom. If a water body is also intended for domestic drinking use, any algicide should be avoided as these toxins can penetrate the treatment works. The use of copper sulphate to control the bloom has led to chronic poisoning in *humans*. If an algicide is used that causes lysing of the cells and hence toxin release, stock can still be allowed to drink from the water body because the toxin only accumulates to sufficient levels to be toxic in scums. On destruction of the bloom the toxin disperses into the water body and the concentration of the toxin is not sufficient to cause adverse effects.

There are several methods to manage blue-green algal blooms, of which the following are the most practical:

- Managing nutrient loads, especially phosphorus.
- Chemical removal using a registered algicide.

Criteria **Effects of Toxic Algae on the Health of Livestock**

Toxic Algae Range[a]	**Effects**
Target Water Quality Range @ ***No visible blue-green scum*** @ ***< 6 colonies of blue-green algae/0.5 mR*** [b] @ ***< 2000 Microcystis cells/mR*** [c]	***No adverse effects***
@ No visible blue-green scum @ > 6 colonies of blue-green algae/0.5 mR[b] @ > 2 000 Microcystis cells/mR[c]	Low risk of acute toxic effects Vigilance for scums should be increased
@ Visible blue-green scum @ > 6 colonies of blue-green algae/0.5 mR[b] @ > 2 000 Microcystis cells/mR[c]	High risk of acute toxic effects Do not allow livestock to drink from or have contact with the scum

[a] The TWQR is a risk assessment based on the following monitoring procedures:

" Water bodies with a ninetieth percentile for phosphate greater than 30 µg/R should be monitored to assess acute risks associated for livestock drinking water as follows:
  - Routine monthly analysis for blue-green algae colonies.
  - On detection of a bloom (dominated by blue-green algae) monitoring should increase to fortnightly and if the TWQR is exceeded a mouse bio-assay should be conducted to determine the acute risks present.
  - On detection of toxic scums (mouse bio-assay) livestock should not be allowed access to the water and monitoring should increase to weekly.

" Water bodies with a ninetieth percentile for phosphate of less than 30 µg/R should be monitored reactively to assess acute risks associated for livestock drinking water, following the same procedure as above once a bloom (dominated by blue-green algae) is detected. *Whenever a bloom is detected visual vigilance for scums should increase*.

[b] This is the preferred guideline due to easier measurement.

[c] The Australian guideline of 2 000 *Microcystis* cells/mR is used to indicate a risk of 1µg/R microcystin.

Sources of Information

FALCONER I.R., J.V. Smith, A. Jones and M.T. Runnegar 1988. Oral Toxicity of a Bloom of the Cyanobacterium *Microcystis Aeruginosa* Administered to Mice Over Periods up to One Year. J*ournal of Toxicology and Environmental Health*, 24: 291-305.

LAWTON L.A., C. Edwards and J.A. Cold 1994. Extraction and High Performance Liquid Chromatographic Method for the Determination of Microcystins in Raw and Treated Water. *The Analyst*, Volume 119.

QUIBELL G., J.E. Badenhorst and C.I.C. Carelson 1995. *A National Toxic Blue-green Algal Surveillance Program for South Africa*. Institute for Water Quality Studies. Department of Water Affairs and Forestry, Draft, Internal Report.

RUNNEGAR M.T., S. Kong and M. Berndt 1993. Protein Phosphatase Inhibition and In Vivo Hepatotoxicity of Microcystins. *American Physiological Society*, 224-230.

Aluminium

Background Information

Introduction

Pure aluminium is a silvery-white, soft, light metal, resistant to corrosion by the formation of a thin protective layer of the oxide of aluminium. Aluminium does not appear to be an essential nutrient for livestock and is for all practical purposes, non-toxic. Aluminium salts are not normally absorbed from food and water and are readily excreted.

Occurrence

Aluminium is the most common metal in the earth's crust, having an abundance of 81g/kg. Aluminium does not occur in the elemental form, but its minerals, particularly the silicates of aluminium, are widespread. Some important minerals containing aluminium are bauxite (hydrated aluminium oxide), spinel (magnesium aluminium oxide) and various aluminium silicates, for example kaolins.

Aluminium occurs in water in two main phases, either as suspended aluminium minerals, or as dissolved aluminium species. Where aluminium occurs as a hydrated Al(III) cation, it hydrolyses and precipitates as insoluble aluminium hydroxide, approximately neutral pH. The concentration of dissolved aluminium in unpolluted water at neutral pH is 0.005 mg/ℓ or less. In acidic waters, or where soluble aluminium complexes are present, the dissolved aluminium concentration can rise to high mg/ℓ values.

Interactions

Aluminium oxide and hydroxide are amphoteric, that is, they are insoluble in water around a neutral pH, but dissolve under strongly acidic or strongly alkaline conditions. As such, the interactions of aluminium are strongly influenced by **pH**. The chemistry of the aluminium hydroxide and the nature of available organic and inorganic complexing ligands also influence the interactions of aluminium. For example, in the presence of **fluoride**, aluminium remains in solution at neutral pH.

Measurement

The criteria refer to dissolved aluminium, i.e. aluminium which passes through a 0.45 µm membrane filter. The reference method for determining the concentration of aluminium is atomic absorption spectrometry using a nitrous oxide flame and addition of potassium as an ionisation suppressant. If other methods are used, such as colorimetric methods, their characteristics relative to the reference method should be known.

If total aluminium (the dissolved plus suspended fraction) is measured, the sample should be acidified before filtration. A vigorous digestion step is required since the acidification step will only dissolve species such as aluminium hydroxide and not aluminium silicate minerals.

Data Interpretation

Mean values should be used to compare with the criteria given. The pH value, as well as the fluoride concentration in the water, should be taken into account when interpreting the aluminium concentration. Fluoride tends to form complexes with aluminium and may keep aluminium in solution at neutral pH, where it would otherwise precipitate.

Treatment Options

The technologies available for removing aluminium from water include:

! The formation and precipitation of insoluble aluminium salts. Aluminium ions will react with alkalinity in the water to form aluminium hydroxide, which is insoluble in the pH range of 6.7 - 7.6. The particles formed are very light and difficult to settle without the addition of a polyelectrolyte to flocculate and increase the specific gravity of the particles. An alternative method is to dose with a phosphate solution and remove the aluminium as insoluble aluminium phosphate.

! Substitution of aluminium with sodium in a cation exchange column along with calcium and magnesium.

! Removal of aluminium together with other dissolved components using desalination techniques such as demineralisation by ion exchange, membrane processes or distillation methods.

All of the methods described require skilled monitoring and control and generate a concentrated waste stream that may cause disposal difficulties.

The Effects of Aluminium

Norms

The norms used in the guideline are based on the toxicological effects associated with the ingestion of aluminium in water by livestock.

Effects

Aluminium is relatively non-toxic and occurs as a trace element in milk. Ingestion of high concentrations of soluble aluminium salts may result in symptoms of neurotoxicity, although aluminium is usually rapidly excreted in the urine of healthy subjects.

Uptake of aluminium increases in a calcium-free medium. As such the effects of ingesting high concentrations of aluminium under conditions of calcium deficiency may be exacerbated. High levels of aluminium are also associated with increased hepatic iron concentrations due to a decreased availability of absorbable iron phosphate complexes.

Mitigation

Sufficient dietary levels of calcium and phosphate indirectly mitigate against the effects of aluminium.

Criteria **Effects of Aluminium on the Health of Livestock**

Aluminium Range (mg/ℓ)	**Effects**
	All species
Target Water Quality Range 0 - 5	***No adverse effects***
5 - 10	**Adverse chronic effects, such as neurotoxicity, may occur but are unlikely if:** - feed concentrations are normal - exposure is short term - adequate dietary intake of calcium and phosphorus Could even be tolerated in the long term, depending on site-specific factors, for example water requirement
> 10	**Adverse chronic and acute effects, such as neurotoxicity, may occur, although:** - short-term exposure can be tolerated depending on site-specific factors, such as adequate calcium and phosphate intake and water requirement

Note: Actual water intake level and subsequent ingestion of aluminium can vary significantly between species and production systems, see **Characterisation of Use**. *High aluminium concentrations in water are only likely in areas subjected to industrial or other pollution*.

Sources of Information

APHA 1989. *Standard Methods for the Examination of Water and Waste Water*, 17th Edition. American Public Health Association, American Water Works Association, Water Pollution Control Federation. Published by the American Public Health Association, Washington DC, USA.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY 1993. *South African Water Quality Guidelines*, Volume 1: Domestic Use, 1st Edition. The Government Printer, Pretoria, South Africa.

ELSENHANS B., K. Schumann and W. Forth 1991. Toxic metals: Interactions with Essential Minerals, In: *Nutrition, Toxicity and Cancer*. Rowland, IR (Ed.). CRC Press, Inc. USA, 197-222.

LITTLE D.A. 1982. Utilization of Minerals. In: *Nutritional Limits to Animal Production from Pastures*. Hacker, JB (Ed.), Commonwealth Agricultural Bureaux, Slough, England, 259-283.

MACDOWELL L.R. 1992. *Minerals in Animal and Human Nutrition*. Academic Press, Inc., New York.

NRC 1980. *Mineral Tolerance of Domestic Animals*. National Academy Press, Washington DC.

NRC 1984. *Nutrient Requirements of Sheep*, 6th Revision, Ed. National Academy Press, Washington DC.

NRC 1985. *Nutrient Requirements of Cattle*, 5th Revision, Ed. National Academy Press, Washington DC.

PROVAN S.D. and R.A. Yokel 1988. Aluminium Uptake by the In Situ Rat Gut Preparation. *J. Pharmacol. Exp. Ther.*, 245: 928.

WEAST R.C. 1979. *CRC Handbook of Chemistry and Physics*, 60th Edition. CRC.

Arsenic

Background Information

Introduction

Arsenic is a greyish semi-metal and occurs in three oxidation states, namely, (0), (III) and (V). In solution arsenic can exist as arsenite, As(III); arsenate, As(V); and as different organic complexes. Inorganic arsenates form arsenate salts with cations of calcium or iron. Soluble arsenic compounds are readily taken up by living organisms and at elevated concentrations can exert toxic effects.

The maximum tolerable dietary level for livestock is 50 mg/kg feed for inorganic forms of arsenic and 100 mg/kg for organic forms.

Occurrence

Arsenic is fairly widespread in the environment: the average concentration in the earth's crust being approximately 2 mg/kg. It is found as arsenates, with sulphides, in association with many other metallic ores and occasionally in the elemental form. Arsenates and arsenites are the major inorganic forms in which arsenic behaves as an anion.

Typically, the concentration of arsenic in fresh water is less than 1 Fg/R and in sea water, approximately 4 Fg/R. Elevated concentrations of arsenic occur where there is pollution from industrial sources, or where geological outcrops of arsenic minerals occur. For example, new borehole water supplies in areas where arsenic minerals occur should be tested for arsenic content.

Arsenic is used in metallurgy, in the manufacture of glassware and ceramics, and as a pesticide and wood preservative. Arsenic is also used to control insects and weeds and to defoliate crops. Arsenical chemicals occur at low concentrations in livestock feeds and feed additives to enhance growth in pigs and poultry. Contamination of water sources from old dip tanks may also be a problem. The use of arsenic as a former livestock remedy is prohibited and sources of arsenic are likely to be from old dip remedies, or disused, often forgotten dip tanks.

Interactions

To a large extent, **pH** and redox potential determine the type of inorganic arsenic species present in the aquatic environment. Metabolically, arsenic interacts with many elements, among them **selenium** and iodine.

Measurement

The reference method for the determination of arsenic is by atomic absorption spectrometry, with hydride generation. The various forms of arsenic are converted to As(V) in an acid digestion and then reduced to As(III), prior to the generation of arsine gas with borohydride. If other methods are used to measure arsenic, their characteristics relative to the reference method should be known.

Data Interpretation

Single-sample maximal values should be used to compare with the criteria given. The target water quality range should not be exceeded. If mean values are used, they should be **five times** less than the non-exceedance limits.

Treatment Options

Arsenic is most effectively removed from water in its pentavalent form. Trivalent arsenic is first converted to the pentavalent form using an appropriate oxidising agent such as chlorine or potassium permanganate. Pentavalent arsenic is effectively removed from water using conventional coagulation and flocculation processes followed by settlement and filtration. Suitable coagulants include aluminium sulphate, ferric salts and lime. The process requires monitoring to ensure the arsenic is effectively removed. The process will also generate a watery sludge rich in arsenic, that may present disposal problems.

The Effects of Arsenic

Norms

The norms used in the guideline are based on the toxicological effects associated with the ingestion of arsenic in water consumed by livestock.

Effects

Metabolically, arsenic compounds are methylated to form monomethylarsonic and dimethylarsinic acid. Arsenic does not appear to accumulate to a great extent in animal tissues and tends to be involved in the redistribution of copper, ultimately leading to a decrease in renal copper excretion. Arsenic has been reported to increase renal copper retention levels by 500 %, while decreasing hepatic copper levels by five percent.

Arsenic has also been shown to increase hepatic iron concentrations and the resultant anaemia found with arsenic exposure may be due to interference by arsenic on the utilisation of iron for haem synthesis.

According to the Canadian Guidelines (1987), the lethal dose for animals in general is 10 - 50 mg/kg feed for lead arsenate and 35 - 100 mg/kg feed for calcium arsenate. The Australian Standards for acute toxicity of inorganic arsenic for farm animals are:

Poultry:	0.05 - 1.0 g /animal
Dogs:	0.1 - 0.2 g /animal
Pigs:	0.05 - 1.0 g /animal
Sheep, goats and horses:	10 - 15 g /animal
Cattle:	15 - 30 g /animal

Poisoning in animals is usually acute or sub-acute, and chronic poisoning, although reported, is seldom seen and not well documented. Symptoms of arsenic exposure are usually of sudden onset and include haemorrhagic diarrhoea, abdominal pain and dehydration. Severe haemorrhagic inflammation of the stomach and intestinal tissue are revealed at necropsy.

Mitigation

The highest tolerable zinc dose (species-specific) will have the most protective effect against As_2O_3. (Arsenic is required for efficient zinc utilisation and the interactions between arsenic and zinc are non-competitive). Cadmium chloride has also been reported to protect against toxic effects associated with arsenic exposure and has been shown to increase survival rates. However, cadmium itself is toxic and the dose has to be carefully calculated and monitored.

Criteria

Effects of Arsenic on the Health of Livestock

Arsenic Range (mg/ℓ)	Effects
Target Water Quality Range 0 - 1.0	***No adverse effects***
1.0 - 1.5	Adverse acute effects such as haemorrhagic diarrhoea and dehydration may occur in sensitive species (pigs and poultry), although short-term exposure is usually tolerated Acute effects unlikely in larger animals (cattle, sheep, goats and horses), but may occur if feed concentrations of arsenic are also elevated. Could even be tolerated in the long term, depending on site-specific factors such as water requirement
> 1.5	Adverse acute effects may occur, particularly in more sensitive species, although short-term exposure could be tolerated depending on site-specific factors, such as adequate zinc intake and water requirement

Note: Actual water intake level and subsequent ingestion of arsenic can vary significantly between species and production systems; see **Characterisation of Use**.

Sources of Information

APHA 1989. *Standard Methods for the Examination of Water and Waste Water*, 17th Edition. American Public Health Association, American Water Works Association, Water Pollution Control Federation. Published by the American Public Health Association, Washington DC, USA.

BERMAN E. 1980. *Toxic Metals and Their Analysis*. Heyden, London.

BOWEN H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

BUCK W.B., G.D. Osweiler and G.A. van Gelder 1976. Clinical and Diagnostic Veterinary Toxicology. Kendall/Hunt Publishing Co. IOWA.

ELSENHAUS B., G. Schmolke, K. Kolls, J. Stokes and W. Forth 1987. Metal-metal Interactions Amount Dietary Toxic and Essential Trace Metals in the Rat. Ecotox. *Environmental Safety*, 14: 275.

ENSMINGER, Olfield (1990).

MAHAFFEY K.R., S.G. Capa, B.C. Claden and B.A. Fowler 1981. Concurrent

Exposure to Lead, Cadmium and Arsenic. Effects on Toxicity and Tissue Metal Concentrations in the Rat. *J. Lab. Clin. Med.*, 98: 463.

McKEE J.E. and H.W. Wolf 1963. *Water Quality Criteria*, 2nd Edition. California State Water Resources Control Board, Publication No. 3-A. California.

SCHMOLKE G. and W. Forth 1988. Arsenic-copper Interactions in the Rat Kidney. Naunyn Schmiedeberg's Arch. Toxicol., 337.

UNDERWOOD E.J. 1977. *Trace Elements in Human and Animal Nutrition*, 4th Edition. Academic Press, New York, USA.

WEAST R.C. 1979. *CRC Handbook of Chemistry and Physics*, 60th Edition. CRC Press Inc., Boca Raton, Florida, USA.

WORLD HEALTH ORGANIZATION 1984. *Guidelines for Drinking Water Quality*, Volume 2: Health Criteria and Other Supporting Information. World Health Organization, Geneva.

Boron

Background Information

Introduction

Amorphous boron is a dark brown semi-metal and is relatively non-toxic. However, its compounds range from being moderately to highly toxic to all living organisms. Compounds of boron such as boric acid and sodium borate are of commercial importance.

Occurrence

Boron is found in nature in the form of various borates and borosilicate minerals. Common minerals include borax ($Na_2B_4O_7.10H_2O$), found in salt deposits of saline lakes, calcium borate (colemanite) and various borosilicate minerals such as tourmaline (an aluminium borosilicate). Boron tends to occur in association with saline conditions. Typically, the concentration of boron in:

- sea water is 4.6 mg/ℓ;
- fresh water is usually less than 0.1 mg/ℓ
- surface water can be as high as 1 mg/ℓ or more, especially if in association with arid, saline conditions.

Once in solution, boron is not easily removed and tends to concentrate in solution on evaporation of water. Hence the ubiquitous finding of elevated boron concentrations in conjunction with saline hydrogeological conditions.

Industrial uses of boron include:

- use in metallurgy to harden other metals;
- use in semi-conductors;
- use in the nuclear industry, as a neutron absorber;
- use of sodium borate (borax) as a preservative in the manufacture of glasses and glazes and in weather-proofing fabrics;
- use of organic complexes of boron as catalysts; synthetic organoboron compounds tend to be more toxic than the naturally-occurring borates.
- use of boric acid as a general household antiseptic agent.

Interactions

Borates are highly soluble in water and the **pH** will influence the ion species of boron present. Boron readily forms a strong complex with **fluoride**.

Measurement

The criteria are given in terms of the total dissolved boron concentration, in units of mg/ℓ. The reference method for the determination of boron is by curcumin colorimetry. Where other methods are used, their characteristics relative to the reference method should be known.

Data Interpretation

Mean values should be used to compare with the numeric criteria given. The pH and fluoride concentration should also be taken into consideration when interpreting the boron concentration in water.

Treatment Options

Boron is most easily removed from water together with other ions comprising TDS. General methods for TDS removal include:

! **Demineralisation** in a mixed-bed ion exchange column, usually where the feed TDS is up to around 2 000 mg/R. On a commercial or industrial scale large banks of large ion exchange filter beds are used, which are capable of being regenerated.

! Treatment by **membrane processes** such as reverse osmosis or electrodialysis, where the TDS concentration is in the range of 2 000 - 3 500 mg/R. Large-scale water treatment is achieved using banks of reverse osmosis modules in parallel.

! **Distillation**, in cases where the TDS is 10 000 mg/R or more.

All of the processes are easily fouled by suspended matter and are prone to severe scaling with hard waters. All processes on a large scale require high levels of design, operator and maintenance skills.

All of the processes produce a concentrated waste stream of the salts removed from the water and these may cause disposal difficulties.

The Effects of Boron

Norms

The norms used in the guideline are based on the toxicological effects associated with the ingestion of boron in water by livestock.

Effects

The effects of boron toxicity on livestock are not well characterised, even for relatively high concentrations. There is no evidence of boron accumulation to any great extent in body tissues, although its presence in milk has been reported. Concentrations of 150 mg/R in water have been shown to result in decreased hay consumption and weight loss in cattle.

Mitigation

No are no known means of mitigating against the effects of boron.

Criteria **Effects of Boron on Livestock Health**

Boron Range (mg/ℓ)	**Effects (All livestock)**
Target Water Quality Range 0 - 5	***No adverse effects***
5 - 50	**Adverse chronic effects (decrease in feed intake and weight loss)** may occur, but are unlikely if: - feed concentrations are normal - exposure is short term **Ruminants may be more tolerant than monogastrics** Could even be tolerated in the long term, depending on site-specific factors such as the concentration of boron in the feed and water requirement
> 50	**Adverse chronic effects may occur (see above), although** short-term exposure may be tolerated depending on site-specific factors such as the concentration of boron in the feed and water requirement

Note: Actual water intake level and subsequent ingestion of boron can vary significantly between species and production systems; see **Characterisation of Use**.

High boron concentrations in water are only likely in areas where industrial effluents enter the source water.

Sources of Information

APHA 1989. *Standard Methods for the Examination of Water and Waste Water*, 17th Edition. American Public Health Association, American Water Works Association, Water Pollution Control Federation. Published by the American Public Health Association, Washington DC, USA.

BERMAN E. 1980. *Toxic Metals and Their Analysis*. Heyden, London.

BOWEN H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

FORD W.E. and E.S. Dana 1963. *A Textbook of Mineralogy*, 4th Edition. John Wiley & Sons Inc., New York.

NRC 1980. *Mineral Tolerance of Domestic Animals*. National Academy Press, Washington DC.

NRC 1984. *Nutrient Requirements of Sheep*, 6th Revision, Ed. National Academy Press, Washington DC.

NRC 1985. *Nutrient Requirements of Cattle*, 5th Revision, Ed. National Press, Washington DC.

WEAST R.C. 1979. *CRC Handbook of Chemistry and Physics*, 60th Edition. CRC Press Inc., Boca Raton, Florida, USA.

Cadmium

Background Information

Introduction

Cadmium is a soft, bluish-white metal, chemically similar to zinc and highly toxic to living organisms. Cadmium has a low solubility under neutral or alkaline conditions and is highly soluble under acidic conditions, where toxic concentrations can easily arise from the dissolution of cadmium from cadmium-plated materials.

The presence of cadmium in the aquatic environment and in livestock drinking water is of concern because it bioaccumulates. The biological half-life of cadmium is approximately 200 days. It can persist in animal tissue longer than antagonistic trace metals, causing delayed toxicity. The rate of absorption of cadmium is higher when ingested through water as compared to dietary intake. Cadmium is retained in the liver and kidney (75 %), but may also be found in muscle tissue and milk.

Occurrence

Cadmium occurs in association with zinc ores and is also found as the mineral Greenockite (cadmium sulphide). Cadmium sulphide, carbonate and hydroxide salts are insoluble in water, whereas cadmium chloride, nitrate and sulphate salts are highly soluble in water. Cadmium binds strongly to sulphydryl groups, hence, the pronounced tendency of cadmium to bioaccumulate in the food chain. Cadmium is not usually found at water in concentrations above 1 Fg/R, unless the water has been subject to pollution from cadmium-containing industrial effluents.

Cadmium is used in electroplating, in alloys, in certain solders and in nickel-cadmium batteries. Salts of cadmium are used in photography, pottery, the electronics industry and as pigments in many different applications.

Interactions

Cadmium interacts strongly with **zinc** due to the chemical similarity of the two metals. Cadmium also interacts with **iron**, **calcium** and **selenium**.

Measurement

The criteria are given in terms of the total cadmium concentration, in units of mg/R. The reference method for the measurement of cadmium is atomic absorption spectrometry. If other methods of analysis are used, their characteristics relative to the reference method should be known.

Data Interpretation

Single-sample maximal values should be used to compare with the numeric criteria given, and should not exceed the Target Water Quality Range. Cadmium concentrations should also be interpreted in relation to the associated zinc concentrations.

Treatment Options

Cadmium in water supplies is most conveniently removed by raising the pH and precipitating the insoluble cadmium salts after the addition of lime or iron salts in the pH range of 8.5 - 11.5. Precipitation is followed by settlement and filtration as in conventional water treatment.

The precipitation process requires careful monitoring to ensure that removal is complete. A watery, cadmium-rich sludge or concentrate stream is generated in the processes, that may present disposal difficulties.

To achieve very low residuals, it may be necessary to pass the stream through an ion exchange column charged with the appropriate resin.

The Effects of Cadmium

Norms

The norms used in the guidelines are based on the toxicological effects associated with the ingestion of cadmium in water used by livestock and the effects of contaminated livestock products.

Effects

Toxicity due to cadmium is not often observed even though cadmium is highly toxic. This is attributable to low absorption of cadmium. Cattle have no homeostatic control for tissue concentrations of cadmium. After absorption, cadmium usually combines with a protein, which reduces toxicity. Tissue concentrations may not necessarily be related to adverse health effects. Low concentrations of cadmium are excreted in milk, 0.0008 % of ingested cadmium, as compared to 8 - 12 % of ingested zinc. Exposure of livestock to cadmium during pregnancy results in adverse effects to maternal organs.

At high concentrations of cadmium, teratogenic, mutagenic and carcinogenic effects may occur. Increases in serum cadmium concentrations can lead to hypochroaemia, osteomalacia and lowered zinc and iron serum concentrations. Cadmium retention is reported to increase with increased dietary Fe^{2+} and Fe^{3+} concentrations. Body iron stores are inversely correlated with cadmium accumulation, and suckling and pregnant livestock are more at risk.

The risk of cadmium toxicity is increased by low dietary protein levels (due to increased intestinal absorption and retention of cadmium in the kidney and liver). Adequate protein levels have been shown to decrease hepato- and nephrotoxicity associated with cadmium toxicity. The type of dietary protein is, however, also a determining factor. Excess cysteine stimulates renal uptake and gives rise to changes in cadmium tissue distribution. Dietary fibre and lignin decrease total cadmium concentrations in tissues, and phytate influences tissue cadmium concentrations (only when dietary calcium concentrations are high). In cases of protein dietary deficiency coupled with cadmium toxicity, a 45 % decrease in fertility has been observed.

Dietary deficiencies of calcium and phosphate enhance cadmium uptake (cadmium effectively substitutes for calcium in *calmodulin* (a calcium-binding protein).

Adverse effects have been observed in livestock at doses of cadmium ranging from 1 - 160 mg/kg (BW). 40 mg/kg (BW) has no adverse effect on calves, but 160 mg/kg (BW) decreases feed intake, growth and water intake. Decreased milk production in dairy cattle is observed at 3 g/day. A concentration of 640 mg/kg has been shown to decrease growth significantly and ten-week-old calves fed 2 650 mg/kg/d for 14 days, showed severe adverse effects.

Table of Effects of Cadmium in Feed on Livestock

Livestock	Cadmium in feed	Symptoms	Source
Calf	160 mg/kg	Reduced growth	Powel *et al.*, 1964
Dairy	3000 mg/d	Reduced milk production	Miller *et al.*, 1967
Lamb	30 mg/kg	Reduced growth	Doyle *et al.*, 1974
Turkey	20 mg/kg	Reduced growth	Supplee, 1961

Symptoms of cadmium toxicity are qualitatively similar to zinc deficiency and include anaemia, abortions, stillbirths, a decline in immune responses, reduced feed intake and milk production, reduced growth, testicular degeneration, enlargement of joints, liver and kidney damage, scaly skin and increased mortality.

Concentrations of cadmium found in milk and muscle tissue are usually low, hence effects associated with the consumption of contaminated products are negligible.

Mitigation

The administration of copper, selenium and zinc compounds can alleviate the effects of cadmium toxicity and provide partial protection against toxic effects. Intestinal cadmium uptake is sensitive to inhibition by zinc, calcium and high concentrations of polyvalent cations, such as lead, nickel, chromium(III), manganese and magnesium. Cadmium toxicity is aggravated during zinc deficiency and pretreatment with zinc has been shown to reduce acute toxic effects. A similar alleviatory effect has been observed with copper administration, but due to the toxic effects of copper it cannot be administered at the same levels as zinc can.

Dietary supplementation of calcium or iron may also reduce liver (but not renal) cadmium retention levels. Cadmium-induced anaemia can be prevented by the administration of iron and by increasing the intestinal availability of iron by increasing Vitamin C levels.

Criteria

Effects of Cadmium on Livestock Health

Cadmium Range (mg/ℓ)	**Effects** (All livestock)
Target Water Quality Range 0 - 0.01	***No adverse effects***
0.01 - 0.02	**Adverse chronic effects** such as anaemia, testicular degeneration, reduced feed intake and milk production and reduced growth may occur, but are unlikely if: - exposure is short term - adequate intake of dietary protein, calcium and phosphorus - feed concentration of cadmium is normal **Adverse acute effects** such as abortions, still births, hepato- and nephrotoxicity may occur, but suckling and pregnant livestock are principally at risk Could even be tolerated in the long term, depending on site-specific factors such as water requirement and Ca:P concentrations
> 0.02	**Adverse chronic and acute effects (as above) may occur, although** short-term exposure could be tolerated depending on: - feed concentrations of cadmium - adequate intake of dietary protein, calcium and phosphorus - water requirement

Note: Actual water intake level and subsequent ingestion of cadmium can vary significantly between species and production systems; see **Characterisation of Use**.

High cadmium concentrations in water are only likely in areas subjected to industrial or other pollution.

Sources of Information

APHA 1989. *Standard Methods for the Examination of Water and Waste Water*, 17th Edition. American Public Health Association, American Water Works Association, Water Pollution Control Federation. Published by the American Public Health Association, Washington DC, USA.

BERMAN E. 1980. *Toxic Metals and Their Analysis*. Heyden, London.

BOWEN H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

ELSENHANS B., K. Schumann and W. Forth 1991. Toxic Metals: Interactions with Essential Minerals, In: *Nutrition, Toxicity and Cancer*. Rowland, IR (Ed.). CRC Press, Inc. USA, 197-222.

FRIBERY L., T. Kjellstrom, G.F. Nordburg and M. Piscator 1975. *Cadmium in the Environment III. A Toxicological and Epidemiological Appraisal*. EPA. 650/2-75-049.

KARGACIN B. and K. Kostial 1991. Toxic Metals: Influence of Macromolecular Dietary Components on Metabolism and Toxicity, In: *Nutrition, Toxicity and Cancer*. Rowland, IR (Ed.). CRC Press, Inc. USA, 197-222.

McKEE J.E. and H.W. Wolf 1963. *Water Quality Criteria*, 2nd Edition. California State Water Resources Control Board, Publication No. 3-A. California.

MURAKAMI M., K. Sano and M. Webb 1987. The Effect of L-cysteine on the Ion-selective Uptake of Cadmium in the Renal Proximal Tubule. *Arch. Toxicol.*, 60: 365.

MILLER W.J. 1979. *Dairy Cattle Feeding and Nutrition*. Academic Press, Inc. California, USA, 95-180.

MINSON D.J. 1990. *Forage in Ruminant Nutrition*. Academic Press, Inc. California, USA, 208-395.

MURATA I., T. Hirono, Y. Saeki and S. Nakagawa 1970. Cadmium Enteropathy Renal Osteomalacia (itai-itai disease in Japan). *Ball. Soc. Int. Chir*. 1: 1.

NEATHERY M.W. 1981. Metabolism and Toxicity of Cadmium in Animals. In: Cadmium in the Environment Part II. Edited by Nriagu, J.O. John Wiley and Sons, Inc.

NRC 1980. *Mineral Tolerance of Domestic Animals*. National Academy Press, Washington DC.

NRC 1984. *Nutrient Requirements of Sheep*, 6th Revision, Ed. National Academy Press, Washington DC.

NRC 1985. *Nutrient Requirements of Cattle*, 5th Revision, Ed. National Academy Press, Washington DC.

UNDERWOOD E.J. 1981. *The Mineral Nutrition of Livestock*. Commonwealth Agricultural Bureaux, 31-176.

WEAST R.C. 1979. *CRC Handbook of Chemistry and Physics*, 60th Edition. CRC Press Inc., Boca Raton, Florida, USA.

WORLD HEALTH ORGANIZATION 1984. *Guidelines for Drinking Water Quality*, Volume 2: Health Criteria and Other Supporting Information. World Health Organization, Geneva.

Calcium

Background Information

Introduction

Calcium is an alkaline earth metal and exists as the doubly positively-charged ion Ca(II). Calcium occurs naturally in varying concentrations in most waters and is, together with magnesium, one of the main components of water hardness. *Soft* waters contain low, while *hard* waters contain high concentrations of calcium (see **total hardness**). Calcium is an essential element for all living organisms and is an important constituent of the bony skeleton of mammals, which consists of phosphates of calcium.

Occurrence

Mineral deposits of calcium are common, usually as calcium carbonate, phosphate or sulphate. Calcium bicarbonate, chloride and nitrate are very soluble in water, calcium sulphate is moderately soluble and calcium carbonate and phosphate are almost insoluble.

Typically, the concentration of calcium in:

- fresh water is 15 mg/ℓ; and
- in sea water is just over 400 mg/ℓ.

Interactions

The solubility of calcium in water is usually governed by the carbonate/bicarbonate equilibrium and is thus strongly influenced by **pH** and temperature. Metabolically, calcium interacts with cations, especially those of **magnesium**, and with both inorganic anions (bicarbonate, sulphate and phosphate) and organic anions (acetate and organic acids). Biologically, calcium exerts an influence on the integrity of cell membranes and thereby strongly influences the absorption and toxicity of heavy metals.

Measurement

The criteria are given in terms of the dissolved calcium concentration, in units of mg/ℓ. The reference method for the determination of calcium is atomic absorption spectrometry, using a phosphate interference inhibitor, such as lanthanum, and an ionisation suppressant, such as caesium or potassium. If other methods are used to measure calcium, their characteristics relative to the reference method should be known.

Data Interpretation

Mean values should be used to compare with the numeric criteria given. Calcium concentrations should be interpreted in conjunction with the major associated anion(s), usually bicarbonate, chloride or sulphate, as well as the concentrations of magnesium, sodium and potassium.

Treatment Options

Calcium is commonly removed from water using treatment processes suitable for softening hard water. These include:

- **Precipitation** of calcium as calcium carbonate by the addition of sodium carbonate. This process will not reduce calcium in solution to less than 40 mg/ℓ.

- **Cation exchange softening** is used to replace the calcium (and magnesium if present) in the water with sodium in ion exchange columns regenerated with a sodium chloride brine.

- **Demineralisation** in mixed-bed ion exchange columns will remove all calcium ions together with other ions in solution, where a particularly low salinity water is required.

The same result may be obtained using a range of desalination techniques such as membrane treatments or distillation, but these may be subjected to scaling problems, particularly in the presence of carbonate or sulphate ions. On an industrial scale the processes need skilled operation and control because the consequences of incomplete calcium removal can be severe. All of the processes produce a concentrated waste stream, that may cause disposal difficulties.

The Effects of Calcium

Norms The norms used in the guidelines are based on the toxicological effects associated with the ingestion of calcium in water used by livestock. The effects on livestock watering systems should also be considered; see **Characterisation of Use** and **Product Quality.**

Effects Calcium is needed for the maintenance of cellular membrane permeability; nerve transmission; release of neurotransmitters and hormones; exocrine excretions; muscular contraction; bone and teeth formation; blood coagulation; milk production; and enzyme activity. Most of the absorbed calcium that is not required by animals is excreted via the urine. The small intestine acts as an effective control in preventing the absorption of excess calcium. The calcium:phosphorus (Ca:P) ratio is very important in animal nutrition and should always be greater than 1:1. Adequate vitamin D is required to facilitate the metabolism of Ca and P.

The high nitrogen content of Kikuyu grass, *Pennisetum Clandestinum,* is associated with a high insoluble oxalate content of the sward. As much as 95% of the calcium may therefore be bound as calcium oxalate, and is probably not available to ruminants; the occurrence of calcium deficiencies is well documented.

Failure of intestinal uptake control of calcium can lead to increased calcium uptake with consequent calcification of the kidneys. Hypercalcaemia is often associated with hyperparathyroidism and resultant effects include the softening and bending of bones, osteopetrosis (dense bone), and an increase of calcium and phosphorus excretion in the urine, which can lead to nephrocalcinosis and renal stones. The polar effects are dependent on the Ca:P ratio.

In addition, excess calcium intake can lead to reduced absorption of magnesium, manganese, zinc and copper. With high calcium concentrations the accompanying anion may exacerbate palatability and salinity effects (see **TDS** and **Characterisation of Use**).

Mitigation If the concentration of dietary phosphorus is adequate, ruminants can tolerate wide ranges of Ca:P (as wide as 7:1) and as much as two percent calcium in their diet.

Criteria

Effects of Calcium on the Health of Livestock

Calcium Range (mg/ℓ)	**Effects** (All species)
Target Water Quality Range ***0 - 1 000***	***No adverse effects***
1 000 - 2 000	**Adverse chronic effects such as hypercalcemia, and adverse palatability effects such as a decline in water and feed intake and weight loss may occur, but are unlikely if:** - stock have adapted to the water - feed concentration and ratios of Ca:P are within nutritional limits - exposure is short term Could even be tolerated in the long term, depending on site-specific factors such as water requirement and synergistic and antagonistic nutritional factors **Ruminants can tolerate a wider Ca:P range than monogastrics**
> 2 000	**Adverse chronic effects may occur (see above), although short term exposure may be tolerated, depending on whether:** - stock have adapted to water - feed concentrations and ratios of Ca:P are within nutritional limits - water requirement

Note: Actual water intake level and subsequent ingestion of calcium can vary significantly between species and production systems; see **Characterisation of Use**.

Sources of Information

BOWEN H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

FORREST A.P.M, D.C. Carter and I.B. Macleod 1991. Urinary Calculi and Calcium Metabolism, In: *Principles and Practice of Surgery*, 2nd Edition. Churchill. Livingstone, 600-617.

McKEE J.E. and H.W. Wolf 1963. *Water Quality Criteria*, 2nd Edition. California State Water Resources Control Board, Publication No. 3-A. California.

RAMACHANDRA HG, M.J. Levis and A.S. Grandison 1994. Effect of Soluble Calcium of Milk on Fouling of Ultrafiltration Membranes. *J. Sci. Food. Agric.*, 65: 249-256.

VICTERY W, C.R. Miller, S.Y. Zhu and R.A. Goyer 1987. Effect of Different Levels and Periods of Lead Exposure on Tissue Levels and Excretion of Lead, Zinc and Calcium in the Rat. *Fund. Appl. Toxicol.*, 8: 506.

Chloride

Background Information

Introduction

Chloride is the anion of the element chlorine, which does not occur free in nature, but is only found as chloride. The chlorides of sodium, potassium, calcium and magnesium are all highly soluble in water.

Chloride is of concern in water supplies because elevated concentrations impart an unpalatable taste to water and accelerate the corrosion rate of metals.

Occurrence

Chloride is a common constituent in water, is highly soluble, and once in solution tends to accumulate. Typical concentrations of chloride in fresh water range from a few to several hundred mg/ℓ. In sea water the concentration is approximately 19 800 mg/ℓ. Chloride inputs to surface waters can arise from irrigation return flows, sewage effluent discharges and various industrial processes.

Interactions

The taste threshold and the corrosion acceleration threshold of chloride are dependent on the action of other water quality constituents such as associated cations, the pH and the calcium carbonate concentration.

Measurement

The criteria are given in terms of the dissolved chloride concentration, in units of mg/ℓ. The reference method for the determination of chloride is usually by means of the ferricyanide method and colorimetry. If other methods are used, their characteristics relative to the reference method should be known.

Data Interpretation

Mean values should be used to compare with the numeric criteria given. Chloride concentrations should be interpreted in conjunction with the major cations and anions present.

Treatment Options

Chlorides are highly soluble and cannot be precipitated at concentrations normally present in water. Chloride can be removed from water by **electrolysis** to form chlorine gas liberated at the anode. Electrolysis is not effective where the conductivity and the chloride concentration are low.

More commonly, chloride is removed together with other ions using:

- **anion exchange resin beds**, in which all significant anions are removed; and

- **desalination techniques** such as reverse osmosis and electrodialysis.

The concentrated waste streams generated from ion exchange and desalination processes may cause disposal difficulties. Desalination techniques require skilled operation, control and maintenance. Capital and operating costs are typically high.

The Effects of Chloride

Norms The norms used in the guidelines are based on toxicological and palatability effects of chloride associated with the ingestion of water used for livestock.

Effects Chloride is found within cells, in body fluids, in gastric secretions and in the form of salt. Metabolically, it is important in regulating osmotic pressure and the acid-base balance. Chloride is efficiently conserved, and its requirement is therefore small, although an increase in muscular activity increases the requirement. Excess chloride from feed is not likely, especially if there is sufficient ingestion of high quality water.

Growing ruminants have a low chloride requirement, thus deficiencies are unlikely under normal production conditions. However, chloride supplementation for lactating dairy cows may be required.

At high concentrations, usually far lower than those which are toxic, chloride renders the water unpalatable to most livestock. Pigs and poultry are more susceptible to excess chloride than sheep or cattle; see **TDS**.

Mitigation No mitigatory measures are known.

Criteria **Effects of Chloride on the Health of Livestock**

Chloride Range (mg/R)	Effects					
	Sheep	Cattle	Dairy cattle, pregnant and lactating cattle	Ruminants	Monogastrics	Poultry
0 - 1500	" " "	" " "	" " "	" " "	" " "	" " "
1500 - 2000	" " "	" " "	" " "	" " "	" " !	" " !
2000 - 3000	" " "	" " "	" " "	" " "	" ! !	! ! !
3000 - 4000	" " !	" " !	" " !	! ! !	! ! !	! ! !
4000 - 5000	" ! !	" ! !	! ! !	! ! !	! ! !	! ! !
5000 - 6000	" ! !	! ! !	! ! !	! ! !	! ! !	! ! !
> 6000	! ! !	! ! !	! ! !	! ! !	! ! !	! ! !

" " " **Target Water Quality Range. No adverse effects**.

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

" ! ! **Adverse chronic effects such as decreased feed and water intake, weight loss and a decline in productivity may occur**, but will most likely be temporary and normal production should continue once stock are adapted; see **TDS**.

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

Note: Actual water intake level and subsequent ingestion of chloride can vary significantly between species and production systems, see **Characterisation of Use**.

Sources of Information

APHA 1989. *Standard Methods for the Examination of Water and Waste Water*, 17th Edition. American Public Health Association, American Water Works Association, Water Pollution Control Federation. Published by the American Public Health Association, Washington DC, USA.

BOWEN H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

CUNHA T.J. 1977. *Swine Feeding and Nutrition*. Academic Press, Inc. California, USA, 184-187.

ENSMINGER M.E., J.E. Olfield and W.W. Heinemann 1990. *Feeds and Nutrition*, 2nd Edition. The Ensminger Publishing Co., California, 95-239.

LEESON S. and J.P. Summers 1991. *Commercial Poultry Nutrition*. University Books. Canada, 61-63.

LITTLE D.A. 1982. Utilisation of Minerals, In: *Nutritional Limits to Animal Production from Pastures*. Hacker, JB (Ed.) Commonwealth Agricultural Bureaux, Slough, England, 259-283.

MACDOWELL L.R. 1992. *Minerals in Animal and Human Nutrition*. Academic Press, Inc., New York.

McKEE J.E. and H.W. Wolf 1963. *Water Quality Criteria*, 2nd Edition. California State Water Resources Control Board, Publication No. 3-A. California.

MILLER W.J. 1979. *Dairy Cattle Feeding and Nutrition*. Academic Press, Inc. California, USA, 95-180.

MINSON D.J. 1990. *Forage in Ruminant Nutrition*. Academic Press, Inc. California, USA, 208-395.

NRC 1980. *Mineral Tolerance of Domestic Animals*. National Academy Press, Washington DC.

NRC 1984. *Nutrient Requirements of Sheep*, 6th Revision, Ed. National Academy Press, Washington DC.

NRC 1985. *Nutrient Requirements of Cattle*, 5th Revision, Ed. National Academy

Press, Washington DC.

SPEARS J.W. 1994. Minerals in Forages, In: *Forage Quality, Evaluation and Utilization*, Fahey, G.C. (Ed.). American Society of Agronomy, Inc., Madison, Wisconsin, USA, 281-307.

UNDERWOOD E.J. 1981. *The Mineral Nutrition of Livestock*. Commonwealth Agricultural Bureaux, 31-176.

WORLD HEALTH ORGANIZATION 1984. *Guidelines for Drinking Water Quality*, Volume 2: Health Criteria and Other Supporting Information. World Health Organization, Geneva.

Chromium(VI)

Background Information

Introduction

Chromium(VI) is a highly oxidised state of metal chromium. It occurs as the yellow-coloured dichromate salt under neutral or alkaline conditions, and as the orange-coloured chromate salt under acidic conditions. Chromium(VI) is highly water soluble at all pH values. The reduced forms of chromium, namely chromium(II) and chromium(III), are less soluble than chromium(VI), have much lower toxicity than chromium(VI), and do not constitute as serious a health hazard.

Chromium can also function as an essential element, being a component of a hormone and a vitamin. Chromium also functions as a co-factor with insulin, required for normal glucose utilisation and growth. The primary storage site is in the liver, while excretion, if absorbed, is largely via the kidneys.

Occurrence

The most common ore of chromium is chromite, in which chromium occurs in the trivalent state. Minerals containing chromium(VI) do occur, but are not common. Elevated concentrations of chromium(VI) found in the environment are due to industrial pollution. Because of the high water solubility of chromium(VI), it is very mobile in the environment and readily moves through the soil profile, contaminating ground water supplies. Chromium(VI) can be reduced to chromium(III) under suitable pH and reducing conditions. However, chromium(III) can also be re-oxidised to chromium(VI) under oxidising conditions. Chromium(VI) is not normally found in water at concentrations higher than 0.01 mg/ℓ. Higher concentrations potentially occur wherever industrial activity using chromium(VI) compounds are located.

Chromium(II) and chromium(III) are not normally found at near-neutral pH in water, since the hydroxides of these two oxidation states are insoluble. They may, however, occur in water under acidic conditions.

Chromic acid or hexavalent chromium salts are used in alloys in the metal pickling and plating industry, in the leather industry and in the manufacture of paints, dyes, explosives, ceramics and paper.

Interactions

The equilibrium between chromium(VI) and the reduced forms of chromium such as chromium(II) and chromium(III) is influenced strongly by the **pH** and redox potential. The presence of oxidisable organic matter and **iron**(II) salts encourages the conversion of chromium(VI) to the lower, less toxic oxidation states.

Measurement

The reference method for the determination of chromium(VI) is diphenyl carbazide spectrophotometry. Whenever the chromium(VI) concentration is measured, the total chromium concentration should be determined in order to establish whether chromium(III) is also present, or whether all the chromium is in the (VI) state. Where other methods are used, their characteristics relative to the above reference method should be known.

Data Interpretation

The numeric criteria should be treated as non-exceedance values.

Treatment Options

Chromium(VI) is the most soluble of the chromium species and removal thereof requires pretreatment of chromium(VI) to a more easily precipitable species. Therefore, removal of chromium(VI) from water requires the reduction of chromium(VI) to the trivalent form with ferrous sulphate or by reaction with oxidisable organic matter. The trivalent chromium can then be removed by various processes including:

- **Precipitation and flocculation** as chromium(III) hydroxide with lime and alum or a ferric salt, followed by settlement and filtration. The process needs careful monitoring to ensure effective removal of chromium.

- Removal with **reverse osmosis** or **ion exchange.**

Alternative methods are available for absorbing chromium(VI) onto ferric hydroxide precipitates. However, these are not as efficient as methods which rely on the reduction of chromium(VI), followed by precipitation of chromium(III) or chromium(II) hydroxides when the pH is raised.

All processes produce a watery sludge or concentrate stream that may be rich in chromium and present disposal difficulties.

The Effects of Chromium(VI)

Norms

The norms used in the guidelines are based on the toxicological effects associated with the ingestion of chromium in water used by livestock.

Effects

Toxicity due to excess chromium ingestion seldom manifests itself, since only small quantities are usually present in water and feeds, body utilisation is poor, and there is a wide margin between beneficial and harmful doses. For these reasons, bioaccumulation does not usually occur to any significant degree.

Toxic effects of chromium(VI) include diarrhoea and dehydration. There is also evidence that chromium(VI) is carcinogenic.

The organic form of chromium present in brewers yeast is utilised by animals. It is also called glucose tolerance factor (GTF). Only approximately one percent or less of inorganic chromium is absorbed, but 10 - 25 % of GTF-chromium (GTF-Cr) may be absorbed. Excesses of inorganic chromium are more toxic than GTF-Cr. A maximum concentration of 10 mg/ℓ of Cr(VI) in the tissues of rats and dogs did not indicate toxic effects but signs of physiological stress were shown.

Mitigation

Oxalates and phytates impede the absorption of chromium. Zinc and vanadium antagonise the effects of chromium. For these reasons, effective dietary supplementation with zinc, oxalates and phytates may indirectly mitigate against adverse effects.

Criteria **Effects of Chromium(VI) on Livestock Health**

Chromium(VI) Range (mg/ℓ)	Effects
	All species
Target Water Quality Range 0 - 1	***No adverse effects***
1 - 2	**Adverse chronic effects such as diarrhoea may occur, but are unlikely if:** - feed concentrations are normal - exposure is short term Can even be tolerated in the long term, depending on site-specific factors such as nutritional interactions and water requirement
> 2	**Adverse chronic effects such as diarrhoea and possible carcinogenic effects may occur, although** short-term exposure could be tolerated depending on site-specific factors such as nutritional interactions and water requirement

Note: Actual water intake level and subsequent ingestion of chromium can vary significantly between species and production systems; see **Characterisation of Use**.

Sources of Information

APHA 1989. *Standard Methods for the Examination of Water and Waste Water*, 17th Edition. American Public Health Association, American Water Works Association, Water Pollution Control Federation. Published by the American Public Health Association, Washington DC, USA.

BERMAN E. 1980. *Toxic Metals and Their Analysis*. Heyden, London.

CANADIAN GUIDELINES 1987. *Canadian Water Quality Guidelines*, Canadian Council of Resource and Environment Ministers. Ottowa.

CUNHA T.J. 1977. *Swine Feeding and Nutrition*. Academic Press, Inc. California, USA, 184-187.

ENSMINGER M.E., J.E. Olfield and W.W. Heinemann 1990. *Feeds and Nutrition*, 2nd Edition. The Ensminger Publishing Co., California, 95-239.

LITTLE D.A. 1982. Utilization of Minerals, In: *Nutritional Limits to Animal Production from Pastures*. Hacker, J.B. (Ed.), Commonwealth Agricultural Bureaux, Slough, England, 259-283.

MACDOWELL L.R. 1992. *Minerals in Animal and Human Nutrition*. Academic Press, Inc., New York.

McKEE E.J. and H.W. Wolf 1963. *Water Quality Criteria*, 2nd Edition. California State Water Resources Control Board, Publication No. 3-A. California.

MILLER W.J. 1979. *Dairy Cattle Feeding and Nutrition*. Academic Press, Inc. California, USA, 95-180.

NRC 1980. *Mineral Tolerance of Domestic Animals*. National Academy Press, Washington DC.

NRC 1984. *Nutrient Requirements of Sheep*, 6th Revision, Ed. National Academy Press, Washington DC.

NRC 1985. *Nutrient Requirements of Cattle*, 5th Revision, Ed. National Academy Press, Washington DC.

UNDERWOOD E.J. 1981. *The Mineral Nutrition of Livestock*. Commonwealth Agricultural Bureaux, 31-176.

WEAST R.C. 1979. *CRC Handbook of Chemistry and Physics*, 60th Edition. CRC Press Inc., Boca Raton, Florida, USA.

WORLD HEALTH ORGANIZATION 1984. *Guidelines for Drinking Water Quality*, Volume 2: Health Criteria and Other Supporting Information. World Health Organization, Geneva.

WORLD HEALTH ORGANIZATION 1993. *Guidelines for Drinking Water Quality*, 2nd Edition, Volume 1: Recommendations. World Health Organization, Geneva.

Cobalt

Background Information

Introduction

Cobalt is a hard, grey magnetic metal. The name cobalt derives from the German "kobelt", a term for gnomes and goblins, as the toxic effects from inhalation of dusts in cobalt mines was originally thought to be the work of goblins.

Cobalt is an essential trace element in nutrition and forms part of vitamin B_{12}. Vitamin B_{12} (cobalamin) contains four percent cobalt and is required for red blood cell synthesis, and the methyl malonyl CoA and methionine synthase enzyme pathways. Bioaccumulation of cobalt can occur in certain plants. Accumulation in sediments can occur as the sulphide of cobalt.

Occurrence

Elemental cobalt is not found in nature, but occurs in various sulphide ores, often associated with arsenic, iron and nickel, and copper. Important ores include cobaltite (CoAsS), linnaeite (Co_3S_4) and smaltite ($CoAs_2$). Cobalt also occurs as the insoluble carbonate (sphaerocobaltite) and rarely as the soluble sulphate (bieberite).

Typically, the concentration of cobalt in unpolluted surface water is 0.2 µg/ℓ and in sea water approximately 0.02 µg/ℓ. Elevated cobalt levels may occur in the vicinity of mines where the ores that are processed contain cobalt.

Cobalt is used in special alloys and magnets and cobalt salts are also used as pigments. The element has various uses in the nuclear industry and radioactive Cobalt-60 is used as a radiation source for treating malignancies in medicine.

Cobalt tends to be concentrated on particles of manganese oxide in soils. The low levels of cobalt in natural waters may be due to an adsorption reaction of this type. The level of cobalt in herbage is dependent primarily on the soil concentration and soil pH. Nitrogen fertilizers can increase the uptake of cobalt by plants. Increasing soil pH (5.4 - 6.4) can reduce cobalt uptake from pastures.

Interactions

Adequate dietary intake of cobalt is important to prevent anaemia and metabolic interaction occurs with **iron**.

Measurement

The criteria are given in terms of the total cobalt concentration, in mg/ℓ. Total cobalt is normally measured after acidification of the sample. The reference method is atomic absorption spectrometry. If other methods are used for measuring cobalt, the characteristics relative to the reference method should be known.

Data Interpretation

Mean values should be used to compare with the criteria given.

Treatment Options

Cobalt can be removed from water by precipitation at alkaline pH, with lime or by flocculation and coprecipitation with a ferric salt. Alternatively, ion exchange can be used. The waste stream produced will have elevated levels of cobalt and will require appropriate disposal.

The Effects of Cobalt

Norms

The norms used in the guideline are based on the toxicological effects associated with the ingestion of cobalt in water consumed by livestock.

Effects

Cobalt is stored in the liver, kidneys, adrenal glands and bones and is poorly retained in body tissues. Excess cobalt is rapidly excreted, primarily as urine, although cobalt is secreted in the bile and hence reabsorption is possible.

The cobalt status of ruminants is determined by serum vitamin B_{12}, plasma methyl malonate (methyl malonate CoA mutase is required for propionate metabolism in ruminants) or liver Co/vitamin B_{12} concentrations. However, serum vitamin B_{12} in cattle may be of limited value due to the presence of vitamin B_{12} analogues in bovine serum. Ruminants are not dependent on a dietary source of vitamin B_{12} due to the synthesizing of vitamin B_{12} by rumen micro-organisms, coupled with the fact that absorption is regulated by an intrinsic factor. Forage cobalt levels are a reliable indicator of cobalt adequacy. Concentrations of Co in temperate pasture grasses range from low levels of less than 0.02 mg/kg (DM) to high levels greater than 250 mg/kg (DM). Normal pasture levels are in the order of 100 - 250 µg/kg (DM).

Under practical conditions, the occurrence of cobalt toxicosis is highly unlikely. There is a wide margin of safety between toxic concentrations and nutritional requirement levels, and retention is poor. The cobalt requirement is approximately 0.1 mg/kg (DM). Ruminants have a higher requirement (due to micro-organism wastage, poor vitamin B_{12} absorption and a high requirement of vitamin B_{12} for propionic metabolism). Non-ruminants synthesize vitamin B_{12} to a lesser extent, usually below their requirement. The toxic level is approximately 1 mg Co/kg (BW)/day for cattle and 3.5 mg Co/kg (BW)/day for sheep.

Toxic effects include a loss of body weight and depressed appetite. It should be noted that no toxic effects for vitamin B_{12} are known.

The effect of cobalt deficiency in ruminants is known as *wasting disease* and is well documented.

Mitigation

No effective mitigatory measures are known.

Criteria

Effects of Cobalt on the Health of Livestock

Cobalt Range(mg/ℓ)	**Effects**
	All livestock
Target Water Quality Range 0 - 1	***No adverse effects***
1 - 2	**Adverse chronic effects such as inappetence and weight loss may occur, but are unlikely if:** - feed concentrations are normal - exposure is short term Could even be tolerated in the long term, depending on site-specific factors such as nutritional interactions and water requirement
> 2	**Adverse chronic effects (as above) may occur, although** short-term exposure can be tolerated depending on site-specific factors such as nutritional interactions and water requirement

Note: Actual water intake level and subsequent ingestion of cobalt can vary significantly between species and production systems; see **Characterisation of Use**.

Sources of Information

CUNHA T.J. 1977. *Swine Feeding and Nutrition*. Academic Press, Inc. California, USA, 184-187.

ELSENHANS B., K. Schumann and W. Forth 1991. Toxic Metals: Interactions with Essential Minerals, In: *Nutrition, Toxicity and Cancer*. Rowland, IR (Ed.). CRC Press, Inc. USA, 197-222.

ENSMINGER M.E., J.E. Olfield and W.W. Heinemann 1990. *Feeds and Nutrition*, 2nd Edition. The Ensminger Publishing Co., California, 95 - 239.

LITTLE D.A. 1982. Utilization of Minerals, In: *Nutritional Limits to Animal Production from Pastures*. Hacker, JB (ed.) Commonwealth Agricultural Bureaux, Slough, England, 259-283.

MACDOWELL L.R. 1992. *Minerals in Animal and Human Nutrition*. Academic Press, Inc., New York.

MILLER W.J. 1979. *Dairy Cattle Feeding and Nutrition*. Academic Press, Inc. California, USA, 95-180.

MINSON D.J. 1990. *Forage in Ruminant Nutrition*. Academic Press, Inc. California, USA, 208-395.

NRC 1980. *Mineral Tolerance of Domestic Animals*. National Academy Press, Washington DC.

NRC 1984. *Nutrient Requirements of Sheep*, 6th Revision, Ed. National Academy Press, Washington DC.

NRC 1985. *Nutrient Requirements of Cattle*, 5th Revision, Ed. National Academy Press, Washington DC.

SPEARS J.W. 1994. Minerals in Forages, In: *Forage Quality, Evaluation and Utilization*, Fahey, GC (Ed.). American Society of Agronomy, Inc., Madison, Wisconsin, USA, 281-307.

UNDERWOOD E.J. 1981. *The Mineral Nutrition of Livestock*. Commonwealth Agricultural Bureaux, 31-176.

Copper

Background Information

Introduction

Copper is an essential trace element in plants, animals and man. Copper occurs in three oxidation states, namely as metallic copper(0), cuprous copper(I) and cupric copper(II).

Occurrence

Many minerals containing copper are known, some of which are important semi-precious minerals, such as malachite, azurite and turquoise. Copper is also sometimes found in the elemental state. Copper(II) carbonate, hydroxide and sulphide are insoluble in water, while copper sulphate, nitrate and chloride are soluble. Ammonium complexes of copper are also soluble in water. At neutral and alkaline pH, the concentration of copper in surface waters is usually low, typically, around 3 Fg/R. In acidic waters, copper readily dissolves, and substantially higher concentrations are found. The concentration of copper in sea water is approximately 0.3 Fg/R. Copper is readily adsorbed and precipitated in sediments at alkaline pH. Remobilisation of copper to underlying water occurs on acidification. Copper also bioaccumulates in certain plants.

Copper has excellent conducting properties. One of the most important industrial uses of copper is in the electrical industry.

Interactions

The oxidation state of copper in water depends strongly on the **pH**, as well as the concentrations of associated salts, such as **sulphate**, **chloride** and **nitrate**. Metabolically, copper interacts with **zinc**, **iron, molybdenum**, **arsenic**, **selenium** and **sulphur**.

Measurement

The criteria are given in terms of the total copper concentration, measured in mg/R. Total copper is measured after acidification of the water sample. The reference method for the determination of copper is atomic absorption spectrometry. If other methods are used for measuring copper, their characteristics relative to the reference method should be known.

Data Interpretation

Single-sample values should be used to compare with the numeric criteria given and should be interpreted as maximal values not to be exceeded. Copper concentrations should also be interpreted in relation to pH, as well as the concentration of ammonia, which can solubilise copper at alkaline pH and facilitate the uptake thereof.

Treatment Options

Copper in solution is most conveniently removed by raising the pH and precipitating the insoluble copper carbonate and hydroxide complexes with lime treatment. The precipitation is followed by settlement and filtration as in conventional water treatment.

The precipitation process requires careful monitoring to ensure complete removal. A watery, copper-rich sludge is generated in the process; that may present disposal difficulties.

The Effects of Copper

Norms

The norms used in the guidelines are based on the toxicological effects of copper associated with ingestion of water consumed by livestock and the effects of contaminated livestock products.

Effects

The difference between the amount of copper required as an essential nutritional micro-element and that which causes toxicity is marginal and depends on a number of interactions.

Copper absorption occurs mainly in the small intestine (approximately less than 10%). Copper facilitates the absorption of iron, is essential for the formation of haemoglobin and is a constituent of several enzymes. Copper is an essential element required in the vascular and skeletal systems, the central nervous system, and in reproductive processes. Copper is therefore widely used as a dietary supplement due to its essential role in nutrition. Dietary excesses of cadmium, calcium, iron, lead, silicon, zinc molybdenum and sulphur reduce copper utilisation. The Cu:Mo ratio should not be less than 2:1. In cases of high molybdenum exposure, the required copper concentrations for horses and cattle should be **five times** above normal. Forage Mo levels of less than 1 mg/kg and 8 - 11 mg Cu/kg can produce toxic effects.

The maximum tolerable levels of copper for growing animals are (NAS, 1980):

Horses:	800 mg/kg of feed
Chicken:	300 mg/kg of feed
Pigs:	250 mg/kg of feed
Cattle:	100 mg/kg of feed
Sheep :	25 mg/kg of feed.

Copper toxicity is dependent on associated molybdenum and sulphate concentrations, and sheep are particularly susceptible. Diarrhoea may occur with the intake of low copper and normal molybdenum concentrations. Necrosis of the liver cells, haemolysis, jaundice, loss of appetite, and death (due to renal failure) occur when high concentrations are ingested.

During the first phase of copper poisoning, accumulation occurs predominantly in the liver. If a concentration higher than 1 000 mg/kg dry mass (DM), on a fat-free basis, is reached in the liver, and the livestock are under stress, the copper is released into the bloodstream where concentrations can increase tenfold. The second phase, haemolytic crisis, is associated with methaemoglobinaemia, haemolysis with subsequent haemoglobinuria and icterus (jaundice).

It is unlikely that the ability of copper to accumulate in the liver is a potential hazard to consumers. In sheep, about 72 % - 79 % of the absorbed copper is found in the liver.

Because numerous metabolic pathways depend on copper, a wide range of deficiency symptoms may occur. *Enzootic ataxia* (swayback) is a well-documented condition in newborn lambs and is caused by insufficient copper intake.

Mitigation If detected early, copper toxicity can be prevented or treated by increasing dietary molybdenum and sulphate concentrations, usually by providing molybdenum-containing licks to improve the Cu:Mo ratio (should not be less than 2:1 or higher than 8:1). High dietary levels of zinc also protect the animal against copper intoxication but supplementation has to be over protracted periods of six weeks or more. Cupric oxide tends to limit the solubility of copper in aerated water at neutral pH.

Criteria **Effects of Copper on the Health of Livestock**

Copper Range (mg/R)	**Effects**		
	Horses, pigs and poultry	Cattle	Sheep and pre-weaned calves
0 - 0.5	" " "	" " "	" " "
0.5 - 1	" " "	" " "	" " !
1 - 2	" " "	" ! !	! ! !
2 - 5	" " "	! ! !	! ! !
5 - 10	" ! !	! ! !	! ! !
> 10	! ! !	! ! !	! ! !

" " " ***Target Water Quality Range. No adverse effects.***

" " ! **Adverse chronic effects such as diarrhoea and liver damage can occur, but may be tolerated if:**

- there is adequate Mo and S intake,
- feed concentrations are normal, and
- exposure is short term.

Can even be tolerated in the long term, depending on site-specific factors such as nutritional interactions and water requirement.

" ! ! **Adverse chronic effects (as above) may occur, but are unlikely if:**

- there is adequate Mo and S intake,
- feed concentrations are normal, and
- exposure is short term.

Can even be tolerated in the long term, depending on site-specific factors such as nutritional interactions and water requirement.

! ! ! **Adverse chronic (as above) and acute effects such as liver damage and haemolytic jaundice may occur, although** short-term exposure can be tolerated depending on site-specific factors such as nutritional interactions and water requirement.

Note: Actual water intake level and subsequent ingestion of copper can vary significantly between species and production systems; see **Characterisation of Use**.

Sources of Information

BERMAN E. 1980. *Toxic Metals and Their Analysis*. Heyden, London.

BOWEN H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

BREMMER I. and J.K. Campbell 1980. The Influence of Dietary Copper Intake on the Toxicity of Cadmium. *Ann. NY Acad. Sci.*, 355-319.

CUNHA T.J. 1977. *Swine Feeding and Nutrition*. Academic Press, Inc. California, USA, 184-187.

ENSMINGER M.E., J.E. Olfield and W.W. Heinemann 1990. *Feeds and Nutrition*, 2nd Edition. The Ensminger Publishing Co., California, 95-239.

LEESON S. and J.P. Summers 1991. *Commercial Poultry Nutrition*. University Books, Canada, 61-63.

LITTLE D.A. 1982. Utilization of Minerals, In: *Nutritional Limits to Animal Production from Pastures*. Hacker, JB (Ed.) Commonwealth Agricultural Bureaux, Slough, England, 259-283.

MACDOWELL L.R. 1992. *Minerals in Animal and Human Nutrition*. Academic Press, Inc., New York.

MILLER W.J. 1979. *Dairy Cattle Feeding and Nutrition*. Academic Press, Inc. California, USA, 95-180.

MINSON D.J. 1990. *Forage in Ruminant Nutrition*. Academic Press, Inc. California, USA, 208-395.

NRC 1980. *Mineral Tolerance of Domestic Animals*. National Academy Press, Washington DC.

NRC 1984. *Nutrient Requirements of Sheep*, 6th Revision, Ed. National Academy Press, Washington DC.

NRC 1985. *Nutrient Requirements of Cattle*, 5th Revision, Ed. National Academy Press, Washington DC.

SPEARS J.W. 1994. Minerals in Forages, In: *Forage Quality, Evaluation and Utilization*, Fahey, G.C. (Ed.). American Society of Agronomy, Inc., Madison, Wisconsin, USA, 281-307.

UNDERWOOD E.J. 1981. *The Mineral Nutrition of Livestock*. Commonwealth Agricultural Bureaux, 31-176.

WEAST R.C. 1979. *CRC Handbook of Chemistry and Physics*, 60th Edition. CRC Press Inc., Boca Raton, Florida, USA.

WHO 1984. *Guidelines for Drinking Water Quality*, Volume 2: Health Criteria and Other Supporting Information. World Health Organization, Geneva.

Fluoride

Background Information

Introduction Fluoride is the most electronegative member of the halogens. It has a strong affinity for positive ions and readily forms complexes with many metals. In its elemental form, fluorine is a greenish-yellow gas which readily dissolves in water to form hydrofluoric acid. Fluorine is highly reactive and will attack most materials, including glass. Apart from the alkali metal fluorides, most fluorides are insoluble in water. Soluble complexes are formed with silicates and the transition metals.

Occurrence Common fluoride minerals are fluor-spar (CaF_2) and fluor-apatite, which is a calcium fluoro-phosphate. Others of importance are various fluoro-silicates and mixed fluoride salts, such as cryolite (Na_3AlF_6).

Typically, the concentration of fluoride in

- unpolluted surface water is approximately 0.1 mg/R;
- ground water is commonly up to 3 mg/R, but as a consequence of leaching from fluoride containing minerals to ground water supplies, a range of 3 - 12 mg/R can be found;
- sea water is approximately 1.4 mg/R.

Fluoride is present in many foods, and water is not the only source thereof. Drinking water is estimated to contribute between 50 % - 75 % of the total dietary fluoride intake in adult human beings.

In industry, fluorine and fluorides are used in the isotopic enrichment of uranium, in the manufacture of various fluorochemicals such as fluorochlorohydrocarbon refrigerants and in the etching of glass.

Interactions Due to the very pronounced electron affinity of the fluoride atom, fluoride interacts with almost every element in the periodic table. It is thought to be one of the main ions that allows for the solubilisation of beryllium, scandium, niobium, tantalum and tin in natural waters. Fluoride reacts readily with calcium to form the relatively insoluble calcium fluoride. Where phosphate is present, an even more insoluble apatite or hydroxy apatite forms. Fluoride also reacts very readily with aluminium, a property which is made use of in the removal of fluoride from water.

Fluoride is readily absorbed in the free fluoride ion form if ingested. Absorption of fluoride complexes depends on their lipid solubility, the ease with which dissociation from complexes occurs in acidic medium and on the ion size and charge.

Measurement The criteria are given in terms of the dissolved fluoride concentration, in units of mg/R. The reference method for the determination of fluoride is the SPADNS colorimetric method. The SPADNS method is based on the formation of a red colour between the fluoride ion and a zirconium dye lake and relies on the tendency of fluoride to complex strongly to the zirconium ion. Where other methods are used, such as a fluoride-specific electrode and ion chromatography, their characteristics relative to the reference method should be known.

Data Interpretation

Mean values should be used when interpreting the numeric criteria given. Fluoride concentrations should always be interpreted in conjunction with temperature and the concentrations of calcium, aluminium and silicate.

Treatment Options

Fluoride is a relatively stable anion which is difficult to remove from water to the required concentrations. Although calcium fluoride is relatively insoluble, its solubility is an order of magnitude higher than the levels which need to be achieved by treatment. Methods for the removal of fluoride include:

- Adsorption in a bed of activated alumina;
- Removal in ion exchange columns along with other anions; and
- Removal in membrane processes such as reverse osmosis and electrodialysis together with virtually all other ions.

Regeneration of the activated alumina or ion exchange bed produces a high fluoride stream which may pose disposal difficulties. A concentrated reject stream is also produced from reverse osmosis and electrodialysis, hence possible disposal problems.

The techniques used are sophisticated and relatively expensive both in capital and operating costs. High levels of skills are needed in the design, operation and maintenance of the equipment.

The Effects of Fluoride

Norms

The norm used in the guideline is primarily based on the toxicological effects associated with ingestion of fluoride in water by livestock.

Effects

Excessive amounts of fluoride result in tooth damage in young growing animals and bone lesions that cause crippling in older animals, especially in cattle. However, fluoride is also beneficial to animals and reduces osteoclast activity and increases osteoblast activity.

Signs of fluorosis are generally observed in the second and third year of exposure. Adverse effects due to fluorosis are indirect and include lameness and decreased feed and water intake (foraging, mastication and drinking become painful), which result in a decline in growth and health. Fluorosis first manifests itself in the permanent incisors; dairy cattle are the most sensitive livestock and the most crucial stages are between six months to three years of age.

The health of calves is not directly affected by fluoride toxicity. Two protection mechanisms exist. Firstly, fluoride is stored in bones and teeth to substantial levels, before adverse effects occur and secondly, high urinary excretion of fluoride occurs. Generally, no toxicity is associated with bone fluoride concentrations less than 4 500 mg/kg (fat-free basis). Toxicity usually occurs at fluoride concentrations of above 5 500 mg/kg, but has also been reported between 2 000 - 8 000 mg/kg. Symptoms of fluorosis include exostosis, pitting and erosion of teeth, loss of appetite, decreased feed intake and reduced performance.

Approximately 30 mg/kg of fluoride in the diet is considered safe for long periods of ingestion. If exposure to high concenrtrations of fluoride occurs after the age of three years in cattle, up to 40 mg F/kg in the diet is acceptable for long-term exposure. The maximum safe level for heifers and bulls between the ages of six months to three years is 20 mg/kg. "Finishing cattle" can safely be fed 100 mg F/kg. Breeding sheep are able to tolerate a diet with less than 60 mg F/kg on a DM basis.

It is generally accepted that milk and meat are free from significant accumulations of fluoride and hence are safe to consumers.

Mitigation

Fluorosis is less severe when drinking water is hard, rather than soft (the presence of calcium and chloride reduces fluoride toxicity) since the occurrence of calcium together with fluoride limits fluoride toxicity. Numerous dietary antagonists such as boron, high protein, low fat, vitamin C and D, copper, iron, vanadium, selenium, molybdenum and aluminium can alleviate the effects of excess fluoride, although not always to a satisfactory degree.

Criteria

Effects of Fluoride on Livestock Health

Fluoride Range (mg/ℓ)	**Effects**	
	Ruminants	Monogastrics
Target Water Quality Range 0 - 2	***No adverse effects***	***No adverse effects***
2 - 4	**No adverse effects**	**Adverse chronic effects associated with dental fluorosis in young livestock and skeletal fluorosis in mature livestock, such as mottling of teeth and enamel hypoplasia, a decrease in feed and water intake and a decline in productivity** may occur, with continuous long-term exposure. But are unlikely if: - feed concentrations are normal - exposure is short term Could even be tolerated in the long term, depending on site-specific factors such as nutritional interactions and water requirement
4 - 6	**Adverse effects may occur**	**Adverse chronic effects (as above) and effects such as crippling , lameness and weight loss may occur, although** short-term exposure could be tolerated depending on site-specific factors such as nutritional interactions and water requirement
6 - 12	**Adverse chronic effects associated with dental fluorosis in young livestock and skeletal fluorosis in mature livestock, such as mottling of teeth and enamel hypoplasia, a decrease in feed and water intake and a decline in productivity,** may occur, with continuous long-term exposure. But are unlikely if: - feed concentrations are normal - exposure is short term Could even be tolerated in the long term, depending on site-specific factors such as nutritional interactions and water requirement	**As above**
> 12	**Adverse chronic effects (as above) and effects such as crippling , lameness and weight loss will occur, although** short-term exposure could be tolerated depending on site-specific factors such as nutritional interactions and water requirement	**As above**

Note: The effects generally occur in the following order, discernable mottling of teeth, enamel hypoplasia, slight gross periosteal hyperostosis, moderate gross periosteal exostosis, significant lameness, decrease in feed intake, milk production, growth and health.

Actual water intake level and subsequent ingestion of fluoride can vary significantly between species and production systems; see **Characterisation of Use**.

Sources of Information

APHA, 1989. *Standard Methods for the Examination of Water and Waste Water*, 17th Edition. American Public Health Association, American Water Works Association, Water Pollution Control Federation. Published by the American Public Health Association, Washington DC, USA.

BOWEN H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

ENSMINGER M.E., J.E. Olfield and W.W. Heinemann 1990. *Feeds and Nutrition*, 2nd Edition. The Ensminger Publishing Co., California, 95-239.

FORD W.E. and E.S. Dana 1963. *A Textbook of Mineralogy*, 4th Edition. John Wiley & Sons Inc., New York.

McKEE J.E. and H.W. Wolf 1963. *Water Quality Criteria*, 2nd Edition. California State Water Resources Control Board, Publication No. 3-A. California.

MILLER W.J. 1979. *Dairy Cattle Feeding and Nutrition*. Academic Press, Inc. California. USA, 95-180.

NRC 1980. *Mineral Tolerance of Domestic Animals*. National Academy Press, Washington DC.

NRC 1984. *Nutrient Requirements of Sheep*, 6th Revision, Ed. National Academy Press, Washington DC.

NRC 1985. *Nutrient Requirements of Cattle,* 5th Revision, Ed. National Academy Press, Washington DC.

UNDERWOOD E.J. 1981. *The Mineral Nutrition of Livestock*. Commonwealth Agricultural Bureaux, 31-176.

WEAST R.C. 1979. *CRC Handbook of Chemistry and Physics*, 60th Edition. CRC Press Inc., Boca Raton, Florida, USA.

WHEELER S.M. and L.R. Fell 1983. Fluoride in Cattle Nutrition. *Nutrition Abstracts and Reviews-Series B,* Commonwealth Bureau of Nutrition, Volume 53, No. 12, 741-766.

Iron

Background Information

Introduction Pure iron is silvery in colour but usually appears as greyish-black or brown deposits as a result of oxidation. Iron is found in three oxidation states, namely 0, II and III of which the III oxidation state is the most common. In water, iron can be present as dissolved ferric iron(Fe III), as ferrous iron(Fe II) or as suspended iron hydroxides. Biologically, iron is an essential micronutrient required by all living organisms.

Occurrence Iron is the fourth most abundant element and constitutes five percent of the earth's crust. It is found in many minerals, the most common of which is haematite (Fe_2O_3), widely used as an iron ore for metallurgical purposes. Other important iron minerals are pyrite (FeS_2), siderite ($FeCO_3$), magnetite (Fe_3O_4), goethite ($Fe_2O_3.H_2O$) and limonite ($2Fe_2O_3.3H_2O$), as well as a number of mixed ores, such as chalcopyrite ($CuFeS_2$) and arsenopyrite (FeAsS). Pyrite is often associated with coal formations and iron may also occasionally be found in the elemental form, either as terrestrial iron or as meteoric iron. The reddish colour of soil is due to iron, the median concentration in soil being 4.0 % (m/m). Typically, the concentration of dissolved iron in:

- unpolluted surface water is between 0.001 - 0.5 mg/ℓ; and
- sea water is approximately 0.002 mg/ℓ.

The speciation of iron is strongly related to the pH and the redox potential of the water. Ferrous salts are unstable under the pH conditions prevailing in drinking water supplies and precipitate as insoluble ferric hydroxide, which settles out as a rust-coloured silt. The dissolved iron concentration is usually in the low µg/ℓ range under neutral or alkaline pH and oxidising conditions, but under reducing conditions, soluble ferrous iron can be formed and substantially higher concentrations in the mg/ℓ range may be encountered. Where marked acidification of the water occurs, for example with acid mine drainage, if the pH drops below 3.5, the dissolved iron concentration can be in the several hundreds of mg/ℓ range.

There is a natural cycling of iron between the dissolved and precipitated phases at the water sediment interface, in which micro-organisms, particularly iron bacteria such as *Gallionella spp.*, play a significant role.

Interactions The concentration of dissolved iron in water is dependent on the **pH**, redox potential, turbidity, suspended matter, the concentration of **aluminium** and the occurrence of several heavy metals, notably **manganese**. The natural cycling of iron can also result in the coprecipitation of trace metals such as arsenic, copper, cadmium and lead.

Measurement The criteria are given in terms of the total iron concentration, expressed in units of mg/ℓ.

The reference method is atomic absorption spectrometry (AAS) using an air acetylene flame. Measurement of the total iron concentration requires acidification followed by filtration prior to AAS analysis. Where other methods of analysis are used, their characteristics relative to the reference method should be known.

Data Interpretation Mean values should be used to compare with the criteria given. Turbidity and pH must be taken into account in the interpretation of iron concentrations.

Treatment Options Iron is commonly removed from water using an oxidising process which will convert the iron into an insoluble oxide removable by filtration. The following treatment approaches are used:

- The water can be **aerated** by devices such as fountains, cascades or mechanical aeration. On a large scale the process usually needs to be more closely controlled and monitored because the consequences of incomplete treatment may be severe.
- The water can be **chemically oxidised** by dosing with chlorine, hydrogen peroxide, ozone or other strong oxidant. On an industrial scale chlorine is commonly used as the chemical oxidant. High levels of residual chlorine after treatment should be avoided since this may interfere with the quality of the water for the purpose intended.

For the optimisation of treatment processes it is important to determine both the total and dissolved iron species and their relative concentrations.

The Effects of Iron

Norms The norms used in the guideline are based on the toxicological effects of iron associated with the ingestion of water used by livestock.

Effects Iron is an essential constituent of animal diets and has a low order of toxicity, but can be harmful in high concentrations. It is an essential component of a number of proteins and enzymes involved in oxygen transport and/or utilisation. There are also several iron-containing enzymes. Metabolically, iron is efficiently conserved and thus dietary requirements are low. Milk also tends to be low in iron. High levels of copper, manganese, lead and cadmium increase the iron requirement by competing for absorption sites.

Iron toxaemia occurs when the iron concentration exceeds the binding capacity of the iron transport protein, transferrin. Under normal conditions only a third of the transferrin reserve is utilised. The ingestion of high concentrations of iron (250 - 1 200 mg/kg ferrous carbonate), has been associated with copper depletion, although long-term high iron-induced copper depletion (24 - 32 weeks) does not result in clinical signs of copper deficiency.

Some evidence indicates that high levels of iron intake (500 mg/kg) may also influence rumen micro-organism activity. However, the solubility of dietary iron and subsequent effects on ruminal fermentation have not yet been satisfactorily quantified.
Acute symptoms of iron toxaemia include vomiting, diarrhoea, acidosis, shock and respiratory failure. Chronic symptoms involve liver and pancreas damage.

Effects of iron deficiency are well documented and occurrence thereof is generally low, because forages usually contain concentrations above the requirements. Pregnancy and egg formation do, however, increase the iron requirement.

Mitigation

Dietary supplementation with high levels of phosphate and phytate may mitigate against iron toxicity, since they decrease the absorption of iron.

The adequate aeration of water is also a consideration, since ferrous salts are oxidised and precipitate as ferric oxide, which is essentially harmless to animals.

Criteria

Effects of Iron on the Health of Livestock

Iron Range (mg/ℓ)	**Effects**
	All livestock
Target Water Quality Range 0 - 10	***No adverse effects***
10 - 50	**Adverse chronic effects such as liver and pancreas damage, may occur, but are unlikely if:** - feed concentrations are normal, and - exposure is short term Could even be tolerated in the long term, depending on site-specific factors, such as adequate intake of phosphate and water requirement
> 50	**Adverse chronic and acute effects such as diarrhoea, vomiting, acidosis and respiratory failure and liver and pancreas damage respectively, may occur, although** short-term exposure could be tolerated depending on site-specific factors such as adequate intake of phosphate and water requirement

Note: Actual water intake level and subsequent ingestion of iron can vary significantly between species and production systems, see **Characterisation of Use**.

The adverse effects of excessive intake of iron are NOT well documented in South Africa.

Sources of Information

APHA 1989. *Standard Methods for the Examination of Water and Waste Water*, 17th Edition. American Public Health Association, American Water Works Association, Water Pollution Control Federation. Published by the American Public Health Association, Washington DC, USA.

BOWEN H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

FORD W.E. and E.S. Dana 1963. *A Textbook of Mineralogy*, 4th Edition. John Wiley & Sons Inc., New York.

McKEE J.E. and H.W. Wolf 1963. *Water Quality Criteria*, 2nd Edition. California State Water Resources Control Board, Publication No. 3-A. California.

SULLIVAN M.F. and P.S. Ruemmler 1987. Effects of Excess Iron and Cadmium or Lead Absorption by Rats. *J. Toxicol. Environ. Health.*, 22: 131.

WATSON W.S., Morrison J., Bethel M.I.F., Baldwin N.M., Lyon D.T.B., Dobson H., Moore M.R. and Hume R. 1986. Food Iron and Lead Absorption in Humans. *Am. J. Clin. Nutr.*, 44: 248.

WEAST R.C. 1979. *CRC Handbook of Chemistry and Physics*, 60th Edition, CRC Press Inc., Boca Raton, Florida, USA.

WORLD HEALTH ORGANIZATION 1984. *Guidelines for Drinking Water Quality*, Volume 2: Health Criteria and Other Supporting Information. World Health Organization, Geneva.

Lead

Background Information

Introduction

Lead is a bluish-white very soft metal, which is highly malleable and ductile. It is highly resistant to corrosion. Lead is a cumulative poison. Lead may accumulate in the roots of some plants, for example hay, potatoes and lettuce to concentrations toxic to humans and animals.

Occurrence

The most common mineral ores of lead are galena (lead sulphide), cerussite (lead carbonate) and anglesite (lead sulphate). The occurrence of lead in its native state is rare. Lead tends to accumulate in sediments and soils in the environment. Lead which has been absorbed by vertebrate organisms is to a large extent deposited in the bony skeleton.

Typically, the concentration of lead in

! surface water is less than 0.010 mg/R;
! sea water is no more than 0.003 mg/R; and
! contaminated water may be several mg/R. Dissolution of lead from lead pipes occurs particularly with soft water low in calcium carbonate.

Lead has many industrial applications which can give rise to sources of lead contamination in water supplies. Lead is used in batteries, in domestic water distribution pipes, in paints and as an organic lead compound, alkyl lead, in gasoline.

Interactions

Metabolically lead interacts with **iron** and interferes with haemoglobin synthesis. Lead uptake is dependent on the action of **calcium** and an intake of adequate dietary calcium tends to suppress uptake.

Measurement

The criteria are given in terms of the total lead concentration, in units of mg/R. Lead can be measured colorimetrically at low concentration (zero to 30 Fg/R) using the dithizone method to form the cherry red lead dithizonate, which is measured spectrophotometrically. Alternatively, lead may be measured by atomic absorption spectrophotometry. These two types of methods constitute the reference methods for lead. If other methods are used their characteristics relative to the reference methods should be known.

Data Interpretation

Mean values should be used to compare with the criteria given.

Treatment Options

Lead in water supplies is most conveniently removed by applying conventional water treatment processes of coagulation with alum, ferric salts or lime followed by settlement and filtration. The coagulation/flocculation process requires careful monitoring to ensure that removal is complete. A watery sludge containing lead is generated in the process and may present disposal difficulties.

The Effects of Lead

Norms

The norms used in the guideline are based on the toxicological effects associated with the ingestion of lead in water by livestock.

Effects

Lead poisoning occurs mainly in cattle and sheep, and is usually acute. Cattle are far more susceptible to lead poisoning than horses, which can withstand ten times the concentration of lead than cattle. Pigs, goats and chicks are moderately resistant. The onset of clinical symptoms is more rapid in young animals. The absorption of lead is higher in the absence of dietary restrictions (10 % - 35 %), in the presence of high dietary fat, and with low dietary calcium intakes. Milk does not appear to be protected against dietary excesses of lead.

Toxic effects from high levels of lead exposure cited by The Canadian Guidelines (1987) include:

- toxic response in cattle from a minimum intake of 6 - 7 mg/kg in feed;
- calves killed by accidental exposure for 30 days to an estimated lead dose of 5 - 8 mg/kg/d; and
- death of sheep from dietary exposure of 4.7 mg/kg body weight (BW).

Symptoms of acute toxicity involve the nervous system and include excessive excitability, frothing from the mouth, blindness, muscular tremors and convulsions, lack of hind limb co-ordination in mature animals, and the faeces often appear dark or black.

Symptoms of chronic toxicity include anorexia, diarrhoea or constipation, emaciation, a "dumb" phase interspersed with convulsive episodes, and respiratory distress and roaring (in horses).

A positive identification requires chemical lead tests of organs.

Mitigation

The ingestion of lead from non-water resources (e.g. accumulator battery plates, lead arsenate sprays and lead based paints) can play a role as a result of pica. Administration of magnesium sulphate tends to purge lead and calcium di-sodium absorbs lead from tissues.

Dietary zinc can partially alleviate lead toxicity by decreasing the absorption rate of lead and hence the lead concentration found in tissue and blood. Iron deficiency aggravates iron toxicity, and adequate iron concentrations can also be an alleviatory factor.

Adequate dietary protein is also important in mitigating against the effects of lead. High protein levels (specifically, sulphur-containing amino acids) alleviate lead toxicity through an increased excretion thereof. A decrease in dietary protein can lead to an increase in lead concentrations in the blood, and therefor increase tissue retention of lead.

Criteria **Effects of Lead on the Health of Livestock**

Lead Range (mg/R)	Effects	
	Pigs	**All other livestock**
Target Water Quality Range ***0 - 0.1***	**" "**	**" "**
0.1 - 0.2	**" "**	**" !**
0.2 - 0.5	**" "**	**! !**
0.5 - 1	**" !**	**! !**
> 1	**! !**	**! !**

" " ***No adverse effects.***

" ! **Adverse chronic effects such as anorexia, emaciation and possible respiratory distress may occur, but are unlikely if**
- feed concentrations are normal, and
- exposure is short term.

Can even be tolerated in the long term, depending on site-specific factors such as adequate dietary protein intake and water requirement.

! ! **Adverse chronic effects (as above) and acute effects such as excessive excitability, frothing from the mouth, muscular tremors, convulsions and hind limb inco-ordination may occur**, although short-term exposure could be tolerated depending on site-specific factors such as adequate dietary protein intake and water requirement.

Note: Actual water intake level and subsequent ingestion of lead can vary significantly between species and production systems; see **Characterisation of Use**.

Sources of Information

APHA 1989. *Standard Methods for the Examination of Water and Waste Water*, 17th Edition. American Public Health Association, American Water Works Association, Water Pollution Control Federation. Published by the American Public Health Association, Washington DC, USA.

BERMAN E. 1980. *Toxic Metals and Their Analysis*. Heyden, London.

DEHICA J., C.A. Hardy, R.G. Burright, P.J. Donovick and R.L. Tuggy 1982. The Effect of Dietary Fat and Lead Ingestion on Blood Lead Levels in Mice. *J. Toxicol. Environ. Health.*, 10: 441.

ELSENHANS B., K. Schumann and W. Forth 1991. Toxic Metals: Interactions with Essential Minerals, In*: Nutrition, Toxicity and Cancer*. Rowland, I.R. (Ed.). CRC Press, Inc. USA, 197-222.

ENSMINGER M.E., J.E. Olfield and W.W. Heinemann 1990. *Feeds and Nutrition*, 2nd Edition. The Ensminger Publishing Co., California, 95-239.

KARGACIN B. and K. Kostial 1991. Toxic Metals: Influence of Macromolecular Dietary Components on Metabolism and Toxicity, In*: Nutrition, Toxicity and Cancer*. Rowland, I.R. (Ed.). CRC Press, Inc. USA, 197-222.

KIM M.K. and K.H. Cho 1986. Metabolic Changes in Growing Rats Fed Diets with Different Levels of Lead and Protein. *Korean J. of Nutr.*, 19: 323.

McKEE J.E. and H.W. Wolf 1963. *Water Quality Criteria*, 2nd Edition. California State Water Resources Control Board, Publication No. 3-A. California.

NRC 1980. *Mineral Tolerance of Domestic Animals*. National Academy Press, Washington DC.

NRC 1984. *Nutrient Requirements of Sheep*, 6th Revision, Ed. National Academy Press, Washington DC.

NRC 1985. *Nutrient Requirements of Cattle*, 5th Revision, Ed. National Academy Press, Washington, DC.

WEAST R.C. 1979. *CRC Handbook of Chemistry and Physics*, 60th Edition. CRC Press Inc., Boca Raton, Florida, USA.

WORLD HEALTH ORGANIZATION 1984. *Guidelines for Drinking Water Quality*, Volume 2: Health Criteria and Other Supporting Information. World Health Organization, Geneva.

WISE A. 1981. Protective Action of Calcium Phytate against Acute Lead Toxicity in Mice. *Bull. Environ. Contam. Toxicol.*, 27: 630.

Magnesium

Background Information

Introduction

Magnesium is an alkaline earth metal which reacts with oxygen and water to form magnesium oxide and magnesium hydroxide, respectively. Magnesium is a common constituent of water and occurs as a doubly positively-charged magnesium (II) ion. The solubility of magnesium in water is governed by the carbonate/bicarbonate equilibrium, and hence, the pH. Magnesium, together with calcium, is responsible for the hardness of water. Magnesium is also an essential nutritional element. Magnesium in water can make a significant contribution to the total dietary magnesium intake.

Magnesium is also a basic, essential element for plants (the central metallic ion in chlorophyll) and most other living organisms, since it is a component of important enzyme co-factors.

Occurrence

Common minerals of magnesium are magnesium carbonate and various magnesium silicates. The solubility of magnesium in water is governed by the pH. Magnesium hydroxide is relatively soluble at pH 7, but gradually becomes less soluble as the pH increases. Magnesium bicarbonate, chloride, nitrate and sulphate are very soluble in water whereas magnesium carbonate, silicate and phosphate are insoluble. Typically, the concentration of magnesium in

- fresh water is between 4 - 10 mg/ℓ; and
- sea water is approximately 1 300 mg/ℓ.

Interactions

Magnesium interacts with **calcium**, as well as with various anions and organic acids.

Measurement

The criteria are given in terms of the total magnesium concentration, in units of mg/ℓ. The reference method for the determination of magnesium is atomic absorption spectrometry, using a phosphate interference inhibitor, such as lanthanum, and an ionisation suppressant, such as caesium or potassium. If other methods are used, their characteristics relative to the reference method should be known.

Data Interpretation

Mean values should be used to compare with the criteria given. Magnesium concentrations should also be interpreted in conjunction with the

- major associated anion(s), usually bicarbonate, sulphate or chloride; and the
- calcium, sodium and potassium concentrations.

Treatment Options

Magnesium is commonly removed from water using the following treatment approaches:

- **Precipitation** of magnesium as magnesium hydroxide by the addition of sodium hydroxide. This process raises the pH of the water substantially and is more suitable as a pretreatment step prior to ion exchange.

- **Cation exchange** columns are used to replace the magnesium (and calcium if present) in the water with sodium. The columns are regenerated with a sodium chloride brine.

- ! **Demineralisation** in mixed bed ion exchange columns will remove all magnesium ions together with other ions in solution, where water of a particularly low salinity is required.

The same result may be obtained using a range of desalination techniques such as membrane treatment or distillation. On an industrial scale the processes need skilled operation and control because the consequences of incomplete treatment may be severe. All of the processes produce a concentrated waste stream that may cause disposal difficulties.

The Effects of Magnesium

Norms

The norms used in the guideline are based on the palatability and toxicological effects associated with ingestion of magnesium in water by livestock.

Effects

Magnesium salts are essential in animal diets. Magnesium is a constituent of bones and teeth, and an essential element of cellular metabolism and other physiological functions. Magnesium absorption is enhanced by protein, lactose, vitamin D, growth hormone and the ionophore antibiotics. Ruminants are dependant on a daily supply of magnesium becuse their homeostatic mechanisms do not regulate blood levels of magnesium sufficiently; deficiencies are unlikely because the requirement is low. Supplemental magnesium is associated with an increased intake and digestion of fibre in ruminants.

Excess magnesium intake upsets calcium and potassium metabolism. Signs of magnesium toxicosis include lethargy, loss of co-ordination, diarrhoea, decreased feed intake and performance. Diets high in magnesium but low in calcium can cause rickets.

High concentrations of magnesium also result in adverse palatability effects; see **TDS**.

Mitigation

High intake of calcium, potassium, oxalic acid and phytate, as well as poorly digested fats interfere with magnesium absorption. Mitigatory measures preventing excessive intake of these elements prevent deficiencies.

Criteria **Effects of Magnesium on the Health of Livestock**

Magnesium Range (mg/ℓ)	**Effects**	
	Ruminants	Non-ruminants
Target Water Quality Range 0 - 500	***No adverse effects***	***No adverse effects***
500 - 1 000	**Adverse chronic effects such as lethargy and decreased feed intake may occur, but** will most likely be temporary and normal production should continue once stock have adapted; see TDS	**Adverse chronic and acute effects such as loss of co-ordination, decreased feed intake and performance and diarrhoea may occur** May be tolerated for short exposure time depending on site-specific factors and adaptation. Stock may subsist under certain conditions, but production will, in all likelihood, decline; see TDS
> 1 000	Adverse chronic effects as above, and acute effects such as diarrhoea may occur. May be tolerated for shorter exposure time depending on site-specific factors and adaptation. Stock may subsist under certain conditions, but production will, in all likelihood, decline; see TDS	Adverse chronic and acute effects (as above) may occur. May be tolerated for short exposure time depending on site-specific factors and adaptation. Stock may subsist under certain conditions, but production will, in all likelihood, decline; see TDS

Note: Actual water intake level and subsequent ingestion of magnesium can vary significantly between species and production systems; see **Characterisation of use**.

Sources of Information

BOWEN H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

ENSMINGER M.E., J.E. Olfield and W.W. Heinemann 1990. *Feeds and Nutrition*, 2nd Edition. The Ensminger Publishing Co., California, 95-239.

LEESON S. and J.P. Summers 1991. *Commercial Poultry Nutrition*. University Books, Canada, 61-63.

LITTLE D.A. 1982. Utilization of Minerals, In: *Nutritional Limits to Animal Production from Pastures*. Hacker, J.B. (Ed.) Commonwealth Agricultural Bureaux, Slough, England, 259-283.

MACDOWELL L.R. 1992. *Minerals in Animal and Human Nutrition*. Academic Press, Inc., New York.

McKEE K.E. and H.W. Wolf 1963. *Water Quality Criteria*, 2nd Edition. California State Water Resources Control Board, Publication No. 3-A. California.

MILLER W.J. 1979. *Dairy Cattle Feeding and Nutrition*. Academic Press, Inc. California, USA, 95-180.

MINSON D.J. 1990. *Forage in Ruminant Nutrition*. Academic Press, Inc. California, USA, 208-395.

NRC 1980. *Mineral Tolerance of Domestic Animals*. National Academy Press, Washington DC.

NRC 1984. *Nutrient Requirements of Sheep*, 6th Revision, Ed. National Academy Press, Washington DC.

NRC 1985. *Nutrient Requirements of Cattle*, 5th Revision, Ed. National Academy Press, Washington DC.

SPEARS J.W. 1994. Minerals in Forages, In: *Forage Quality, Evaluation and Utilization*, Fahey, G.C. (ed.). American Society of Agronomy, Inc., Madison, Wisconsin, USA, 281-307.

UNDERWOOD E.J. 1981. *The Mineral Nutrition of Livestock*. Commonwealth Agricultural Bureaux, 31-176.

Manganese

Background Information

Introduction

Manganese is a grey-white brittle metal and is found in several oxidation states. It is an essential element for humans and animals, but is neurotoxic in excessive amounts. At typical concentrations encountered in water, manganese has aesthetic rather than toxic effects.

Uptake of manganese occurs by ingestion from both food and water, but more so from food. Manganese exhibits a low solubility in gastric fluids; only three to four percent of ingested manganese is absorbed from the gastrointestinal tract. Metabolically, manganese is regulated primarily by excretion through the pancreas, although excretion directly through the gut wall and in the urine also takes place.

Occurrence

Manganese is a relatively abundant element, constituting about 0.1 % of the earth's crust. Commonly occurring minerals containing manganese include pyrolusite (MnO_2), manganite ($Mn_2O_3.H_2O$), rhodochrosite ($MnCO_3$) and rhodonite ($MnSiO_3$). Manganese is found in solution predominantly as the manganous ion, Mn(II), which may be stabilised by complexation to humic acids. On oxidation to the manganic ion, Mn(IV), manganese tends to precipitate out of solution to form a black hydrated oxide, which is responsible for the staining problems often associated with manganese-bearing waters.

Typically the median concentration of manganese in

- freshwater is 8 µg/ℓ with a range of 0.02 - 130 µg/ℓ;
- soils is 1 000 mg/kg; and
- sea water is approximately 0.2 µg/ℓ.

Manganese concentrations in the mg/ℓ range can be found in anaerobic bottom-level waters, where manganese has been mobilised from the sediments. Industrial uses of manganese include

- use in the manufacture of steel and manganese alloys;
- use of the salts of manganese as drying compounds in varnishes and oils;
- use of manganese chloride in dry cell batteries;
- use of manganese carbonate as the pigment, "manganese white"; and
- use of manganese dioxide in making amethyst glass and decorative porcelain.

Interactions

The aquatic chemistry of manganese is closely associated with that of **iron**, and the two elements tend to behave synergistically in their dissolution from sediments under anaerobic conditions and reprecipitation under aerobic conditions. Manganese, once in solution, is more readily stabilised by complexation than iron and is often difficult to remove from solution except at high pH, where it precipitates as the hydroxide. Like iron, manganese can be utilised by metallophilic bacteria.

Other water constituents and properties that govern the action of manganese in water are **pH**, redox potential, turbidity, suspended matter, and the concentration of **aluminium**.

Measurement

The criteria are given in terms of the total manganese concentration, in units of mg/ℓ. The reference method for the determination of manganese in water is atomic absorption spectrometry, using an air-acetylene flame. Samples should be acidified prior to analysis to dissolve manganese adsorbed to suspended matter. Where other methods are used, their characteristics relative to the reference method should be known.

Data Interpretation

Mean values should be used to compare with the criteria given. The occurrence of elevated manganese concentrations in surface waters are typically cyclic unless directly due to pollution by manganese-bearing effluents. Transient episodes of elevated manganese concentrations in distribution systems can result in a long-standing manganese problem through precipitation in reservoirs or in the distribution system, followed by gradual release.

Treatment Options

Manganese is commonly removed from water using an oxidising process which will convert the manganese into an insoluble oxide removable by filtration. The reaction is considerably more difficult to achieve than with iron and normally requires the use of a **strong oxidising agent**. Agents commonly used include

- chlorine;
- hydrogen peroxide;
- potassium permanganate; and
- ozone.

Where the oxidant used leaves a residual, as is the case with chlorine, the residual should be removed before the water is supplied for use. On an industrial scale the process usually needs to be closely controlled and monitored because the consequences of incomplete treatment may be severe.

The Effects of Manganese

Norms

The norms used in the guideline are primarily based on the toxicological effects associated with the ingestion of manganese in water by livestock.

Effects

Moderate excesses of manganese are not toxic to livestock. Manganese is essential for growth and fertility. Manganese is a component of the enzyme pyruvate carboxylase, and numerous enzymes are activated by manganese. There is limited storage of manganese, and little is known about the dietary factors that affect absorption and utilisation of stored reserves. Higher concentrations of manganese occur in the bones, liver and kidney compared to the blood or muscle tissue.

Levels of 500 mg/kg feed have been shown to result in depressed appetites in pigs. Deficiencies in manganese are of far more concern than toxicity and can lead to perosis and nutritional chondrodystrophy in chicks. The manganese requirement of poultry is higher than of other livestock, and hence deficiencies are more likely to occur in poultry.

Mitigation

Manganese absorption is reduced by high levels of calcium, phosphate and iron.

Criteria **Effects of Manganese on the Health of Livestock**

Manganese Range (mg/ℓ)	Effects
	All livestock
Target Water Quality Range 0 - 10	***No adverse effects***
10 - 50	**Adverse chronic effects such as weight loss due to inappetence may occur, but are unlikely if:** - feed concentrations are normal, and - exposure is short term. Could even be tolerated in the long term, depending on site-specific factors such as adequate intake of calcium, phosphorus and iron and water requirement
> 50	**Adverse chronic effects such as weight loss and anaemia (where iron intake is not adequate) may occur, although** short-term exposure could be tolerated depending on site-specific factors (as above)

Note: Actual water intake level and subsequent ingestion of manganese can vary significantly between species and production systems; see **Characterisation of Use**.

Sources of Information

APHA 1992. *Standard Methods for the Examination of Water and Waste Water*, 16th Edition. American Public Health Association, American Water Works Association, Water Environment Federation. Published by the American Public Health Association, Washington DC, USA.

BERMAN E. 1980. *Toxic Metals and Their Analysis*. Heyden, London.

BOWEN H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

ENSMINGER M.E., J.E. Olfield and W.W. Heinemann 1990. *Feeds and Nutrition*, 2nd Edition. The Ensminger Publishing Co., California, 95-239.

FORD W.E. and E.S. Dana 1963. *A Textbook of Mineralogy*, 4th Edition. John Wiley & Sons Inc., New York.

LEESON S. and J.P. Summers 1991. *Commercial Poultry Nutrition*. University Books, Canada, 61-63.

LITTLE D.A. 1982. Utilization of Minerals, In: *Nutritional Limits to Animal Production from Pastures*. Hacker, J.B. (ed.). Commonwealth Agricultural Bureaux, Slough, England, 259-283.

MACDOWELL L.R. 1992. *Minerals in Animal and Human Nutrition*. Academic Press, Inc., New York.

MILLER W.J. 1979. *Dairy Cattle Feeding and Nutrition*. Academic Press, Inc. California, USA, 95-180.

MINSON D.J. 1990. *Forage in Ruminant Nutrition*. Academic Press, Inc. California, USA, 208-395.

NRC 1980. *Mineral Tolerance of Domestic Animals*. National Academy Press, Washington DC.

NRC 1984. *Nutrient Requirements of Sheep*, 6th Revision, Ed. National Academy Press, Washington DC.

NRC 1985. *Nutrient Requirements of Cattle*, 5th Revision, Ed. National Academy Press, Washington DC.

SPEARS J.W. 1994. Minerals in Forages, In: *Forage Quality, Evaluation and Utilization* Fahey, G.C. (ed.). American Society of Agronomy, Inc., Madison, Wisconsin, USA, 281-307.

UNDERWOOD E.J. 1981. *The Mineral Nutrition of Livestock*. Commonwealth Agricultural Bureaux, 31-176.

WEAST C. 1979. *CRC Handbook of Chemistry and Physics*, 60th Edition. CRC Press Inc., Boca Raton, Florida, USA.

Mercury

Background Information

Introduction

Mercury is a heavy metal of quite rare geological occurrence, and concentrations thereof in the environment are normally very low. Mercury occurs in three oxidation states in the natural environment, as the metal, as mercury(I) and as mercury(II). It is also found as organomercurials, the most important of which is methyl mercury. The occurrence of mercury contaminants in water is predominantly site-specific and related to identifiable site-specific discharges. Mercury and organomercurial complexes are severely neurotoxic. Intake may occur *via* air, food or water. Food, particularly fish and fish products, are usually the major source of exposure to mercury.

Occurrence

The principal source of mercury in the environment is the natural degassing of the earth's crust. Mercury deposits occur in igneous, sedimentary and metamorphic rocks. Mercury is present in the atmosphere as metallic mercury vapours and as volatilised organic mercury compounds. Atmospheric mercury can enter terrestrial and aquatic habitats through particle deposition and precipitation.

Mercury concentrations in surface waters are generally less than 1 Fg/R, except in areas where mineral deposits of mercury occur. Although mercury is unlikely to occur naturally in surface waters at concentrations which are of concern to human health, it may occur at high concentrations in water bodies subject to industrial pollution. Several industrial activities contribute significantly to the presence of mercury in the environment. Major industrial sources are the chlor-alkali industry, and the paint and fungicide industries. Mercury is also used in dentistry, in pulp and paper manufacturing processes, in thermometers, electrical equipment and in some therapeutic medicinal compounds.

Mercury has a strong affinity for -SH and -OH groups and is therefore strongly associated with sediments and suspended solids where bacterial methylation occurs readily under anaerobic conditions. Methyl mercury, being lipid soluble, readily accumulates in food chains and is the main form in which mercury is found in the tissues of fish and mammals.

Interactions

Alkylated mercury compounds, such as mono- and di- methyl mercury, are of serious concern in the aquatic environment because of their much greater toxicity to man and animals than the inorganic forms of mercury. As alkylation is bacteriologically and biologically mediated, factors such as **pH** and the concentrations of **dissolved oxygen and organic carbon** influence both the degree of methylation and type of organo-mercurials formed.

Measurement

The criteria apply to total mercury concentrations and the methods used must measure both the dissolved and particulate forms of mercury, particularly if water is consumed without the removal of finer particulates, where most of the mercury tends to be concentrated. The reference method for the determination of mercury is flameless atomic absorption spectrometry (AAS). Acid digestion of the sample is required before analysis by AAS.

Data Interpretation

Since mercury accumulates in the body, a single exposure to a high concentration of mercury can have very serious effects. The criteria given should therefore be treated as maximal values, not to be exceeded.

Mercury can occur in different forms in water, for example in the dissolved state, as suspended particles, and as complexes with other substances. Both the method of analysis selected and the treatment of water samples before analysis will determine how much mercury in each of the above categories is included in the analysis. It is therefore crucial that the analyst state whether the method employed measures one or more of the mercury forms present, or total mercury.

Treatment Options

Current technology capable of removing inorganic mercury to within the TWQR includes

- precipitation:
  - coprecipitation with aluminium hydroxide by addition of alum; and
  - coprecipitation with ferric hydroxide by addition of iron salts;
- adsorption, using powdered or granular activated carbon; and
- ion exchange, using appropriate resins.

Mercury residuals within the target water quality range will not be consistently achieved without skilled process control of precipitation reactions, or careful monitoring for breakthrough from activated carbon or ion exchange columns. Inorganic mercury can be removed to a significant extent (70 % - 80 %) by coagulation and flocculation with iron salts, followed, if necessary, by powdered activated carbon or granular activated carbon treatment.

Organically-bound mercury is not satisfactorily removed by precipitation but is effectively removed by adsorption to activated carbon.

Disposal of the hazardous mercury-rich precipitates, regeneration solutions, or loaded activated carbon require appropriately designed and licensed facilities.

The Effects of Mercury

Norms

The norms used in the guidelines are based on the toxicological effects associated with ingestion of mercury in water used by livestock and the effects of contamination on livestock product quality and consumption of contaminated products.

Effects

Livestock

The high levels of toxicity associated with methylmercury are attributable to a greater absorption rate, slower turnover rate in tissues, and longer retention in the body than inorganic forms of mercury (59 % absorption compared to two percent for inorganic Hg).

Methylmercury has a more even tissue distribution than Hg^{2+} which accumulates primarily in the kidney. The half-life of methylmercury is twice that of Hg^{2+}.

Most inorganic mercury absorbed is retained in the liver and kidney, but the concentration of methylmercury tends to be highest in the liver. Appreciable amounts are also found in muscle and brain tissue. Zinc and mercury mutually influence tissue accumulation in the liver and kidneys (zinc and cadmium, and cadmium and mercury compete for absorption sites in the intestine, whereas zinc and mercury do not). As such, zinc-deficient diets aggravate mercury toxicity.

The ingestion of mercury-contaminated milk seems to increase mercury retention. Signs of poisoning have been observed at 2 mg/kg in turkeys, at 8 mg/kg in cattle and at 10 mg/kg in sheep. The maximum daily intake should be less than 0.1 mg Hg/kg BW.

It is extremely difficult to distinguish between symptoms associated with poisoning from mercury and other poisons. Organic mercury poisoning results in nervous system disorders such as ataxia, a lack of co-ordination, tetanic spasms, eyelid twitching, salivation, recumbency, convulsions and death. Inorganic forms of mercury are caustic to the oral and digestive tracts.

Symptoms of chronic mercury poisoning may include depressed appetite, decreased live weight gains, stiff gait, paralysis, loss of hair, scabby lesions around anus, tender gums and loss of teeth.

Consumption of contaminated livestock products

Up to 72 % of the absorbed methylmercury may be found in muscle tissue and, as such, is potential consumer hazard. Human poisoning has been recorded after the consumption of animals that were fed grain treated with a mercurial fungicide. Very little mercury (any form) is in milk (0.17 % after 14 days and 0.01 % recorded). To be safe for human consumption, levels in the blood and tissue should not exceed 0.1 mg/ℓ and 0.5 mg/kg, respectively.

Mitigation

Because Hg^{2+} has a high affinity for sulphydryl groups, increasing dietary protein by 10 % - 20 %, together with the addition of cystine or selenium in the feed, can decrease the toxicity of methylmercury. The source of protein supplements has been found to be crucial; fish protein treatments compared with casein treatments result in an increase in survival of 20 %. This is probably due to a higher selenium content of the fish protein.

Levels of 0.4 % cystine and 0.6 mg/kg selenium appear to be the optimum dietary levels for the decrease of visible toxic signs in diets containing 25 mg/kg methylmercury chloride. These protective effects are probable due to a decrease in mercury deposition in the kidney, and hence a delay in the onset of renal failure and an increase in the rate of conversion of methylmercury to inorganic mercury (due to an increase in the availability of sulphydryl binding sites that complex with mercury).

There is evidence that intestinal micro-organisms metabolise methylmercury to inorganic mercury which results in increased mercury excretion and decreased tissue deposition. Since it is known that fibre intake affects ruminal micro-organisms, adequate dietary fibre intakes in ruminants may also mitigate indirectly against the toxic effects of mercury.

Pre-treatment with cadmium may also reduce renal toxicity caused by mercury.

Criteria **Effects of Mercury on the Health of Livestock**

Mercury Range (Fg/R)	Effects
	All livestock
Target Water Quality Range 0 - 1	***No adverse effects***
1 - 6	**Adverse chronic effects may occur if mercury is in the organic form, but should be tolerated if** - there is adequate intake of zinc and selenium, - feed concentrations are normal, and - exposure is short term. Could even be tolerated in the long term, depending on site-specific factors such as adequate dietary protein intake and water requirement
> 6	**Adverse chronic and acute effects such as neuro-, hepato- and renal toxicity may occur, although** short-term exposure could be tolerated depending on site-specific factors (as above)

Note: Actual water intake level and subsequent ingestion of mercury can vary significantly between species and production systems; see **Characterisation of Use**.

Sources of Information

APHA 1989. *Standard Methods for the Examination of Water and Waste Water*, 17th Edition. American Public Health Association, American Water Works Association, Water Pollution Control Federation. Published by the American Public Health Association, Washington DC, USA.

ASCE/AWWA 1990. *Water Treatment Plant Design*. American Society of Civil Engineers/American Water Works Association. McGraw Hill, New York, USA, 2nd Edition.

BAKIR F., S.F. Damluji, L. Amin-Zaki, M. Murtadha, A. Khalidi, N.Y. Al-Rawi, S. Tikriti, H.I. Dhahir, T.W. Clarkson, J.C. Smith and R.A. Doherty 1973. Methylmercury Poisoning in Iraq. An Inter-university Report. *Science*, 181-230.

CANADIAN GUIDELINES 1987. *Canadian Water Quality Guidelines*, Canadian Council of Resources and Environment Ministers. Ottowa.

CLARKSON T.W. 1971. Epidemiological and Experimental Aspects of Lead and Mercury Contamination of Food. *Food. Cosmet. Toxicol.*, 9: 229.

CUNHA T.J. 1977. *Swine Feeding and Nutrition*. Academic Press, Inc. California, USA, 184-187.

ELSENHANS B., K. Schumann and W. Forth 1991. Toxic Metals: Interactions with Essential Minerals, In: *Nutrition, Toxicity and Cancer*. Rowland, I.R. (Ed.). CRC Press, Inc. USA, 197-222.

ENSMINGER M.E., J.E. Olfield and W.W. Heinemann 1990. *Feeds and Nutrition*, 2nd Edition. The Ensminger Publishing Co., California, 95-239.

KARGACIN B. and K. Kostial 1991. Toxic Metals: Influence of Macromolecular Dietary Components on Metabolism and Toxicity, In: *Nutrition, Toxicity and Cancer*. Rowland, I.R. (Ed.). CRC Press, Inc. USA, 197-222.

KEMPSTER P.L. and R. Smith 1985. *Proposed Aesthetical Physical and Inorganic Drinking-water Criteria for the Republic of South Africa*. Research Report No. 628, National Institute for Water Research, CSIR, Pretoria, South Africa.

KEMPSTER P.L. and H. van Vliet 1991. *Water Quality Fitness for Use Curves for Domestic Water*. Draft Report, Hydrological Research Institute, Department of Water Affairs and Forestry, Pretoria, South Africa.

NRC 1980. *Mineral Tolerance of Domestic Animals*. National Academy Press, Washington DC.

NRC 1984. *Nutrient Requirements of Sheep*, 6th Revision, Ed. National Academy Press, Washington DC.

NRC 1985. *Nutrient Requirements of Cattle*, 5th Revision, Ed. National Academy Press, Washington DC.

ROWLAND I.R., A.K. Mallett, J. Flynn and R.J. Hargreaves 1986. The Effect of Various Dietary Fibres on Tissue Concentration and Chemical Form of Mercury after Methylmercury Exposure in Mice. *Arch. Toxicol.*, 59: 94.

UNDERWOOD E.J. 1981. *The Mineral Nutrition of Livestock*. Commonwealth Agricultural Bureaux, 31-176.

WORLD HEALTH ORGANIZATION 1984. *Guidelines for Drinking Water Quality*, Volume 2: Health Criteria and Other Supporting Information. World Health Organization, Geneva.

Molybdenum

Background Information

Introduction

Molybdenum is a silvery-white, very hard metal and is an essential micro-element for all living organisms, but is toxic at high concentrations. Molybdenum plays a role in many enzymes, notably the flavoprotein enzyme, xanthine oxidase.

Occurrence

The principle ore of molybdenum is molybdenite (MoS_2), frequently found in association with tungsten-bearing minerals. Molybdenum is also found in association with lead, as the mineral wulfenite ($PbMoO_4$). Typically, the concentration of molybdenum in

- fresh water is between 0.03 - 10 µg/ℓ, with a median concentration of 0.5 µg/ℓ;
- sea water is similar to that of fresh water; and
- soils is between 0.1 - 40 mg/kg, with a median concentration of 1.2 mg/kg.

Molybdenum tends to be associated with the suspended sediment fraction of water. Higher concentrations are generally found in sediments and soils and not in solution.

Molybdenum is used in the manufacture of hardened alloys and high strength steels, and as a lubricant additive. It is used as a filament material in the electronics industry, and in glass and ceramics. It is also used as a corrosion inhibitor.

Interactions

Metabolically, molybdenum interacts with **copper** and **sulphur** and the occurrence of molybdenum toxicity is strongly influenced by the dietary intake of **copper** and **sulphur**.

Measurement

The criteria are given in terms of the total molybdenum concentration, in units of mg/ℓ. The reference method for the measurement of molybdenum is electrothermal atomic absorption spectrometry. Where other methods are used their characteristics relative to the reference method should be known.

Data Interpretation

Mean values should be used to compare with the criteria given. Molybdenum concentrations in water should be interpreted in conjunction with molybdenum concentrations in soils and sediments and also in relation to copper and sulphate concentrations.

Treatment Options

Molybdenum in water supplies is most conveniently removed by raising the pH and precipitating the insoluble salts after the addition of lime or iron salts in the pH range of 8.5 - 11.5. The precipitation is followed by settlement and filtration as in conventional water treatment.

The precipitation process requires careful monitoring to ensure that removal is complete.

In order to achieve very low residuals, it may be necessary to pass the stream through an ion exchange column charged with the appropriate resin.

A watery, molybdenum-rich sludge or concentrate stream is generated in the process that may present disposal difficulties.

The Effects of Molybdenum

Norms

The norms used in the guideline are based on the toxicological effects associated with the ingestion of molybdenum in water by livestock.

Effects

Molybdenum functions as a component of xanthine oxidase, sulphite oxidase and aldehyde oxidase, and appears to enhance microbial activity in the rumen.

Molybdenum forms insoluble complexes with copper and sulphate and decreases the utilisation of dietary copper. As such, molybdenum toxicity is closely linked to the concentrations of copper and inorganic sulphate in the diet.

Molybdenum intake at lower levels than those that cause acute toxicity can result in a copper deficiency. It appears that molybdenum may have direct effects on metabolic processes independent of changes in copper metabolism. Sheep, swine and poultry are more tolerant of elevated concentrations of dietary molybdenum than are cattle, especially calves and "cows-in-milk". Toxicity can occur from 6 mg/kg onwards, but is also dependent on the amount of copper available. Pigs can tolerate 1 000 mg/kg for up to three months; this is 10 - 20 times the dietary level that adversely affects cattle. For chicks, an intake of 200 mg/kg has been shown to reduce growth.

Symptoms of excessive molybdenum intake include persistent diarrhoea with watery, bubbly and "scouring" characteristics, loss of appetite, loss of weight, anaemia, lack of co-ordination, infertility, bone malformation and depigmentation of hair.

Molybdenum deficiency does not appear to occur under practical conditions in South Africa.

Mitigation

Molybdenosis can usually be overcome by supplementation with sufficient amounts of copper. Cattle require a Cu:Mo ratio of 2:1 to prevent molybdenum poisoning. The administration of copper sulphate at 2 g/d/cow and 1 g/d/young stock or an intravenous dose of 200 - 300 mg Cu/ day are effective controls. High SO_4 levels tend to be antagonistic and affect the absorption retention and excretion of molybdenum inversely. An oral dose of potassium sulphate rapidly increases molybdenum excretion. Iron supplementation may also ameliorate the effects of molybdenosis in cattle.

Criteria **Effects of Molybdenum on the Health of Livestock**

Molybdenum Range (mg/ℓ)	**Effects (All livestock)**
Target Water Quality Range 0 - 0.01	***No adverse effects***
0.01 - 0.02	**Adverse chronic effects such as weight loss and anaemia may occur, but are unlikely if** - there is adequate Cu and SO_4 intake; - feed concentrations are normal, and - exposure is short term **Cattle are less tolerant than sheep, pigs and poultry to excess molybdenum** Could even be tolerated in the long term, depending on site-specific factors such as nutritional interactions and water requirement
> 0.02	**Adverse chronic effects such as inco-ordination and infertility, and acute effects such as persistent diarrhoea are likely, although** short-term exposure could be tolerated depending on site-specific factors (see above)

Note: Actual water intake level and subsequent ingestion of molybdenum can vary significantly between species and production systems; see **Characterisation of Use**.

High molybdenum concentrations in water are only likely in areas subjected to industrial or other pollution.

Sources of Information

APHA 1992. *Standard Methods for the Examination of Water and Waste Water*, 18th Edition. American Public Health Association, American Water Works Association, Water Environment Federation. Published by the American Public Health Association, Washington DC, USA.

BERMAN E. 1980. *Toxic Metals and Their Analysis*. Heyden, London.

BOWEN H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

ENSMINGER M.E., J.E. Olfield and W.W. Heinemann 1990. *Feeds and Nutrition*, 2nd Edition. The Ensminger Publishing Co., California, 95-239.

FORD W.E. and E.S. Dana 1963. *A Textbook of Mineralogy*, 4th Edition. John Wiley & Sons Inc., New York.

LITTLE D.A. 1982. Utilization of Minerals, In: *Nutritional Limits to Animal Production from Pastures*. Hacker, J.B. (ed.). Commonwealth Agricultural Bureaux, Slough, England, 259-283.

MACDOWELL L.R. 1992. *Minerals in Animal and Human Nutrition*. Academic Press, Inc., New York.

McKEE J.E. and H.W. Wolf 1963. *Water Quality Criteria*, 2nd Edition. California State Water Resources Control Board, Publication No. 3-A. California.

MILLER W.J. 1979. *Dairy Cattle Feeding and Nutrition*. Academic Press, Inc. California, USA, 95-180.

MINSON D.J. 1990. *Forage in Ruminant Nutrition*. Academic Press, Inc. California, USA, 208-395.

NRC 1980. *Mineral Tolerance of Domestic Animals*. National Academy Press, Washington DC.

NRC 1984. *Nutrient Requirements of Sheep*, 6th Revision, Ed. National Academy Press, Washington DC.

NRC 1985. *Nutrient Requirements of Cattle*, 5th Revision, Ed. National Academy Press, Washington DC.

SPEARS J.W. 1994. Minerals in Forages, In: *Forage Quality, Evaluation and Utilization* (1994). Fahey, G.C. (ed.). American Society of Agronomy, Inc., Madison, Wisconsin, USA, 281-307.

UNDERWOOD E.J. 1981. *The Mineral Nutrition of Livestock*. Commonwealth Agricultural Bureaux, 31-176.

WEAST R.C. 1979. *CRC Handbook of Chemistry and Physics*, 60th Edition. CRC Press Inc., Boca Raton, Florida, USA.

Nickel

Background Information

Introduction Nickel is a silvery-white, hard metal which is somewhat magnetic and occurs most commonly as a sulphide ore. Nickel is considered an essential trace element in animal nutrition and is thought to be involved in nucleic acid metabolism. Pasture concentrations of nickel are usually 0.5 - 3.5 mg/kg DM and the concentrations in wheat are approximately 300 - 600 µg/kg DM.

Occurrence Nickel is widespread in the environment, with a slightly higher occurrence than copper in the earth's crust and tends to be concentrated in particles of manganese oxide in soils. Nickel occurs together with iron as a major constituent of most meteorites. Nickel minerals include sulphides and arsenides. Important minerals are millerite (NiS), niccolite (NiAs) and chloanthite ($NiAs_2$). The common state in water is the oxidised state Ni^{2+}. Most of the nickel released globally is from the burning of fossil fuels. Nickel is insoluble in water and other common solvents. Most soils tend to tie up relatively large quantities of nickel.

Typically, the concentration of nickel in unpolluted water is 0.0005 mg/ℓ and approximately 0.0006 mg/ℓ in sea water. Higher concentrations may be found around mines where the ores contain nickel. Nickel is used for manufacturing a variety of alloys and is widely used for making coins, in armour plate and for burglar-proof vaults. Nickel compounds are also used for the catalytic properties in the chemical industry and in the hydrogenation of fats in the manufacturing of margarine.

Accumulation of nickel can occur in certain plants and well as in sediments as the sulphide.

Interactions Metabolically, nickel interacts with rhodium and **iron**. The reaction of nickel in soil is affected by soil pH, organic matter content and oxidation-reduction status of the soil. At pH more than 6.5, nickel is only slowly available to plants. Nickel has a tendency to chelate in the presence of organic matter.

Measurement The criteria are given in terms of the total nickel concentration, in mg/ℓ. Total nickel is normally measured by atomic absorption spectrometry after acidification of the sample. If other methods are used for the measurement of nickel, the characteristics relative to the reference method should be known.

Data Interpretation Mean values should be used to compare with the criteria given.

Treatment Options Nickel can be removed from water by precipitation at alkaline pH, with lime, or by flocculation and coprecipitation with a ferric salt. Alternatively, ion exchange can be used. The waste stream produced will have elevated levels of nickel and will require appropriate disposal.

The Effects of Nickel

Norms The norms used in the guideline are based on the toxicological effects associated with the ingestion of nickel in water consumed by livestock.

Effects Nickel is relatively non-toxic and absorption following oral ingestion is poor. Growth reductions have been recorded in calves with a 250 mg/kg addition of nickel salts to the diet while 100 mg/kg DM does not adversely affect performance of lactating dairy cattle. Nickel acetate at a concentration of 5 mg/R had no observable effect in rats, but the same concentration of nickel chloride increased mortality in third-generation pups and the number of runts.

Iron deficiency increases nickel absorption and, conversely, high nickel levels decrease iron concentrations in tissues. Nickel is thought to be involved in Fe(III) absorption and not Fe(II). Zinc, mercury and calcium also impair nickel absorption, since they are antagonists to nickel.

Physiological symptoms of nickel deficiency have been observed in chicks, rats and pigs under laboratory conditions.

Mitigation Suspected cases of nickel intoxication should be confirmed by *post mortem* analyses. If positive, ingestion of contaminated waters should be limited to stock which are destined for slaughter or weaner markets. Copper supplementation is alleviatory, but dependant on adequate dietary iron levels.

Criteria **Effects of Nickel on the Health of Livestock**

Nickel Range (mg/R)	**Effects**	
	Pigs	**All other livestock**
Target Water Quality Range 0 - 1	**" "**	**" "**
2 - 5	**" "**	**" !**
5 - 10	**" !**	**! !**
> 10	**! !**	**! !**

" " *No adverse effects*

" ! **Adverse chronic effects such as reduced growth may occur, but are unlikely if**
- feed concentrations are normal, and
- exposure is short term

Could even be tolerated in the long term, depending on site-specific factors such as nutritional interactions and water requirement.

! ! **Adverse chronic (as above) and acute effects such as possible adverse reproductive effects may occur, although** short-term exposure may be tolerated depending on site-specific factors such as nutritional interactions and water requirement.

Note: Actual water intake level and subsequent ingestion of nickel can vary significantly between species and production systems; see **Characterisation of Use**.

Sources of Information

BERMAN E. 1980. *Toxic Metals and Their Analysis*. Heyde, London.

BOWEN H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

CUNHA T.J. 1977. *Swine Feeding and Nutrition*. Academic Press, Inc. California, USA, 184-187.

FORD W.E. and E.S. Dana 1963. *A Textbook of Mineralogy*, 4th Edition. John Wiley & Sons Inc., New York.

ELSENHANS B., K. Schumann and W. Forth 1991. Toxic Metals: Interactions with Essential Minerals, In: *Nutrition, Toxicity and Cancer*. Rowland, I.R. (Ed.). CRC Press, Inc. USA, 197-222.

MILLER W.J. 1979. *Dairy Cattle Feeding and Nutrition*. Academic Press, Inc. California, USA, 95-180.

SPEARS J.W., R.W. Harvey and L.J. Samsell 1986. Effects of Dietary Nickel and Protein on Growth, Nitrogen Metabolism and Tissue Concentrations of Nickel, Iron, Zinc, Manganese and Copper in Calves. *J. Nutr.*, 116: 1873.

SPEARS J.W., E.E. Hatfield and G.C. Fahey 1978a. Nickel Depletion in the Growing Ovine. *Nutr. Rep. Int.*, 18: 621.

UNDERWOOD E.J. 1981. *The Mineral Nutrition of Livestock*. Commonwealth Agricultural Bureaux, 31-176.

WEAST R.C. 1979. *CRC Handbook of Chemistry and Physics*, 60th Edition. CRC Press Inc., Boca Raton, Florida, USA.

Nitrate/Nitrite

Background Information

Introduction

Nitrate is the end product of the oxidation of ammonia or nitrite. Nitrate (NO_3^-) and nitrite (NO_2^-) are the oxyanions of nitrogen in which nitrogen is found in the +V and +III oxidation states respectively. Nitrates and nitrites occur together in the environment and interconversion readily occurs. Under oxidising conditions nitrite is converted to nitrate, which is the most stable *positive* oxidation state of nitrogen and far more common in the aquatic environment than nitrite.

Nitrate in water used by livestock is of concern, in that it can be readily converted in the gastrointestinal tract to nitrite, as a result of bacterial reduction.

Occurrence

Mineral deposits of nitrates are rare due to the high water solubility of nitrates, although large deposits of sodium nitrate (saltpetre) occur in the desert regions of Chile. Nitrates are ubiquitous in soils and in the aquatic environment, particularly in association with the breakdown of organic matter and eutrophic conditions.

Concentrations of nitrate in water are typically less than 5 mg/R of nitrate-nitrogen (or, alternatively, 22 mg/R nitrate). A significant source of nitrates in natural water results from the oxidation of vegetable and animal debris and of animal and human excrement. Excessive use of nitrogen fertilizers for crops and pastures results in high concentrations of nitrate in runoff water. Treated sewage wastes also contain elevated concentrations of nitrate.

Nitrate tends to increase in shallow ground water sources in association with agricultural and urban runoff, especially in densely populated areas. Nitrate together with phosphates stimulates plant growth. In aquatic systems elevated concentrations generally give rise to accelerated algae growth and the occurrence of algal blooms.

Interactions

Interactions with nitrate are present with all conditions associated with the presence or breakdown of organic matter. For example, enrichment of waters with dissolved organic carbon can increase the rate of denitrification by providing an energy source for the denitrifying bacteria. The processes of nitrification, denitrification and the active uptake of nitrate by algae and higher plants are regulated by temperature and pH.

When dealing with high concentrations of nitrate/nitrite in water used by livestock, the interrelationships between nitrogen, nitrate-nitrogen content and nitrate toxicity of the pasture must be taken into account. Nitrogen-related health problems can often be attributed to a wasteful use of nitrogen fertilizer. This is well documented for certain forages, such as Midmar ryegrass (*Lolium multiflorum*, cv. Midmar) and Kikuyu grass (*Pennisetum clandestinum*). Unadapted and hungry animals should not be allowed free access to highly-fertilized pastures.

Measurement

The criteria are given in terms of nitrate concentration, in units of mg/R. The reference method for determining the sum of the nitrate and nitrite concentration is by the cadmium reduction method followed by diazotisation. Nitrite alone can be determined by diazotisation without prior reduction of the nitrate present to nitrite. Where other methods are used, their characteristics relative to the reference method should be known.

Data Interpretation

Single-sample maximal values should be used to compare with the numeric criteria given and should be interpreted as maximum values not to be exceeded. Transient elevations of nitrate and nitrite concentrations above the criteria limits are of less importance than continuously elevated concentrations. Where water is well-oxygenated, it can be assumed that the nitrate plus nitrite nitrogen concentrations are largely due to the presence of nitrate. Nitrite concentrations only become significant in deoxygenated systems. The concentration of nitrate/nitrite in pastures should also be taken into account.

Treatment Options

Nitrate is not readily removed from water supplies. Some reduction of nitrate may be achieved using slow sand filtration, but the method is not reliable. Biological reduction of nitrate to nitrogen gas (denitrification) is feasible in the presence of a suitable carbon source, but the increase in carbonaceous matter is not compatible with a high quality water supply. Non-specific methods of removing nitrate include:

! Passing the water stream through an **ion exchange** column with a selective affinity for nitrates. The method is expensive because other anions will be removed at the same time, depending on the nature of the resin used.

! **Reverse osmosis** will remove nitrate effectively from water, along with high percentages of virtually all other ions and many organic compounds.

On a commercial scale, the processes described require competent operation, control and maintenance.

The Effects of Nitrate and Nitrite

Norms

The norms used in the guideline for nitrate and nitrite are based on the toxicological and palatability effects associated with nitrate in water used by livestock.

Effects

Nitrate does not cause direct toxic effects, but its reduced form, nitrite, does and is 10 - 15 times more toxic than nitrate. Nitrite is formed through the biological reduction of nitrate in the rumen, and ruminants are therefore susceptible to nitrite poisoning. The same process occurs in the caecum of horses. They are therefore also susceptibility to nitrite toxicity due to the ingestion of nitrate, although less so than ruminants, but more so than monogastrics.

It is essential to adapt livestock to water with elevated nitrate concentrations, in order to avoid poisoning by nitrite. If unadapted animals are suddenly exposed to too high nitrate/nitrite levels, the rumen is unable to "detoxify" (reduce NO_2 to ammonia), whereas adapted animals cope without any signs of adverse effects. However, there is a large variation in adaptation to high nitrate levels, as is ascribed to the microbial species present in the rumen and their relative differences in further reducing nitrite to ammonia. Non-ruminants are less susceptible, as conversion to nitrite is limited (saliva and intestinal flora) to approximately five percent of that of ruminants.

Nitrite oxidises haemoglobin to methaemoglobin which, unlike haemoglobin, cannot transport oxygen in body tissues. Poisoning results in suffocation due to lack of oxygen in the tissues and the mucous membranes are often visibly "brownish" in colour due to the presence of methaemoglobin. Nitrites also cause vasodilation of the capillary bed and thus a profound drop in blood pressure, which can cause death, even without excessive amounts of methaemoglobin being formed. Nitrite can cross the placental barrier; the haemoglobin of foetuses is more susceptible to toxic effects, and abortions may result. Nitrite is not usually found in milk.

Symptoms of acute nitrate toxicity in non-ruminants include clinical signs of restlessness, frequent urination, dyspnoea and cyanosis. Advanced stages may include vomiting, ataxia, convulsions, inability to rise and death. Symptoms of methemoglobinemia include weakness, ataxia, hypersensitivity, dyspnoea, rapid pulse rate, increase in respiration and urination and cyanosis. Acute nitrate poisoning in ruminants may manifest itself within two to three hours after ingestion. Chronic poisoning is associated with a decrease in methemoglobinemia within one week due to rumen micro-organism adaptation.

Nitrate in the diet can lead to a decreased feed intake due to adverse effects on palatability. Nitrite buildup in the rumen has been implicated in reducing the digestibility of forages. Adverse palatability effects have also been observed. Interactions with ionophores may be important in feedlot situations (microbial population shifts). Nitrate toxicity in ruminants appears to be inversely correlated to the TDS and sulphate concentrations. This involves micro-organism adaptation. Nitrogen supplementation responses depend on concurrent sulphur supplementation.

Mitigation

After an adaption period, ingestion of water with a high nitrate concentration is less dangerous. Ingestion of carbohydrate supplements in high quality forages increases nitrite reduction in the rumen and thus prevents methemo-globinemia.

Criteria

Effects of Nitrate on the Health of Livestock

Nitrate Range (mg/R)	**Effects**			
	Non-pregnant ruminants	**Pregnant ruminants**	**Non-pregnant monogastrics**	**Pregnant monogastrics**
Target Water Quality Range 0 - 100 (NO_3)	" "	" "	" "	" "
100 - 200	**" "**	**" "**	**" !**	**! !**
200 - 400	**" !**	**! !**	**! !**	**! !**
> 400	**! !**	**! !**	**! !**	**! !**

" " *Target Water Quality Range. No adverse effects.*

" ! **Adverse effects such as restlessness, frequent urination, dyspnoea, cyanosis associated with methaemoglobinemia and decreased feed and water intake associated with adverse palatability effects may occur, but can be tolerated if**

- feed concentration is normal;
- there is adequate carbohydrate intake; and
- exposure is short term.

Could even be tolerated in the long term depending on site-specific factors such as nutritional interactions, adaptation of micro-organisms and water requirement.

! ! **Adverse chronic effects (as above) and acute effects such as severe gastroenteritis in non-ruminants and acute methaemoglobinemia in ruminants (severe dyspnoea and cyanosis) may occur**. May be tolerated under certain conditions, depending on site-specific factors such as nutritional carbohydrate levels, TDS and sulphate concentrations in the water, and the type of micro-organisms present in the rumen.

Note: Actual water intake level and subsequent ingestion of nitrate can vary significantly between species and production system; see **Characterisation of Use**.

Sources of Information

APHA 1992. *Standard Methods for the Examination of Water and Waste Water*, 18th Edition. American Public Health Association, American Water Works Association, Water Environment Federation. Published by the APHA, Washington DC, USA.

CANADIAN WATER QUALITY GUIDELINES 1987. *Canadian Water Quality Guidelines*, Canadian Council of Resource and Environment Ministers. Ottowa.

CUNHA T.J. 1977. *Swine Feeding and Nutrition*. Academic Press, Inc. California, USA, 184-187.

ECKARD R.J. 1990. The Relationship between Nitrogen and Nitrate Content and Nitrate Toxicity Potential of *Lolium Multiflorum*. *J. Grassl. Soc. South. Afr*. 7(3): 174-178.

ENSMINGER M.E., J.E. Olfield and W.W. Heinemann 1990. *Feeds and Nutrition*, 2nd Edition. The Ensminger Publishing Co., California, 95-239.

FORD W.E. and E.S. Dana 1963. *A Textbook of Mineralogy*, 4th Edition. John Wiley & Sons Inc., New York.

LEESON S. and J.P. Summers 1991. *Commercial Poultry Nutrition*. University Books, Canada, 61-63.

LITTLE D.A. 1982. Utilization of Minerals, In: *Nutritional Limits to Animal Production from Pastures*. Hacker, J.B. (ed.). Commonwealth Agricultural Bureaux, Slough, England, 259-283.

MACDOWELL L.R. 1992. *Minerals in Animal and Human Nutrition*. Academic Press, Inc., New York.

MILLER W.J. 1979. *Dairy Cattle Feeding and Nutrition*. Academic Press, Inc. California, USA, 95-180.

MORRISON M., A.N. Boniface and R.M. Murray 1990. Nutrient Metabolism and Rumen Microorganisms in Sheep Fed a Poor-quality Tropical Grass Hay Supplemented with Sulphate. *J. Agric. Sci. Camb*., 115: 269-275.

NRC 1980. *Mineral Tolerance of Domestic Animals*. National Academy Press, Washington DC.

NRC 1984. *Nutrient Requirements of Sheep*, 6th Rev., Ed. National Academy Press, Washington DC.

NRC 1985. *Nutrient Requirements of Cattle*, 5th Rev., Ed. National Academy Press, Washington DC.

SPEARS J.W. 1994. Minerals in Forages, In: *Forage Quality, Evaluation and Utilization* 1994. Fahey, G.C. (ed.). American Society of Agronomy, Inc., Madison, Wisconsin, USA, 281-307.

UNDERWOOD E.J. 1981. *The Mineral Nutrition of Livestock*. Commonwealth Agricultural Bureaux, 31-176.

WORLD HEALTH ORGANIZATION 1984. *Guidelines for Drinking Water Quality*, Volume 2: Health Criteria and Other Supporting Information. WHO, Geneva.

Pathogens

Tentative Guideline

Background Information

Introduction

Microbial populations vary in both number and kind, depending on the source of the water, the microbial nutrient status, and the geographical, biological and climatic conditions.

Occurrence

Faecal pathogens are excreted by healthy animals and form part of the natural flora of their faeces. They form only a small fraction of the microbial flora of the gut of healthy animals and many non-pathogenic and facultative pathogens are also present.

If the coliform count is too high, the bacteria of concern are usually those belonging to the *Enterobacteriacae* family, which includes pathogenic forms of *Escherichia coli* and *Salmonella spp*. Alternatively, waterborne diseases may indicate specific symptoms of infection or toxicity and may be due to:

- *Clostrium botulinum* which causes Botulism;
- *Bacillus anthracis* which causes Anthrax;
- *Leptospira*; and
- *Corynebacterium*.

Several natural processes in aquatic systems such as sedimentation, adsorption, coagulation and flocculation may remove pathogenic micro-organisms from the water without inactivation, and may even provide protection for the organisms from extreme environmental pressures. These processes are significant since subsequent release of organisms may cause an apparent increase in the microbial population.

Interactions

Numerous physical, chemical and biological factors influence the rate of die-off or disappearance of micro-organisms in water. Among the most significant are the organism and its physiological state, sunlight, temperature, pH, salinity, competition, predation, algae, nutrient deficiencies, toxic substances, organism density in the discharge, settling of organisms after discharge, resuspension of particulates and multiplication of organisms in the water body. Extremes in pH, elevated temperatures and solar radiation promote microbial decay, while elevated nutrient concentrations and lower temperatures promote microbial survival. Polluted water may contain enough nutrients to support the growth of some bacterial organisms, especially in temperate waters.

Micro-organisms demonstrate increased survival in sediments and when aggregated to particles, possibly due to reduced predation and parasitism. The nature and stability of such aggregates are highly dependent on environmental conditions and the physical and chemical nature of the particles.

Measurement

In this guideline, faecal coliforms are used as indicator bacteria, to test for the possible presence of pathogens. They are usually enumerated as counts (number of colonies)/100 mR of water. Water samples must be refrigerated immediately after collection and should be analysed within 24 hours. Analysis may be by membrane filtration (0.45 Fm diameter pore size), pour plates or by multiple tube fermentation techniques. Faecal coliform bacteria are all bacteria which produce typical blue colonies on m-FC agar within 20 - 24 hours of incubation at 44.5 EC. *Escherichia coli* are considered to be all the faecal coliforms which test indole-positive at 44.5 EC.

Data Interpretation

Strictly, faecal coliform indicators should be used to indicate the presence of bacterial pathogens only. However, they are widely used to indicate the microbial quality of water in general, which includes viruses and parasites.

None of the above mentioned organisms can be used as reliable indicators for the presence of protozoan parasites in water.

Treatment Options

Several conventional water purification processes including sedimentation, absorption, coagulation and flocculation will all result in the partial removal of micro-organisms in water. These processes, however, do not necessarily inactivate the micro-organisms and additional disinfection processes need to be applied. Chlorine disinfection is often practised. Disinfection, however, requires careful process control of the disinfection species, dosage and contact time.

The Effects of Pathogens

Norms

The guideline for faecal coliforms is primarily based on the toxicological effects associated with the ingestion of waterborne pathogens in water used by livestock.

Effects

Many microbes in a given water source are non-pathogenic. It is therefore essential to determine the presence of any microbes which are potentially pathogenic. That may include *Escherichia spp*., *Clostridia spp*., *Brucella spp*., *Salmonella spp*. and *Leptospira spp*.

Adverse effects usually occur in young stock. The risk of infection in intensive production systems such as piggeries and poultry houses, where the ratio of young : mature animals is high, is far greater than with extensive production systems.

Mitigation

Contamination of the water source contributes significantly to the spread of infectious diseases. Management of water quality can therefore form a valuable defence against such diseases.

If water contains bacterial pathogens, withholding the water for 48 hours and/or the administration of an effective disinfectant such as chlorine may be sufficient.

Avoiding oxygen depletion and the formation of anaerobic conditions is important as temporary or permanent anaerobic water may be dangerous, mainly due to the potential of *Clostridia* infections under these conditions. Parasitic protozoa can cause livestock losses, mainly due to direct spread among animals, but also through water. The most effective method is the removal of the livestock from the water source, so as to interrupt the organism's lifecycle.

Criteria **Effects of Faecal Coliforms on the Health of Livestock**

Faecal coliform count (counts/100 mℓ)	**Effects**	
	Young livestock, swine and poultry	Mature livestock
Target Water Quality Range ***0 - 200*** ***0 - 1 000 for < 20 % of the samples***	***No adverse effects***	***No adverse effects***
200 - 1 000 1 000 - 5 000 for < 20 % of the samples	Significant risk of infection	No adverse effects likely
200 - 1 000 for > 50 % of the samples	Samples must be scanned to determine species present, before allowing stock access Significant risk of infection	Significant risk associated with use
1 000 - 5 000 for > 50 % of the samples	Samples must be scanned to determine species present, before allowing stock access Significant risk of infection	Significant risk associated with use

Sources of Information

BATH G. Herd Health, Onderstepoort Faculty.

HENTON M. Bacteriology Section, Onderstepoort Veterinary Institute.

Pesticides

Tentative Guideline

Background Information

Introduction Pesticides are a large group of mainly organic compounds or, in some cases, organometallic compounds, that are used to control pests. The target organisms may be insects, weeds or undesirable animals. Pesticides vary widely in composition and in their ability to persist in the environment. The organophosphate pesticides cause acute toxicities, but break down rapidly in the aquatic environment. The more persistent pesticides, such as DDT, which are chemically relatively stable, can remain in the environment for decades. Pesticides and their breakdown products also vary tremendously in their effects on non-target species and hence, in general toxicology.

Pesticides considered of importance as potential contaminants to water sources are:

- *Alachlor:* A herbicide used to control annual grasses and weeds.
- *Aldicarb*: A systemic pesticide used to control soil nematodes, mites and insects. Aldicarb is highly water solubility, mobile in soils and can contaminate ground water.
- *Aldrin and Dieldrin:* Highly persistent organochlorine pesticides that *may still* occur in water, despite severe restriction or banning of their use. Aldrin rapidly converts to dieldrin under most conditions, which then persists.
- *Atrazine:* A persistent triazine herbicide, often found in low concentrations in water, but due to its high solubility able to contaminate surface waters.
- *Bentazone:* A broad spectrum herbicide; highly mobile in soil; readily contaminates ground water.
- *Carbofuran:* An acaricide, nematocide and insecticide which can leach from soils and appears in ground water.
- *Chlordane:* A very persistent insecticide which is strongly bound in soil and, consequently, not often found in water.
- *Chlorotoluron:* A slowly biodegradable herbicide, mobile in soil and, consequently, appears in water sources.
- *DDT:* A persistent insecticide with limited solubility in water and tends to be absorbed into any particulate matter present in water .
- *2,4-Dichlorophenoxy acetic acid (2,4-D):* A herbicide used to control broad leaf weeds. Other chlorophenoxy herbicides are *MCPA; 2,4-DB; dichloroprop; fenoprop; MCPB; mecoprop and 2,4,5-T*. MCPA is very soluble in water and highly mobile, but has low persistence. The remaining chlorophenoxy herbicides have relatively short half-lives, in the order of several days.
- *1,3-Dichloropropane:* A soil fumigant that can contaminate water.
- *1,3-Dichloropropene:* A soil fumigant and potential water contaminant due to its high solubility.

- *Ethylene dibromide (EDB):* An insecticidal fumigant; its solubility and resistance to degradation make it a potential water contaminant.

- *Heptachlor and heptachlor epoxide:* Broad spectrum persistent insecticides, bound to soil, but may migrate slowly and contaminate water supplies.
- *Hexachlorobenzene (HCB):* A selective fungicide; persistent and strongly adsorbed to soil. Consumption of contaminated food is the major source of exposure to HCB.
- *Isoproturon:* A selective herbicide, moderately biodegradable, mobile in soil and can contaminate water sources.
- *Lindane:* A persistent insecticide used as a wood preservative. It is a ubiquitous environmental contaminant also detected in water.
- *Methoxychlor:* A general insecticide poorly soluble in water, immobile in most soils and not often found in water.
- *Molinate:* A herbicide used for weed control in rice. Ground water pollution is restricted to rice-growing regions.
- *Pendimethalin:* A pre-emergence herbicide that is fairly persistent, but immobile in soil. Is not often found in water.
- *Pentachlorophenol:* A wood preservative which may contaminate surface and ground water.
- *Permethrin:* A widely used synthetic pyrethroid insecticide that has a strong affinity for soil and sediments.
- *Propanil:* A contact herbicide used mainly on rice crops. It is mobile in the water environment but not persistent.
- *Pyridate:* A non-persistent herbicide, rapidly hydrolysed and biodegraded and not often found in water.
- *Simazine:* A persistent pre-emergence herbicide, which is stable and persistent in the environment. Often found in ground and surface waters in the low µg/l range.
- *Trifluralin:* A herbicide with low water solubility and a high affinity for binding to soil.

Occurrence

The occurrence of pesticides in the aquatic environment is related to

- the amount, degree and type of pesticides used;
- exposure to rain and the proximity to water sources;
- the ease of mobility of the pesticide in the environment and whether the pesticide adsorbs strongly to soil particles or moves freely through the soil profile;
- the breakdown rate of the pesticide, and site-specific factors which either retard or accelerate the breakdown rate;
- the water solubility of the pesticide, which will determine partitioning between the dissolved phase and adsorption onto inorganic suspended matter or sediments; and
- the lipid solubility of the pesticide which will relate to uptake rate by organic matter and micro-organisms in the water.

The fate of pesticides in the aquatic environment depends strongly on the stability, breakdown mechanisms and products of the specific pesticide in question. Pesticides can be broken down by a variety of mechanisms, such as hydrolysis, photolysis and microbiological degradation. Hydrolysis rates in general are influenced by pH.

Individual properties of pesticides will also determine whether there is an affinity for soil or water.

Interactions

Pesticides can show considerable interactions with other water constituents. Any oily substances present will affect the water solubility of pesticides. For those pesticides that have an affinity for soil, adsorption will occur to the suspended particulate matter.

Measurement

Pesticide concentrations are normally given in units of µg/ℓ. Pesticides are usually measured by a chromatographic technique, the definitive methods being those using gas chromatography and mass spectrometric measurement.

Data Interpretation

In interpreting pesticide data, it is helpful to know typical background values for the particular environment or catchment being studied, as well as comparative data for similar circumstances and conditions. *Where mass spectrometry has not been used in the determination of pesticide concentrations, considerable caution should be exercised in the interpretation of the results.*

Treatment Options

Pesticides form a diverse group of compounds related more by their uses than their chemical formulations. As such, treatment methods for their removal may differ from one to another. However, the more commonly -used pesticides can be effectively removed from water by passing it through a granular activated carbon column. These include:

- Aldrin;
- Dieldrin;
- Atrazine;
- Chlordane;
- 2,4-D;
- DDT;
- Heptachlor; and
- Lindane

The filtered water requires monitoring to ensure that removal is complete. The carbon may be stripped of certain pesticides by steaming.

Methods currently being investigated use ozone or Peroxone for oxidative destruction of the compound.

The Effects of Pesticides

Norms

The norms used in the guideline are based on the toxicological effects of pesticides associated with the ingestion of water consumed by livestock and the effects of product contamination.

Effects

Although mammals generally have a greater tolerance to pesticides than birds or fish, increasing concentrations resulting from the growing use of pesticides, notably insecticides in agriculture, can have adverse effects on livestock. There is a possibility of adverse interactions between pesticides and drugs used in animal feeds.

Organophosphate and carbamate pesticides cause, among other symptoms, salivation, excessive urination, diarrhoea, respiratory problems and muscle tremors, which may be followed by restlessness and weakness. Chlorinated hydrocarbon pesticides cause severe nervous stimulation and locomotory disturbances.

The primary problem with pesticides is unacceptable residues in animal products. Fish are used as indicators to monitor pesticides in water supplies.

Mitigation It is very difficult to mitigate against the ingestion of pesticides.

Criteria **Target Water Quality Ranges for some Pesticides and Herbicides**

Pesticide	Target Water Quality Range (μg/ℓ)*
Chlorinated Hydrocarbons:	
Aldrin	1
Chlordane	3
DDT	50
Dieldrin	1
Endrin	0.5
Heptachlor	0.1
Lindane (BHC)	5
Methoxychlor	1 000
Toxaphene	5
Organophosphates:	
Parathion	100
Malathion	100
Herbicides:	
2.4 -D	20
2.4.5-T	2
2,4,5-TP	30

* Based on Kempster *et al.*, (1980).

Sources of Information

WORLD HEALTH ORGANIZATION 1993. *Guidelines for Drinking Water Quality*, 2nd Edition, Volume 1: Recommendations, World Health Organization, Geneva.

KEMPSTER, *et al*. 1980. Summarized Water Quality Criteria, Department of Water Affairs, Forestry and Environmental Conservation, Technical report TR108, Pretoria.

Selenium

Tentative Guideline

Background Information

Introduction

Selenium is a semi-metallic element with pronounced photoconductivity. At low concentrations it is an essential nutritional micro-element in humans and animals, and is an integral part of the enzyme glutathione peroxidase.

Occurrence

Selenium occurs in association with sulphide ores of heavy metals such as copper, iron and zinc, and is found in various oxidation states. Selenium forms insoluble metal selenides, which tend to be incorporated into sediments, particularly under anaerobic conditions. Selenium is also bioaccumulated by certain plants consequently used as indicators in the bio-measurement of selenium. Typically, the concentration of selenium in surface water is less than 10 Fg/R. Elevated concentrations can occur in ground waters in seleniferous areas, which do not occur in South Africa.

Selenium is used in a variety of industrial processes. It is used in the manufacture of glass and ceramics, ink and paint pigments, plastics, rubber, photoelectric cells and various alloys.

Interactions

The chemistry of selenium is similar to that of **sulphur**. Metabolically, selenium interacts with **sulphur, iron** and **arsenic**, as well as with metals such as **copper**, **cadmium** and **mercury**.

Measurement

The criteria are given in terms of the total selenium concentration, in units of mg/R. The reference method for the determination of selenium is atomic absorption spectrometry. Prior to analysis, digestion of the sample followed by reduction of Se(VI) to Se(IV) with hydrochloric acid and the formation of selenium hydride using a borohydride reagent is required. If other methods of measuring selenium are used their characteristics relative to the reference method should be known.

Data Interpretation

Single-sample values should be used to compare with the criteria given and should be interpreted as maximal values, not to be exceeded. The total dietary intake of selenium is relevant in the interpretation of the possible effects of a given concentration of selenium in water.

Treatment Options

Selenium in water supplies is most effectively removed by one of two processes:

- Coagulation and precipitation by treatment with lime or ferric chloride at pH values greater than 8.5. Careful monitoring is needed to ensure effective removal.

- Adsorption onto activated alumina at low pH levels.

The processes involved require skilled operation and process control. Both processes produce a waste stream that may be rich in selenium, presenting disposal difficulties.

The Effects of Selenium

Norms The norms used in the guideline are based on the toxicological effects associated with the ingestion of selenium in water used by livestock.

Effects Generally, naturally-occurring deficiencies of selenium in livestock are more commonly encountered than selenium toxicity. Selenium is also one of the most potentially toxic minerals commonly supplemented for.

Generally, a selenium concentration range of 100 - 300 Fg/kg is accepted as sufficient to prevent deficiency. The FDA recommends feeding (supplements) consumption rates of 0.7 mg/h/d for sheep and three mg/h/d for cattle, and a limit in fortification of salt mineral mixtures for sheep and cattle of 90 and 120 mg/kg, respectively. Adequate levels in pastures are given as 100 - 300 µg/kg dry mass (DM).

Selenium concentrations in plasma, whole blood and RBCs and the level of blood glutathione peroxidase are used to assess the selenium status. Plasma/serum concentrations of 0.07 - 0.1 µg/R indicate adequacy in dairy cattle.

Absorption of selenium occurs mainly in the duodenum, and excretion of absorbed selenium takes place primarily through the kidneys. Increases in the bloodstream concentration of selenium do not appear to result in concurrent increases in the milk. Selenium is protective against the adverse effects of arsenic, cadmium and mercury, and is also thought to be anti-carcinogenic. Selenium plays a role in the breakdown of toxic polyunsaturated fats. Since vitamin E prevents the formation of polyunsaturated fats, an interrelationship between selenium and vitamin E exits.

Organic selenium (usually selenomethionine) in forages may affect the selenium status differently from supplemental selenium (selenite) as it is absorbed more efficiently than selenite and can be incorporated into non-specific body proteins in place of methionine. Selenium supplementation for deficiency is often as a free choice mineral supplement, a three-monthly injection or fertilizing of cultivated pastures.

Selenium deficiency is called *white muscle disease* in cattle, *stiff lamb disease* in sheep, *liver necrosis* in pigs and *exudative diathesis* in poultry. The clinical signs resulting from deficiency result from degeneration and necrosis in skeletal and cardiac muscle. The maximum tolerable selenium concentration is approximately 2 mg/kg diet. Toxic concentrations occur at 0.5 mg/kg in soil and 10 mg/kg in the diet.

Table of Maximum and Toxic Concentrations of Selenium for Livestock (NRC, 1980)

Livestock	Maximum total recommended by US FDA (mg/head/d)	Toxic level in feed (mg/kg)	Toxic level (mg/head/d)
Beef	3	10 - 30	100 - 300
Dairy	2	3 - 5	30 - 60
Sheep	0.7	3 - 20	7 - 50
Swine	-	5 - 10	8 - 16
Chicken	-	2	-
All other species	2 mg/kg	-	-

Young animals are more susceptible to selenium poisoning than adults. Chronic toxicity is called Alkali Disease. Chronic toxicity has been observed with rations containing 8.5 mg Se/kg and symptoms include loss of hair (from the mane and tail in horses, the tail in cattle, and general hair loss in pigs); sloughing off of hooves, lameness, decrease in feed intake and resultant death from starvation.

Acute toxic symptoms are more obvious in cattle than sheep. Initially, locomotory and posture abnormalities and a loss of appetite occur. This is followed by difficult breathing, diarrhoea and signs of abdominal pain and bloat. Death from selenium poisoning is as a result of respiratory failure.

Mitigation

High sulphate concentrations can protect against selenium toxicity by effecting an increased requirement of selenium. Alleviatory treatments of chronic toxicity may include

! high protein rations;
! oral administration of naphthalene, bromobenzene and arsenic compounds; and
! maintenance of a 1:1 ratio of mercury:selenium (inorganic forms).

No treatment is known for acute selenium poisoning.

Criteria **Effects of Selenium on the Health of Livestock**

Selenium Range (Fg/R)	Effects
	All livestock
Target Water Quality Range 0 - 50	***No adverse effects***
50 - 75	**Adverse chronic effects such as a decrease in feed and water intake, weight loss, loss of hair, sloughing off of hooves, lameness and a decline in productivity may occur, but are unlikely if** - feed concentrations are normal, and - exposure is short term. Could even be tolerated in the long term, depending on site-specific factors such as nutritional interactions and water requirement
> 75	**Adverse chronic effects (as above) and acute effects such as diarrhoea, loss of appetite, breathing difficulties, locomotory and posture abnormalities and bloating may occur, although** short term exposure could be tolerated depending on site-specific factors (as above)

Note: ***The criteria should be considered tentative since selenium requirements are not well defined and influencing factors are not well described.***

! *The occurrence of toxicity due to water intake is very rare*.

! Actual water intake level and subsequent ingestion of selenium can vary significantly between species and production systems; see **Characterisation of Use**.

Sources of Information

APHA 1989. *Standard Methods for the Examination of Water and Waste Water*, 17th Edition. American Public Health Association, American Water Works Association, Water Pollution Control Federation. Published by the American Public Health Association, Washington DC, USA.

BOWEN H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

ENSMINGER M.E., J.E. Olfield and W.W. Heinemann 1990. *Feeds and Nutrition*, 2nd Edition. The Ensminger Publishing Co., California, 95-239.

LITTLE D.A. 1982. Utilization of Minerals, In: *Nutritional Limits to Animal Production from Pastures*. Hacker, J.B. (ed.). Commonwealth Agricultural Bureaux, Slough, England, 259-283.

MACDOWELL L.R. 1992. *Minerals in Animal and Human Nutrition*. Academic Press, Inc., New York.

MCKEE J.E. and Wolf H.W. 1963. *Water Quality Criteria*, 2nd Edition. California State Water Resources Control Board, Publication No. 3-A. California.

MILLER W.J. 1979. *Dairy Cattle Feeding and Nutrition*. Academic Press, Inc. California, USA, 95-180.

MINSON D.J. 1990. *Forage in Ruminant Nutrition*. Academic Press, Inc. California, USA, 208-395.

NRC 1980. *Mineral Tolerance of Domestic Animals*. National Academy Press, Washington DC.

NRC 1984. *Nutrient Requirements of Sheep*, 6th Revision, Ed. National Academy Press, Washington DC.

NRC 1985. *Nutrient Requirements of Cattle*, 5th Revision, Ed. National Academy Press, Washington DC.

SPEARS J.W. 1994. Minerals in Forages, In: *Forage Quality, Evaluation and Utilization*, Fahey, G.C. (ed.). American Society of Agronomy, Inc., Madison, Wisconsin, USA, 281-307.

UNDERWOOD E.J. 1981. *The Mineral Nutrition of Livestock*. Commonwealth Agricultural Bureaux, 31-176.

UNDERWOOD E.J. 1977. *Trace Elements in Human and Animal Nutrition*, 4th Edition. Academic Press, New York, USA.

WEAST R.C. 1979. *CRC Handbook of Chemistry and Physics*, 60th Edition. CRC Press Inc., Boca Raton, Florida, USA.

WORLD HEALTH ORGANIZATION 1984. *Guidelines for Drinking Water Quality*, Volume 2: Health Criteria and Other Supporting Information. World Health Organization, Geneva.

Sodium

Background Information

Introduction

Sodium is an alkali metal which reacts with water to form highly soluble, positively charged sodium. It is an essential dietary element important for electrolyte balance and the maintenance of many essential physiological functions. Sodium is present in all food to varying degrees.

Occurrence

Sodium is ubiquitous in the environment and usually occurs as sodium chloride, but sometimes as sodium sulphate, bicarbonate or even nitrate. Sodium is found as solid sodium chloride (rock salt) in areas where geological deposits occur. The levels of sodium in surface water are generally low in areas of high rainfall, and high in arid areas with low mean annual precipitation. Sodium is highly soluble in water and does not precipitate when water evaporates, unless saturation occurs. Hence, water in arid areas often contains elevated concentrations of sodium. High concentrations thereof occur in sea water, at approximately 11 g/ℓ.

Industrial wastes, especially processes that give rise to brines, contain elevated concentrations of sodium. Sodium is also present at high concentrations in domestic waste water. This is in part due to the addition of table salt (sodium chloride) to foods. Furthermore, with re-use or recycling of water, the sodium concentration will tend to increase with each cycle or addition of sodium to the water. For this reason, sodium concentrations are elevated in runoffs or leachates from irrigated soils.

Interactions

Metabolically, sodium interacts with **potassium**. Sodium and potassium are the most important extracellular and intracellular cations respectively, and vital to all living organisms.

Measurement

The criteria are given in terms of the dissolved sodium concentration, in units of mg/ℓ. For all practical purposes this is identical to the total sodium concentration as sodium is usually in the dissolved form, except in supersaturated brines.

The reference method for the determination of sodium is flame photometry, with lithium as the internal standard. If other methods for measuring sodium are used, their characteristics relative to the reference method should be known.

Data Interpretation

Mean values should be used to compare with the numeric criteria given. Sodium concentrations should be interpreted in conjunction with the major cation associated with the sodium ion, usually chloride, sulphate or bicarbonate. However, if present, the concentrations of other cations such as potassium, calcium and magnesium should also be taken into account. The concentration of sodium in the feed should also be known and taken into account.

Treatment Options

It is highly unlikely that sodium can be economically removed from water intended for livestock consumption, especially for extensive production systems. In practice, water with a high concentration of sodium is mixed with water of a better quality (low concentration of sodium), or allotted to non-productive classes of livestock.

However, if removal of sodium is required, it can be removed together with other ions which constitute the **TDS** by the following desalination processes :

- **demineralisation** in a mixed-bed ion exchange column, usually where the feed TDS is up to approximately 2 000 mg/ℓ;
- treatment by **membrane processes** such as reverse osmosis or electrodialysis, where the TDS concentration is in the range of 2 000 - 3 500 mg/ℓ; and
- **distillation**, in cases where the TDS is 10 000 mg/ℓ or more.

Demineralisation by ion exchange can be used to produce low-sodium water on a commercial or industrial scale, using banks of large ion exchange filter beds which are capable of being regenerated.

Large-scale water treatment is achieved by using banks of reverse osmosis modules in parallel.

All of the processes are easily fouled by suspended matter and are prone to scaling with hard waters. All of the processes produce a concentrated waste stream of the salts that may cause disposal difficulties. If used on a large scale, all of the processes require high levels of design, operator and maintenance skills.

The Effects of Sodium

Norms

The norms used in the guideline are primary based on the toxicological and palatability effects associated with ingestion of sodium in water used by livestock.

Effects

Sodium is the principal cation responsible for extracellular osmolality. It plays a vital role in acid-base balance of body fluids and is also involved in a host of other crucial physiological functions. Metabolically sodium interacts mainly with chloride and potassium. Nearly all ingested sodium is absorbed through the intestines and excess sodium (90 % of ingested sodium) is excreted via the kidneys. Sodium is efficiently conserved in the body and its requirement is therefore small. Muscular activity does, however, increase the requirement.

The primary symptom of sodium deficiency is loss of appetite. In very hot areas this is particularly noticeable in cattle. Reduced growth and milk production and a decrease in reproduction may also result.

Decreased palatability and consequent problems tend to occur prior to toxicity effects (see **TDS**). Chronic effects range from a decline in water and feed intake, with subsequent production losses to gastroenteritis and dehydration. Primary hypertension may occur, although this effect is not well documented in livestock. The clinical consequences of primary hypertension depend on the duration and severity of increased arterial pressure. Principally, the heart (left ventricle hypertrophy), brain (intracerebral haemorrhage), eyes and kidneys (renal vascular lesions) are affected over the long term. Acute clinical signs in poultry include excessive thirst, respiratory distress, discharge of fluid from the beak, wet faeces, paralysis of the limbs and generalised tissue edema.

Criteria **Effects of Sodium on the Health of Livestock**

Sodium Range (mg/R)	Effects		
	Sheep	**Cattle**	**All other livestock**
Target Water Quality Range 0 - 2 000	**" "**	**" "**	**" "**
2 000 - 2 500	**" !**	**" !**	**! !**
2 500 - 4 000	**" !**	**" !**	**! !**
> 4 000	**! !**	**! !**	**! !**

" " ***No adverse effects***

" ! **Adverse chronic effects such as reduced feed and water intake with a decline in productivity may occur,** but will most likely be temporary and normal production should continue once stock are adapted (see **TDS**).

! ! **Adverse chronic (as above) and acute effects** (see text) may occur. May be tolerated in the short term depending on site-specific factors such as water requirement.

Note: Actual water intake level and subsequent ingestion of sodium can vary significantly between species and production systems; see **Characterisation of Use**.

Sources of Information

BOWEN H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

CUNHA T.J. 1977. *Swine Feeding and Nutrition*. Academic Press, Inc. California, USA, 184-187.

ENSMINGER M.E., J.E. Olfield and W.W. Heinemann 1990. *Feeds and Nutrition*, 2nd Edition. The Ensminger Publishing Co., California, 95-239.

LEESON S. and J.P. Summers 1991. *Commercial Poultry Nutrition*. University Books, Canada, 61-63.

LITTLE D.A. 1982. Utilization of Minerals, In: *Nutritional Limits to Animal Production from Pastures*. Hacker, J.B. (ed.). Commonwealth Agricultural Bureaux, Slough, England, 259-283.

MACDOWELL L.R. 1992. *Minerals in Animal and Human Nutrition*. Academic Press, Inc., New York.

McKEE J.E. and H.W. Wolf 1963. *Water Quality Criteria*. California State Water Resources Control Board, Publication No. 3-A. California.

MILLER W.J. 1979. *Dairy Cattle Feeding and Nutrition*. Academic Press, Inc. California, USA, 95-180.

NRC 1980. *Mineral Tolerance of Domestic Animals*. National Academy Press, Washington DC.

NRC 1984. *Nutrient Requirements of Sheep*, 6th Revision, Ed. National Academy Press, Washington DC.

NRC 1985. *Nutrient Requirements of Cattle*, 5th Revision, Ed. National Academy Press, Washington DC.

SPEARS J.W. 1994. Minerals in Forages, In: *Forage Quality, Evaluation and Utilization*, Fahey, G.C. (ed.). American Society of Agronomy, Inc., Madison, Wisconsin, USA, 281-307.

UNDERWOOD E.J. 1981. *The Mineral Nutrition of Livestock*. Commonwealth Agricultural Bureaux, 31-176.

WORLD HEALTH ORGANIZATION 1993. *Guidelines for Drinking Water Quality*, 2nd Edition, Volume 1: Recommendations. World Health Organization, Geneva.

WORLD HEALTH ORGANIZATION 1984. *Guidelines for Drinking Water Quality*, Volume 2. Geneva.

Sulphate

Background Information

Introduction

Sulphate is the oxy-anion of sulphur in the VI^+ oxidation state and forms salts with various cations such as potassium, sodium, calcium, magnesium, barium, lead and ammonium. Potassium, sodium, magnesium and ammonium sulphates are highly soluble whereas calcium sulphate is partially soluble and barium and lead sulphates are insoluble.

Sulphur is essential for life, mainly as a component of amino acids, saliva, bile and the hormone insulin. Water with excessive amounts of sulphate is unpalatable and ingestion thereof typically results in diarrhoea.

Occurrence

Sulphate is a common constituent of water and arises from the dissolution of mineral sulphates in soil and rock, particularly calcium sulphate (gypsum) and other partially soluble sulphate minerals. Since most sulphates are soluble in water, and calcium sulphate is relatively soluble, sulphates, when added to water, tend to accumulate to progressively increasing concentrations. Typically the concentration of sulphate in:

- surface water is 5 mg/ℓ, although concentrations of several hundred mg/ℓ may occur where dissolution of sulphate minerals or discharge of sulphate-rich effluents from acid mine drainage takes place; and
- sea water is just over 900 mg/ℓ.

Sulphates are discharged from acid mine wastes and many other industrial processes, such as tanneries, textile mills and processes using sulphuric acid or sulphates. Ion-exchange processes can remove or add sulphate to water and microbiological reduction or oxidation can interconvert sulphur and sulphate. The microbiological processes tend to be slow and require anaerobic conditions usually only found in sediments and soils. Atmospheric sulphur dioxide, discharged on combustion of fossil fuels, can give rise to sulphuric acid in rainwater (acid-rain) and as such, this results in the return of sulphate to surface waters in the environment.

Interactions

The interactions of sulphate are governed by the associated cations, usually **magnesium** and **sodium**.

Measurement

The criteria are given in terms of the dissolved sulphate concentration, in units of mg/ℓ. Dissolved sulphate is normally measured turbidimetrically on precipitation as insoluble barium sulphate. This is the reference method. For rain water, or water with low sulphate concentrations, ion-chromatography is preferentially used. If other methods are used to measure sulphate, their characteristics relative to the reference methods given should be known.

Data Interpretation

Single-sample values should be used to compare with the criteria given. Sulphate concentrations should also be interpreted in conjunction with the major associated cations as well as the pH.

Treatment Options

Sulphate can be removed from water by a variety of processes, including:

- **Precipitation** with calcium or barium salts followed by settlement and filtration to remove the insoluble calcium or barium sulphate. Barium is highly toxic and should not be used for the removal of sulphate from water which will be used for domestic purposes, or which may come into contact with foodstuffs. Calcium salts will not reduce sulphate concentrations to less than 2 000 mg/ℓ. Precipitation is only suitable for industrial application although, more commonly, the method of choice would be ion exchange or membrane treatment.

- **Ion exchange** in an anion exchange column which will remove all anions.

- Any **desalination** technique in which scaling due to insoluble sulphate can be avoided or tolerated. These include

    - **demineralisation** in mixed-bed ion exchange columns;
    - **membrane treatment** by reverse osmosis or electrodialysis; and
    - a range of **distillation** processes.

All of the processes produce a concentrated waste stream or slurry which may cause disposal difficulties. The industrial scale processes require high levels of design, operator and maintenance skills.

The Effects of Sulphate

Norms

The norms used in the guideline are based on the toxicological and palatability effects associated with sulphate in water consumed by livestock.

Effects

Sulphur is principally absorbed in the small intestines and inorganic sulphates are poorly absorbed. Rumen micro-organisms can synthesise all required organic sulphur-containing compounds from inorganic sulphur. Sulphur functions as a component of the sulphur-containing amino acids in various hormones, enzymes and co-enzymes that are involved in fat, carbohydrate and energy metabolism.

Sulphate has an adverse effect on the palatability of water below the concentration that causes acute toxic effects. Sulphate often causes diarrhoea in stock that are unadapted to sulphate waters.

Sulphate can cause diarrhoea and poor productivity in young animals and animals without prior exposure. The degree of sulphate tolerance depends on species, age, adaptation period and the principal cations associated with the sulphate ion. Adverse effects are more likely associated with high concentrations of magnesium and sodium sulphate than calcium sulphate.

The production of ruminal hydrogen sulphide from sulphur can cause severe purgation.

A dietary deficiency of sulphur can depress microbial numbers and reduce microbial digestion and protein synthesis. Adverse effects of deficiency are mainly due to a reduced amount of sulphur-containing amino acids necessary for protein synthesis. Symptoms associated with insufficient dietary sulphur are retarded growth and reduced wool growth.

Mitigation See **TDS**.

Criteria **Effects of Sulphate on the Health of Livestock**

Sulphate Range (mg/ℓ)	Effects
Target Water Quality Range 0 - 1 000	***No adverse effects***
1 000 - 1 500	**Adverse chronic effects may occur, such as** - diarrhoea; - adverse palatability effects (water and feed intake decline); - poor productivity These effects will most likely be temporary and normal production should continue within a few days once the stock are adapted. Young stock are less tolerant than mature stock
1 500 - 2 000	An increased possibility of adverse chronic effects in mature stock and a possibility of acute effects such as severe diarrhoea and refusal to consume water (young stock) may occur. If, however, the stock have been adapted to sulphate concentrations close to the upper limit of the TWQR, then adaptation to this range should be within a few days
> 2 000	**Adverse chronic effects and acute effects may occur with both mature and young stock**. Depending on the production system, nutritional status, degree of adaptation to sulphate waters, and antagonistic/synergistic interactions of other salts present in the water, concentrations far in excess of this concentration may be tolerated without adverse effects

Note: Actual water intake level and subsequent ingestion of sulphate can vary significantly between species and production systems; see **Characterisation of use**.

Sources of Information

BOWEN H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

ENSMINGER M.E., J.E. Olfield and W.W. Heinemann 1990. *Feeds and Nutrition*, 2nd Edition. The Ensminger Publishing Co., California, 95-239.

KEMPSTER P.L. and H.R. van Vliet 1991. *Water Quality Fitness for Use Curves for Domestic Water*. Draft Report, Department of Water Affairs and Forestry, Pretoria, 86pp.

KEMPSTER P.L. and R. Smith 1985. *Proposed Aesthetic/physical and Inorganic Drinking-Water Criteria for the Republic of South Africa*. Division of Water Technology, CSIR, Pretoria, 51pp.

LEESON S. and J.P. Summers 1991. *Commercial Poultry Nutrition*. University Books, Canada, 61-63.

LITTLE D.A. 1982. Utilization of Minerals, In: *Nutritional Limits to Animal Production from Pastures*. Hacker, J.B. (ed.). Commonwealth Agricultural Bureaux, Slough, England, 259-283.

MACDOWELL L.R. 1992. *Minerals in Animal and Human Nutrition*. Academic Press, Inc., New York.

McKEE J.E. and H.W. Wolf 1963. *Water Quality Criteria*, 2nd Edition. California State Water Resources Control Board, Publication No. 3-A. California.

MILLER W.J. 1979. *Dairy Cattle Feeding and Nutrition*. Academic Press, Inc. California, USA, 95-180.

NRC 1980. *Mineral Tolerance of Domestic Animals*. National Academy Press, Washington DC.

NRC 1984. *Nutrient Requirements of Sheep*, 6th Revision, Ed. National Academy Press, Washington DC.

NRC 1985. *Nutrient Requirements of Cattle*, 5th Revision, Ed. National Academy Press, Washington DC.

OWEN H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

SPEARS J.W. 1994. Minerals in Forages, In: *Forage Quality, Evaluation and Utilization*, Fahey, G.C. (ed.). American Society of Agronomy, Inc., Madison, Wisconsin, USA, 281-307.

WORLD HEALTH ORGANIZATION 1984. *Guidelines for Drinking Water Quality*, Volume 2: Health Criteria and Other Supporting Information, World Health Organization, Geneva.

WORLD HEALTH ORGANIZATION 1993. *Guidelines for Drinking Water Quality*, 2nd Edition, Vol.1: Recommendations, World Health Organization, Geneva.

Total Dissolved Solids

Background Information

Introduction

The total dissolved solids (TDS) concentration is a measure of the quantity of various inorganic salts dissolved in water. The TDS concentration is directly proportional to the electrical conductivity (EC) of water. Since EC is much easier to measure than TDS, it is routinely used as an estimate of the TDS concentration.

Electrical conductivity (EC) is a measure of the ability of water to conduct an electrical current. This ability is a result of the presence of ions in water such as carbonate, bicarbonate, chloride, sulphate, nitrate, sodium, potassium, calcium and magnesium, all of which carry an electrical charge. Most organic compounds dissolved in water do not dissociate into ions, consequently they do not affect the EC.

Occurrence

Virtually all natural waters contain varying concentrations of TDS as a consequence of the dissolution of minerals in rocks, soils and decomposing plant material. Therefore, the TDS of natural waters often depend on the characteristics of the geological formations that the water was, or is, in contact with.

The concentrations of TDS in

- rainwater is low, generally less than 1 mg TDS/R;
- water in contact with granite, siliceous sand and well-leached soils is generally low, less than 30 mg TDS/R;
- water in contact with precambrian shield areas is generally less than 65 mg TDS/R; and
- water in contact with palaeozoic and mesozoic sedimentary rock formations is in the range of 195 - 1 100 mg TDS/R.

TDS are likely to accumulate in water as water moves downstream because salts are continuously being added through natural and manmade processes, while very little are removed by precipitation or natural processes. Domestic and industrial effluent discharges and surface runoff from urban, industrial and cultivated areas are examples of the types of return flows that contribute to increased TDS concentrations.

High TDS concentrations in surface waters are also caused by evaporation in water bodies which are isolated from natural drainage systems. The saline pans in the central parts of South Africa are such water bodies.

Interactions

The properties of the TDS in water are governed by the nature of the inorganic salts that constitute the TDS. The TDS content is also closely related to other water constituents such as the **total hardness** of water and the **corrosion and scaling potential**.

Measurement

The guideline is given in terms of TDS in mg/R as well as the equivalent EC, expressed in milli-Siemens per metre (mS/m), measured at, or corrected to, a temperature of 25 EC.

The TDS concentration can be measured as

- an estimate of the EC value (see below);
- the dry weight of the salts after evaporation of a known volume of filtered water; and
- the sum of the concentrations of the constituent cations and anions.

For most natural waters electrical conductivity is related to the TDS concentration by a conversion factor ranging from 5.5 - 7.5. The average conversion factor for most waters is 6.5. The conversion equation is as follows:

$$EC(mS/m \text{ at } 25°C) \times 6.5 = TDS(mg/ℓ)$$

The exact value of the conversion factor depends on the ionic composition of the water, especially the pH and bicarbonate concentration. Should very accurate measures of TDS be required, the conversion factor should be determined for specific sites and runoff events.

Data Interpretation

Mean values should be used to compare with the criteria given because the TDS concentration in water prevailing for long periods of time, rather than a few extreme events, is important. Therefore comparisons with annual or seasonal mean TDS concentrations should be made.

Treatment Options

Although some salts, such as those of calcium, magnesium and certain heavy metals, can be removed by chemical precipitation, most of the inorganic salts dissolved in water can only be removed by distillation or by highly sophisticated physical-chemical separation technologies. All these technologies are characterised by their high cost and/or high energy requirements, and are therefore not economically feasible for water intended for livestock consumption.

In practice, should the TDS concentration be too high, it is mixed with water of a better quality from another source, or given to non-productive stock.

However, should removal of TDS be required, the technologies available for reducing the concentration of TDS in water include:

- Demineralisation in a mixed-bed ion exchange column, usually where the feed TDS concentration is approximately 2 000 mg/ℓ. On an industrial scale large banks of ion exchange filter beds, capable of being regenerated, are used. Ion exchange processes are also used for the production of ultrapure water.

- Treatment by membrane processes such as reverse osmosis or electrodialysis where the TDS concentration is in the range of 2 000 - 3 500 mg/ℓ. Large-scale treatment is achieved with banks of reverse osmosis modules in parallel.

- Distillation in cases where the TDS concentration is approximately 10 000 mg/ℓ.

All the processes are usually fouled by suspended matter and are prone to scaling from hard waters. All large-scale processes require high levels of design, operator and maintenance skills. Furthermore, all processes produce a concentrated waste stream of the salts that may cause disposal difficulties.

The Effects of Total Dissolved Solids

Norms The norms used in the guidelines are based on

- the palatability and toxicological effects of the TDS on livestock consumption; and
- the effects of the TDS on clogging and encrustation of livestock watering systems.

Effects Common salt, sodium chloride (NaCl), is frequently added to livestock rations to regulate feed intake, enhance palatability, and as a carrier for other required elements. The term "salt poisoning" is a misnomer, since it is invariably the disruption of water balance which is problematic. (See **sodium**).

- **Palatability Effects**

Saline water may detrimentally affect animal health and thus performance by rendering the water unpalatable. Palatability is also influenced by the types of salts present and not just the level of salinity. Magnesium sulphate (Epsom salts) is more harmful than sodium chloride or sodium sulphate (Glauber's salt). The main water quality constituents implicated in palatability effects are chloride, sulphate, magnesium, bicarbonates and calcium. However, other factors such as dust, temperature and algae can also contribute to whether or not a water is deemed palatable or unpalatable by livestock.

Direct effects of unpalatable water

- Refusal to consume water.
- Depending on the degree of unpalatability stock may consume the water, but at a level below the physiological requirement (a concurrent increase in water intake with increasing salinity is required for adequate renal plasma clearance to take place).
- In extreme cases, the stock will refuse the water but will eventually be driven to it by thirst. This may result in a consumption of excessive amounts of water and therefore salts, which may manifest as "salt poisoning" when a sodium salt is involved. See **sodium**.

Indirect effects of unpalatable water

- Initial refusal to consume water and hence a decline in productivity. Typically, this may last a few days for stock which have not previously encountered saline waters. The implications are:

  - economic loss for intensive systems where time is a crucial factor; and
  - health implications for systems where new, young stock are brought in and are stress-sensitive (electrolyte imbalance), such as in feedlots.

- In more severe cases the stock may regularly consume sufficient water for adequate plasma clearance, but production declines. This is primarily due to the high positive correlation between water intake and feed intake. A decline in water intake results in a decrease in feed intake (dehydration-induced hypophagia) with a resultant drop in performance parameters such as milk production, average daily gain (ADG), feed conversion ratio (FCR) and body weight.

The types of effects of exposure to TDS concentrations in excess of the TWQR depend on the ability of the stock to adapt to saline or unpalatable water, and whether or not the stock have been previously exposed to saline water.

Adaptation period

Livestock can adapt to highly saline water and continue production without adverse effects after an initial decline in production. Adaptation may require several days or weeks, depending on the TDS level and salts involved. Adaptation implies that the decline in performance is acceptable for a limited time with the provision that once adapted, stock will resume normal production for the site-specific production system.

No adaptation period

For intensive systems (feedlots, poultry, pigs and dairy production), if stock are given access to waters in excess of the TWQR without an adaptation period, then a decline in production can be expected. Furthermore, stock should preferably only be allowed access to waters in the upper regions of the TWQR, if they have had previous exposure to saline waters.

Previous exposure

Stock which have had previous exposure to saline waters or are already consuming saline waters will accept an increase in salinity far more readily than stock which have not previously encountered saline water. Therefore, stock which have had previous exposure can be adapted to TDS concentrations in excess of the TWQR over a shorter period of time, while care must be exercised for stock which have not had previous exposure.

! **Toxicological effects**

The main effects of TDS on toxicological aspects are attributed to the following:

- Symptoms of diarrhoea and dehydration due to initial exposure to saline waters. The primary constituents involved are sulphate, magnesium and bicarbonate.
- Ingestion of large volumes of highly saline water following a period of refusal to unpalatable water. Adverse effects are usually osmotic which may lead to "salt poisoning", but may be related to a specific ion, depending on the amount of water ingested and the concentration of the specific ion in the water and feed.

  Salt poisoning is invariably acute. Toxic effects related to specific ions are often indirectly due to the increased water intake and can result in constituents eliciting a toxic response at levels normally safe. Salts that have little effect on the palatability of water but are toxic include nitrates, fluorides and the salts of heavy metals.

Mitigation

! **Palatability Effects**

Stock should preferably be exposed to water with increasing salinity concentrations if a period of adaptation is feasible. Depending on the length of time of refusal to ingest the water, stock will usually recover completely within a couple of days if water within the TWQR is given. Water with high concentrations of TDS can also be mixed with water of a better quality from another source to dilute the TDS concentration, or given directly to non-productive stock.

! **Toxicological Effects**

The recovery from volume-loaded hypertension depends on the TDS concentration, the length of exposure time and the primary salts involved. Recovery may be complete or stock may never recover. Recovery from high ingestion rates of potentially hazardous constituents depends on the specific salts and constituents involved (see relevant section for specific constituent).

It should be noted that there are vast differences in salt tolerance between and also within species. The removal of salt from the diet is an option, but care must be taken specifically with the more susceptible species, as often the saline water may not have adequate chloride. The dietary correction may thus induce chloride deficiency.

Criteria **Effects of TDS on Livestock Production**

TDS mg/R	**Sheep**	**Beef**	**Horses**	**Dairy**	**Pigs and Poultry**
0 - 1 000	" " " "	" " " "	" " " "	" " " "	" " " "
1 000 - 2 000	" " " "	" " " "	" " " "	" " " !	" " " !
2 000 - 3 000	" " " "	" " " !	" " " !	" " " !	" " ! !
3 000 - 4 000	" " " !	" " " !	" " ! !	" " ! !	" ! ! !
4 000 - 5 000	" " " !	" " " !	" " ! !	" ! ! !	! ! ! !
5 000 - 6 000	" " " !	" " " !	" " ! !	" ! ! !	! ! ! !
6 000 - 7 000	" " ! !	" " ! !	" ! ! !	! ! ! !	! ! ! !
7 000 - 10 000	" " ! !	" ! ! !	! ! ! !	! ! ! !	! ! ! !
10 000 - 13 000	" " ! !	! ! ! !	! ! ! !	! ! ! !	! ! ! !
> 13 000	" ! ! !	! ! ! !	! ! ! !	! ! ! !	! ! ! !

Symbol **Effects (E) are dependent on the Action (A)**

" " " " **Target Water Quality Range**

E No significant adverse effects.

A Immediate access allowed without any previous exposure to saline waters.

" " " ! **E** Possible initial reluctance to drink, but should be temporary. No significant adverse effects.

A Immediate access allowed with previous exposure to saline waters (TDS of approximately 50 %).

E Initial reluctance to drink may lead to a decline in water intake and, subsequently, production. However, the stock should adapt within a

		relatively short period of time (within a week) and return to normal production level.
	A	Immediate access allowed without any previous exposure to saline waters.
" " ! !	**E**	Care should be taken when allowing stock access to these waters, specifically for intensive systems. Initial reluctance to drink may lead to a decline in water intake and subsequently production. However, the stock should adapt to the water within a relatively short period of time (within a week) and return to normal production levels. Increased need to adapt stock to salinity levels.
	A	Immediate access allowed only with previous exposure to saline waters (TDS of approximately 50%).
" ! ! !	**E**	Production will in all likelihood decline significantly. Stock should survive (at maintenance level) and recover when offered water with TDS within the TWQR, provided exposure is not too long. Increased need to adapt stock to salinity levels. Some species can tolerate once adapted (see text).
	A	Immediate access allowed only with previous exposure to saline waters (TDS of approximately 50%) for limited periods of time.
! ! ! !	**E**	Extreme caution should be taken when allowing stock access to these ranges. Some species can tolerate once adapted (see text).
	A	No immediate access allowed. Stock must be adapted incrementally to water source.

Sources of Information

ADELAAR T.F. 1974. Die Invloed van Brakwater op Vee in Suid-Afrika. Faculty of Veterinary Science, University of Pretoria, South Africa. Reuter and Gouws.

BUCK W.P., G.D. Osweiler and G.A. van Gelder. Clinical and Diagnostic Veterinary Toxicology. IOWA State University. Kendall Hunt Publishers.

CANADIAN GUIDELINES 1987. Canadian Water Qaulity Guidelines. Prepared by the Task Force on Water Quality Guidelines of the Canadian Council of Resource and Environment Ministers. Canada.

CLARKE M.L., D.G. Harver and D.J. Humpreys 1981. Veterinary Toxicology, 2nd Edition. Bailliere Tindell, London.

CUNHA T.J. 1977. Swine Feeding and Nutrition. Academic Press, Inc. California, USA.

ENSMINGER M.E., J.E. Olfield and W.W. Heinemann 1990. Feeds and Nutrition (2nd Edition). The Ensminger Publishing Co., California.

ETTINGER S.J. 1989. Textbook of Veterinary Internal Mediscene, Volume 2, 3rd Edition. Saunders Co.

GROSSMAN S.P. 1990. Thirst and Sodium Appetite. Physiological basis. Academic Press, new York.

HART B.T., C. Angehern-Bettinazzi, I.C. Campbell and M.J. Jones 1992. Draft Australian Water Quality Guidelines. Australian and New Zealand Environment and Conservation Council.

NRC 1980. Mineral Tolerance of Domestic Animals. National Academy Press, Washington, DC.

SMITH R. 1988. Water Quality Criteria for Livestock Watering and Human Consumption. CSIR: Division of Water Technology. Project No. 670 2170 9.

UNDERWOOD E.J. 1981. The Mineral Nutrition of Livestock. Commonwealth Agricultural Bureaux.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY. Proposed Criteria for Water Quality, Volume 1. United States EPA.

Vanadium

Tentative Guideline

Background Information

Introduction

Vanadium is a white, soft, ductile metal resistant to corrosion. Vanadium occurs in several oxidation states, namely II, III, IV and V. Vanadium salts and compounds are often highly coloured. Soluble vanadium salts are readily taken up by living organisms. Vanadium is considered to be a possible essential element. Vanadium in the aquatic environment is of concern since it can be concentrated in vegetation.

Occurrence

Minerals containing vanadium are widespread and include vanadium sulphide and the calcium salt of vanadium. Metallic vanadium does not occur in nature. Vanadium(IV) and vanadium(V) salts are generally soluble in water, tend to remain in solution and are not strongly adsorbed onto soil particles. Compounds of vanadium such as trifluoride, trioxide and trisulphide are insoluble in water and are associated with sediments.

Typically, the concentration of vanadium in

- fresh water is less than 1 Fg/R; and
- sea water is approximately 3 Fg/R.

Vanadium compounds have various industrial applications and are used as catalysts in the chemical industry, in certain glassware and ceramic products, in the textile industry and in the manufacture of dyes.

Interactions

Metabolically, vanadium interacts with **chromium** and **iron** and the concentrations of these two elements should be considered in assessing the effects of vanadium toxicity.

Measurement

The criteria are given in terms of the total vanadium concentration, in units of mg/R. The reference method for the determination of vanadium is atomic absorption spectrometry, using a nitrous oxide-acetylene flame. If other methods are used, their characteristics relative to the reference method should be known.

Data Interpretation

Single-sample values should be used to compare with the criteria given, and should be interpreted as maximal values, not to be exceeded.

Treatment Options

Vanadium in water supplies is most conveniently removed by raising the pH and precipitating the insoluble vanadium salts after the addition of lime or iron salts in the pH range of 8.5 - 11.5. Precipitation is followed by settlement and filtration as in conventional water treatment. The precipitation process requires careful monitoring to ensure that removal is complete.

To achieve very low residuals it may be necessary to pass the stream through an ion exchange column charged with the appropriate resin.

A watery, vanadium-rich sludge or concentrate stream is generated in the processes that may present disposal difficulties.

The Effects of Vanadium

Norms The norms used in the guideline are based on the toxicological effects associated with the ingestion of vanadium in water used by livestock.

Effects The occurrence of toxicity associated with the ingestion of excessive amounts of vanadium in water used by livestock is rare and only scant information exists. It is thought that iron saturation of transferritin and ferritin play a role in the retention of vanadium. Symptoms of vanadium toxicity in livestock include diarrhoea, reduced growth, emaciation and a "staring" (dull, lack-lustre, long) coat. High concentrations of vanadium have been correlated to reduced growth rates in chickens.

Mitigation No mitigatory measures are known.

Criteria **Effects of Vanadium on the Health of Livestock**

Vanadium Range (mg/ℓ)	**Effects**
	All livestock
Target Water Quality Range 0 - 1	***No adverse effects***
1 - 2	**Adverse chronic effects such as diarrhoea, emaciation, staring coat and reduced growth rate may occur, but are unlikely if** - feed concentrations are normal, and - exposure is short term. Could even be tolerated in the long term, depending on site-specific factors such as nutritional interactions and water requirement
> 2	**Adverse chronic effects (as above) and acute effects such as diarrhoea and emaciation may occur, although** short-term exposure could be tolerated depending on site-specific factors (as above)

Note: ! The occurrence of toxicity due to water intake is rare. Cases of vanadium poisoning, not due to water sources, have been reported in Middelburg, Transvaal.

! Actual water intake level and subsequent ingestion of vanadium can vary significantly between species and production systems; see **Characterisation of Use**.

Sources of Information

APHA 1989. *Standard Methods for the Examination of Water and Waste Water,* 17th Edition. American Public Health Association, American Water Works Association, Water Pollution Control Federation. Published by the American Public Health Association.

BERMAN E. 1980. *Toxic Metals and Their Analysis*. Heyden, London.

BOWEN H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

CUNHA T.J. 1977. *Swine Feeding and Nutrition*. Academic Press, Inc. California, USA, 184-187.

ELSENHANS B., K. Schumann and W. Forth 1991. Toxic Metals: Interactions with Essential Minerals, In: *Nutrition, Toxicity and Cancer*. Rowland, I.R. (Ed.). CRC Press, Inc. USA, 197-222.

McKEE J.E. and Wolf H.W. 1963. *Water Quality Criteria*, 2nd Edition. California State Water Resources Control Board, Publication No. 3-A. California.

MILLER W.J. 1979. *Dairy Cattle Feeding and Nutrition*. Academic Press, Inc. California, USA, 95-180.

NRC 1980. *Mineral Tolerance of Domestic Animals*. National Academy Press, Washington DC.

NRC 1984. *Nutrient Requirements of Sheep*, 6th Revision, Ed. National Academy Press, Washington DC.

NRC 1985. *Nutrient Requirements of Cattle*, 5th Revision, Ed. National Academy Press, Washington DC.

UNDERWOOD E.J. 1977. *Trace Elements in Human and Animal Nutrition*, 4th Edition. Academic Press, New York, USA.

WEAST R.C. 1979. *CRC Handbook of Chemistry and Physics*, 60th Edition. CRC Press Inc., Boca Raton, Florida, USA.

WORLD HEALTH ORGANIZATION 1984. *Guidelines for Drinking Water Quality*, Volume 2: Health Criteria and Other Supporting Information. World Health Organization, Geneva.

Zinc

Background Information

Introduction

Zinc is a metallic element, with the stable oxidation states being the metal (0) and the +II oxidation state, which is the form found in nature. The carbonate, hydroxide and oxide forms of zinc are relatively resistant to corrosion, therefore zinc has many applications. Biologically, zinc is an essential nutritional trace element for plants and animals, but is toxic at high concentrations.

Occurrence

The most common mineral form of zinc is the sulphide (sphalerite). Zinc is also found as a carbonate, oxide or silicate and may occur in association with many other metal ores such as copper and arsenic. The chloride, sulphate and nitrate salts of zinc are highly soluble in water, but at neutral and alkaline pH tend to hydrolyse to form relatively insoluble hydroxides which tend to be associated sediments. On acidification of the water, the insoluble hydroxides are released back into the dissolved phase. If the water is acidic, zinc leaching caused by dissolution of the protective zinc hydroxide layer of galvanised piping can give rise to relatively high concentrations of zinc in solution.

The concentration of zinc in water is usually low, typically around 0.015 mg/ℓ. Elevated zinc concentrations at neutral and alkaline pH arise where zinc occurs largely as a colloidal suspension of zinc hydroxide which imparts a milky white appearance to the water. In sea water the zinc concentration is also very low, typically around 0.005 mg/ℓ.

Zinc and zinc salts are used in many industrial processes. Zinc itself is extensively used in galvanising processes and in alloys. Zinc salts are used in paint pigments, in cosmetics and in the manufacture of pharmaceuticals, dyes and insecticides.

Interaction

Zinc interacts strongly with **cadmium**, to which it is chemically very similar. Zinc is an essential nutritional micro-element of relatively low toxicity, whereas cadmium, which is not essential, is highly toxic to all higher organisms. Metabolically, zinc interacts with **copper** and **calcium**. As is the case with all metals, the **pH** of the water determines the concentration of soluble zinc.

Measurement

The criteria are given in terms of the total zinc concentration, in units of mg/ℓ. Total zinc is measured after acidification of the sample by atomic absorption spectrometry, which is the reference method. If other methods are used, their characteristics relative to the reference method should be known.

Data Interpretation

Mean values should be used to compare with the criteria given. Zinc concentrations should also be interpreted in relation to the pH and the concentrations of the suspended solids and related metals, such as cadmium and copper. The concentration of zinc in the feed should also be taken into account.

Treatment Options

Zinc in water supplies is most conveniently removed by raising the pH and precipitating the insoluble zinc hydroxide with lime treatment in the pH range of 9.5 - 10.0. The precipitation is followed by settlement and filtration as in conventional water treatment.

The precipitation process requires careful monitoring to ensure complete removal. A watery, zinc-rich sludge is generated in the process that may present disposal difficulties.

The Effects of Zinc

Norms The norms used in the guideline are based on toxicological effects of zinc associated with ingestion of zinc in water used by livestock.

Effects Zinc is critical for the metabolism of proteins, nucleic acids and carbohydrates. (Over 200 enzymes are known to be zinc metallo-enzymes and many enzymes are also activated by zinc). Zinc requirements are affected by dietary and physiological factors and zinc supplementation is commonly practised, although results are inconsistent. Diets high in phytic acid result in an increased availability of zinc and the addition of chelating agents (EDTA) to feed may also improve zinc availability. However, zinc availability is adversely affected by large amounts of phytates, calcium, oxalates, high fibre, copper and EDTA. Zinc deficiency primarily occurs in young intensively-housed swine. High calcium levels tend to aggravate zinc deficiency.

Animals tend to have a high tolerance to excess zinc intake and this may be attributed to the fact that the body reserves of zinc are small and have a rapid turnover. Less than ten percent of metallic zinc and the carbonate, sulphate and oxide forms are absorbed from the intestines and hence zinc excretion readily occurs. Zinc will tend to accumulate in bones rather than the liver.

Zinc toxicity is manifested by inappetence, loss of condition (hair loss, poor wound healing), diarrhoea, haemolysis and icterus. High intakes of zinc have been reported to induce copper deficiency and a high incidence of abortions and stillbirths in ewes and poor semen quality in males.

Mitigation Iron and lead supplementation can overcome anaemia caused by excessive zinc. Intake of high calcium and copper concentrations decreases zinc absorption and may be indirectly alleviatory.

Criteria **Effects of Zinc on the Health of Livestock**

Zinc Range (mg/ℓ)	Effects
	All livestock
Target Water Quality Range 0 - 20	***No adverse effects***
20 - 40	**Adverse chronic effects such as inappetence, anaemia icterus and diarrhoea may occur, but are unlikely if** - feed concentrations are normal; - calcium intake is adequate; and - exposure is short term Could even be tolerated in the long term, depending on site-specific factors such as nutritional interactions and water requirement
> 40	**Adverse chronic effects (as above) and acute effects such as haemolysis and icterus may occur, although** short-term exposure could be tolerated depending on site-specific factors (as above)

Note: Actual water intake level and subsequent ingestion of zinc can vary significantly between species and production systems; see **Characterisation of Use**.

Sources of Information

BERMAN E. 1980. *Toxic Metals and Their Analysis*. Heyden, London.

BOWEN H.J.M. 1979. *Environmental Chemistry of the Elements*. Academic Press, London.

CUNHA T.J. 1977. *Swine Feeding and Nutrition*. Academic Press, Inc. California, USA, 184-187.

ENSMINGER M.E., J.E. Olfield and W.W. Heinemann 1990. *Feeds and Nutrition*, 2nd Edition. The Ensminger Publishing Co., California, 95-239.

FOUKES E.C. and C. Voner 1981. Effects of Zn-status, Bile and Other Endogenous Factors on Jejunal Cadmium Absorption. *Toxicology*, 22: 115.

LEESON S. and J.P. Summers 1991. *Commercial Poultry Nutrition*. University Books, Canada, 61-63.

LITTLE D.A. 1982. Utilization of Minerals, In: *Nutritional Limits to Animal Production from Pastures*. Hacker, J.B. (ed.). Commonwealth Agricultural Bureaux, Slough, England, 259-283.

MACDOWELL L.R. 1992. *Minerals in Animal and Human Nutrition*. Academic Press Inc., New York.

McKEE J.E. and Wolf H.W. 1963. *Water Quality Criteria*, 2nd Edition. California State Water Resources Control Board, Publication No. 3-A. California.

MILLER W.J. 1979. *Dairy Cattle Feeding and Nutrition*. Academic Press Inc., California, USA, 95-180.

MINSON D.J. 1990. *Forage in Ruminant Nutrition*. Academic Press Inc., California, USA, 208-395.

NRC 1980. *Mineral Tolerance of Domestic Animals*. National Academy Press, Washington DC.

NRC 1984. *Nutrient Requirements of Sheep*, 6th Revision, Ed. National Academy Press, Washington DC.

NRC 1985. *Nutrient Requirements of Cattle*, 5th Revision, Ed. National Academy Press, Washington DC.

SPEARS J.W. 1994. Minerals in Forages, In: *Forage Quality, Evaluation and Utilization*, Fahey, G.C. (ed.). American Society of Agronomy Inc., Madison, Wisconsin, USA, 281-307.

UNDERWOOD E.J. 1981. *The Mineral Nutrition of Livestock*. Commonwealth Agricultural Bureaux, 31-176.

WHO 1994.

Chapter 6

Glossaries

Glossary of Terminology

aerobic:	organisms requiring molecular oxygen for respiration *or* conditions where oxygen is available
adsorption/elution:	the attachment of molecules or ions to, and their removal from, a substrate by manipulation of electrical charge or pH
amphoteric:	the capability of a substance to react as an acid or a base, hence of dissolving under basic or acidic conditions
anaemia:	an abnormal decrease in red blood cells (i.e. in their production, circulation and degeneration but not in homeostasis); the symptoms include, among others, listlessness, decreased physical capabilities, pale mucous membranes and increased pulse rate
anaerobic:	conditions lacking oxygen or organisms not requiring oxygen for respiration
anions:	negatively-charged ions
anionic:	characteristic behaviour or property of an ion that has a negative charge. Anions move to the anode in electrolysis
ascariasis:	a disease caused by helminthic parasites of the genus *Ascaris*, in man *A. lumbricoides*
benthic:	inhabiting the bottom of a water body
biochemical oxygen demand (BOD):	the amount of dissolved oxygen consumed by organisms in water rich in inorganic matter
buffering capacity:	a measure of the relative sensitivity of a solution to pH changes on addition of acids or bases
carcinogenic:	capable of causing, promoting or giving rise to the development of cancer
cationic:	the characteristic behaviour or property of an ion with a positive charge. Cations move to the cathode in electrolysis
cations:	positively-charged ions
chlorophyll:	the green pigment in plants and algae that, during photosynthesis, captures sunlight energy and converts it into chemical energy in the form of carbohydrates. Chlorophyll *a*, *b* and *c* are three forms of chlorophyll found in different proportions in different plants
coagulation:	the separation or precipitation of particles in a dispersed state from a suspension resulting from their growth. This may result from the addition of an electrolyte (coagulant), prolonged heating or from a condensation reaction between a solvent and solute

cyanosis:	the discolouration of the skin due to the presence of oxygen-deficient blood
dissolution:	the process of dissolving
electrodialysis:	a process of selective diffusion through a membrane conducted with the aid of an electromotive force applied to electrodes on both sides of the membrane
electron acceptor:	is an atom or part of a molecule that receives electrons from other substances in a chemical reaction of binding the substances together with a covalent bond
epidemiology:	the science or study of diseases in the community
etiological:	causative, as in causing disease
eutrophic:	refers to not only water, particularly in lakes and dams, which is high in nutrients and hence has excessive plant and algal growth
flocculation:	the addition of chemical reagents (flocculants) to bring small particles together in flocs through the process of *coagulation*, aggregation or biochemical reaction of fine suspended particles
haematology:	the study of blood
haemochromatosis:	a metabolic disorder, especially in males, involving the accumulation of large amounts of iron in body tissues. This is accompanied by cirrhosis of the liver and progressive involvement of the pancreas and other organs
haemoglobin:	the protein occurring in the red blood cells of vertebrates and responsible for the transport of oxygen and carbon dioxide in the bloodstream
haematocrit:	the ratio of red blood cells to plasma
haemorrhagic inflammation:	inflammation due to the escape of blood from a ruptured blood vessel
histopathology:	the study of the structure of abnormal tissue. Examination of tissues after death may serve to identify the cause of death and possibly the causative agent
hyperplasia:	excessive development due to an increase in the number of cells
hypertrophy:	excessive development due to an increase in the size of cells
hypoxia:	lack of sufficient oxygen
igneous rock:	rock, formed from the cooling of magma,that has not changed appreciably since its formation
intensive systems:	systems in which the production is based on the formulated artificial feed only
ion exchange:	the interchange of ions of like-charge, usually on a solid medium; used in water treatment, such as water softening

lignin:	an organic polymer providing strengthening and thickening in plant cell walls. The properties of wood are due to the encrustation of plant cell walls with lignin.
macrophyte:	any macroscopic form of aquatic vegetation; encompasses certain species of algae, mosses and ferns as well as aquatic vascular plants
mesotrophic:	a term applied to freshwater bodies that contain moderate quantities of plant nutrients and are therefore moderately productive
metamorphic rock:	rock that has been greatly altered from its previous condition through the combined action of heat and pressure
methaemoglobin:	haemoglobin with the haem iron in the ferric state and unable to bind oxygen. Produced by the action of oxidising agent, for example nitrate
methaemoglobinaemia:	a condition, usually in infants, in which nitrite in the blood combines with the red blood pigment, haemoglobin, to form methaemoglobin. Unlike haemoglobin, methaemoglobin is incapable of carrying oxygen
microbes:	microscopic organisms such as bacteria or viruses
miracidia:	free-swimming larvae of a trematode, for example *Schistosoma*. This is the stage which infests humans and animals
monogastric:	an organism having one stomach; also called non-ruminants
mucilaginous:	the tacky or slimy property of extracellular substances secreted by certain groups of bacteria, such as the slime-producing bacteria
mutagenic:	the capability of inducing mutations, for example chemicals, radiation
necrosis:	the death of cells or tissues
necropsy:	the process of establishing the cause of death of cells or tissue
occlusion:	blockage
organoleptic:	characteristics of water which affect the sense organs, for example taste and odour
osmoregulation:	the regulation of the osmotic pressure of body fluids by controlling the amount of water and/or salts in the body
osmosis:	the diffusion of a solvent, usually water, through a semi-permeable membrane, into a more concentrated solution
ozonation:	disinfection using ozone
palatability:	acceptable, satisfactory taste
pathogenic:	causing disease
pelagic:	refers to animals able to be living in the water column

permeability:	the condition of allowing the passing of fluid molecules through a particular medium, such as soil, etc.
photosynthesis:	the trapping of solar energy and its conversion to chemical energy by plants and algae, which use the energy in manufacturing food molecules from carbon dioxide and water
physico-chemical:	refers to the physical (e.g. pH, temperature, electrical conductivity) and chemical (e.g. concentrations of nitrate, mercury) characteristics of water
raw water:	source water in its untreated state
redox potential:	an expression of the oxidising or reducing power of a solution relative to a reference potential. This potential is dependent on the nature of the substances dissolved in the water, as well as on the proportion of their oxidised and reduced components
reducing conditions:	conditions prevailing within an aquatic environment in which the redox potential is such that substances become reduced
reverse osmosis:	a technique in the desalination of water in which pressure is applied to the surface of the saline solution, forcing pure water to pass through a semi-permeable membrane which prevents the passage of other ions
ruminants:	even-toed, hoofed animals such as cattle, sheep, goats, etc. which ruminate (regurgitate and chew a cud); they have a complex four-compartment stomach, characterised by a large storage space and microbial fermentation, which is adapted to the efficient use of high-fibre feeds and the manufacture of B-complex vitamins and essential amino acids
salinity:	a measure of the salt content of soil or water
scaling:	the formation of a dense coating of predominantly inorganic material formed from the precipitation of water soluble constituents. The most common substances forming scale are carbonates and sulphates of calcium and magnesium hydroxide
sub-lethal:	the concentration or dose of a toxic substance below the threshold which causes death
supersaturation:	a solution containing more solute than equilibrium conditions will allow; unstable to the addition of solute crystals
teratogenic:	an agent or factor causing deformed embryos or offspring
toxaemia:	blood poisoning or a disease of pregnancy with increased blood-pressure
treatment breakthrough:	the occurrence of contaminants in final water after treatment as a result of failure of a component of the treatment process. This is usually an isolated event with a clearly definable cause and effect, for example appearance of bacteria in treated water as a result of failure of chlorination

trihalomethanes:	are organic molecules containing a single carbon atom on which hydrogen atoms have been replaced by halogens, generally either chlorine or bromine. Frequently formed during disinfection by chlorination or bromination
valency:	the number of electrons required to be gained or lost by an atom to reach a state where the outermost electron shell is full
vascular plants:	plants with woody conducting vessels (i.e. most terrestrial plants)

Glossary of Abbreviations / Acronyms

ADI	acceptable daily intake. Refers to a concentration of a chemical or substance which can be tolerated as a daily dose over a long exposure period, usually a lifetime. This is usually applied to toxic chemicals which do not have carcinogenic effects
APHA	American Public Health Association
ASCE	American Society of Civil Engineers
AWWA	American Water Works Association
BOD	biological oxygen demand
COD	chemical oxygen demand
CSIR	Council for Scientific and Industrial Research
DAF	dissolved air flotation
DM	dry mass
DOC	dissolved organic carbon
EC	electrical conductivity
EC	European Community - in this document, the European Community (EC) is referred to as such when discussing it as an economic/political entity. It is referred to the European Economic Community (EEC) when directly citing a Directive promulgated prior to the formal 1992 change from EEC to EC. Now EUROPEAN UNION (EU)
EEC	European Economic Community
EDTA	ethylenediamine tetra-acetic acid
GAC	granular activated carbon
HPLC	high performance liquid chromatography
IAWPRC	International Association for Water Pollution Research and Control
NAS/NAE	National Academy of Sciences/National Academy of Engineering (USA)
NTU	nephelometric turbidity units
PFU	plaque-forming units
PVA	polyvinyl alcohols
SD	Secchi disk depth in metres

$TCID_{50}$	dose of virus required to cause 50% infection in tissue culture
TDS	total dissolved solids
THMs	trihalomethanes
TOC	total organic carbon
TON	threshold odour number
TWQR	Target Water Quality Range
US EPA	United States Environmental Protection Agency
WHO	World Health Organization

Glossary of Units of Measure

kg/h	kilograms per hectare
µg/R	micrograms per litre
µS/cm	micro-Siemens per centimetre
meq/R	milli-equivalents per litre
mg/R	milligrams per litre
mM/R	millimoles per litre
mS/m	milli-Siemens per metre
ng/R	nanograms per litre
nm	nanometre
NTU	nephelometric turbidity units
TCID_{50}	Dose of virus required to cause 50% infection in tissue culture
EC	degrees centigrade