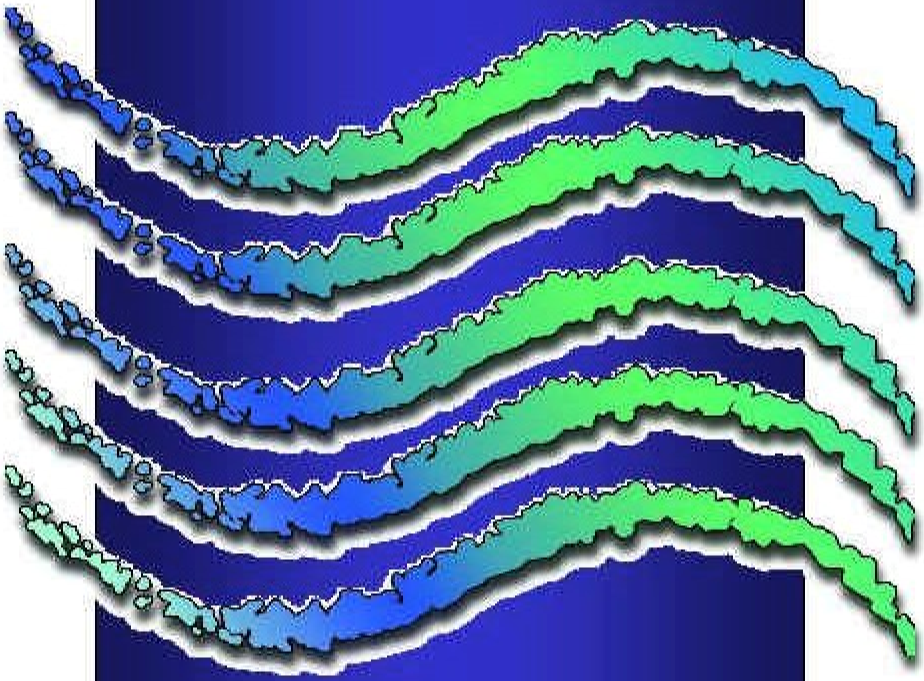
SOUTH AFRICAN

WATER QUALITY GUIDELINES

VOLUME 6

AGRICULTURAL USE: AQUACULTURE



Department of Water Affairs and Forestry
Second Edition 1996

SOUTH AFRICAN WATER QUALITY GUIDELINES

Volume 6: Agricultural Water Use: Aquaculture

Second Edition, 1996

I would like to receive future versions of this document

(Please supply the information required below in block letters and mail to the given address)

Name:..
Organisation:...
Address:..
....
....
....
PostalCode:.. Telephone No.:...
E-Mail:...

Mail reply to:

Director: Water Quality Management
Department of Water Affairs & Forestry
Private Bag X313
PRETORIA
0001
SOUTH AFRICA

South African Water Quality Guidelines

Volume 6
Agricultural Use: Aquaculture

Department of Water Affairs
and Forestry

Second edition
1996

Published by

Department of Water Affairs and Forestry
Private Bag X313
PRETORIA
0001

Republic of South Africa
Tel: (012) 299-9111

Printed and bound by
The Government Printer, Pretoria

ISBN 0-7988-5338-7 (Set)
ISBN 0-7988-5344-1 (Volume 6)

This report should be cited as:

> Department of Water Affairs and Forestry, 1996. South African Water Quality Guidelines (second edition). Volume 6: Agricultural Water Use: Aquaculture.

Edited by S Holmes, CSIR Environmental Services

Produced by:

CSIR Environmental Services
P O Box 395
PRETORIA
0001
Republic of South Africa

This volume is the sixth 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

The following persons and organisations are thanked for their contributions to the guidelines.

EXECUTIVE COMMITTEE
Dr D C Grobler, Environmental Services, CSIR
Dr S Holmes, Environmental Services, CSIR
Mr J L J van der Westhuizen, Department of Water Affairs and Forestry
Dr H R van Vliet, Institute for Water Quality Studies, Department of Water Affairs and Forestry

PROJECT TEAM
Prof T Hecht (Project Leader), Department of Ichthyology and Fishery Science, Rhodes University
Mr A J Booth, Department of Ichthyology and Fishery Science, Rhodes University
Mr N Deacon, Department of Ichthyology and Fishery Science, Rhodes University
Ms J Lockyear, Department of Ichthyology and Fishery Science, Rhodes University
Ms A Olivier, Department of Ichthyology and Fishery Science, Rhodes University
Mr Q Rouhani, Department of Ichthyology and Fishery Science, Rhodes University

TECHNICAL REVIEWERS
Dr J Day, Department of Zoology, University of Cape Town
Prof H Du Preez, Department of Zoology, Rand Afrikaans University
Prof J F Prinsloo, Aquaculture Centre, University of the North

DISTRIBUTION LIST
Draft copies of the guidelines were circulated to the following people and organisations. All comments received were considered.

Dr Peter Britz, Department of Ichthyology and Fisheries Science, Rhodes University
Mr T T de Villiers, Elsenburg Agricultural Development Institute, Department of Agriculture
Prof I G Gaigher, Dept. of Zoology, University of Venda
Mrs I Haigh, Institute of Freshwater Studies, Rhodes University
Mr R Heath, Hydrobiology, Rand Water
Dr G J Steyn, Department of Zoology, Rand Afrikaans University
Dr W Uys, Blyde River Aquaculture
Mr J B Visser, J B Visser Trout Hatchery, Paarl

Chapter 1

Introduction

Introduction

Scope and Purpose of the Water Quality Guidelines

Scope

The *South African Water Quality Guidelines for Aquaculture* is essentially a user needs specification of the quality of water required for the extensive or intensive production of fresh water fish. It is intended to provide the information required to make judgements as to the fitness of fresh water to be used for fish farming.

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

The guidelines do not address water use for crocodile or waterblommetjie farming. The reason for this is that there is no known published information on the water quality requirements for these species.

Purpose

The *South African Water Quality Guidelines* are used by the Department of Water Affairs and Forestry as its primary source of information and decision-support to judge the fitness for use of receiving water and for other water quality management purposes.

The *South African Water Quality Guidelines* contain information similar to what is available in the international literature. However, the guidelines deal not only with information on the ideal water quality for water uses but in addition provide background information to help users of the guidelines make informed judgements about the fitness of water for use.

Users of the Guidelines

The *South African Water Quality Guidelines for Aquaculture* are being developed as an important information resource, primarily for aquaculturists and water quality managers. Nevertheless, educators and other interested and affected members of the general public are likely to find that they are a valuable source of information for many aspects of water quality in relation to freshwater aquaculture.

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 Aquaculture* is divided into six chapters:

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

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

- Chapter 6 consists of appendices which provide additional support information to users of the guidelines.

Water Quality

Introduction To be able to use the *South African Water Quality Guidelines* correctly it is important for users of the guidelines 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 which determine its fitness for use and its ability to maintain the health of farmed aquatic organisms. 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 for the substances dissolved or suspended in it, for example *water quality variable*, *characteristic* or *determinand*. Examples of constituents which 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/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 states 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 health of aquatic ecosystems before the fitness of water for a particular use can be determined.

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 effect on the fitness of water for a particular use or on the protection of aquatic ecosystems. These ranges were determined by assuming long-term continuous use (life-long exposure) and incorporate a margin of safety.

Target Water Quality Range

As a matter of policy, the Department of Water Affairs and Forestry (DWAF) strives to maintain the quality of South Africa's water resources such that they remain 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 as such in the water quality criteria provided for each of the constituents.

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 that 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, which includes the Target Water Quality Range, 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* consists of the guidelines for domestic, recreational, industrial and agricultural (irrigation, livestock and aquacultural) water uses, guidelines for the protection of aquatic ecosystems and 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 of water for use 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 the use of water for:

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

The DWAF's mandate also requires that the health and integrity of aquatic ecosystems be protected. The water quality requirements of these water uses and those for the protection 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 divided into a number of subcategories such as the use of water for static, through-flow or re-circulating aquacultural purposes. 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 subuse.

The characterisation of water uses involves identifying and describing those characteristics which will help determine its significance as well as those which dictate its 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, i.e. whether it is consumptive or not, or whether it is abstractive or not.

- The water quality requirements of a water use are 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;
  - 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.

To be able to make judgements about 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 aquatic ecosystems;
- 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 aquatic ecosystems will be affected by the prevailing water quality;
- Determine whether the undesirable effects of water quality on a particular use can be mitigated.

The fitness for use of water can range from being completely unfit to being 100% or ideally fit for a specific use. 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;
- 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;
- production of fish under aquaculture;
- 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 and product 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

Sustained use is generally an important objective for the development and maintenance of water resources for different uses. The long-term sustainability of water use was an important consideration in the development of the guidelines. For example, the water quality criteria for aquaculture are based on the assumptions of life-long and continuous exposure of cultured organisms to water of a given quality.

The assumptions underlying the development of the guidelines must be taken into account particularly when making judgments about the fitness of water that needs to be used for a short duration only.

Chapter 2

Approach to Guideline Development

Approach to Guideline Development

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 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 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 utilization in South Africa;

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

Approach

The approach used to develop the *South African Water Quality Guidelines for Aquaculture* was that the guidelines should, as far as is practically possible, serve as a stand-alone source of information and support base for water resource managers to make judgements about the fitness for use of water used for different aquacultural purposes. It is accepted that in many cases the user will 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 users the kinds of information to look for.

Thus, 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 aquaculture.

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 characterised. The product specification of the *South African Water Quality Guidelines*, delineating the information requirements of the guidelines was provided to the technical teams responsible for the development of the guidelines.

Methodology

The methods used to develop aquacultural water quality guidelines for South Africa consisted of:

Listing the various purposes for which water is 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, and from this information develop a list of constituents for the aquaculture guidelines;

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

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

Tentative Guidelines

The information available on the effects of some constituents on water uses is 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 will eventually be replaced by regular guidelines, when sufficient information becomes available or sufficient consensus is reached amongst experts concerning the effects of these constituents on water uses.

Sources of Information used to Develop the Guidelines

Introduction

Because the *South African Water Quality Guidelines* are primarily aimed at local 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 water treatment, 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 aquaculture:

ALABASTER J.S. and R. Lloyd 1980. Water Quality Criteria for Freshwater Fish. FAO, United Nations. Butterworths, London.

BOYD C.E. 1982. Water Quality Management for Pond Fish Culture. Developments in Aquaculture and Fisheries Sciences Vol. 9. Elsevier Science Publishers. The Netherlands.

CANADIAN GUIDELINES 1987. Canadian Water Quality Guidelines. Prepared by the Task Force on Water Quality Guidelines of the Canadian Council of Resource and Environment Ministers, Toronto, Canada.

GARDINER J. and T. Zabel 1989. United Kingdom Water Quality Standards Arising from European Community Directives - An Update. Water Research Centre Report No. PRS 2287-M.

HEATH A.G. 1987. Water Pollution and Fish Physiology. CRC Press, Inc. Boca Raton, Florida.

JOINT RESEARCH CENTRE 1989. European Community (EC) Drinking Water Standards.

TRAIN R.E. 1979. Quality Criteria for Water. US Environmental Protection Agency, Washington DC. Castle House Publications.

US EPA 1986. Criteria for Water Quality. EPA 440/5086-001, Washington DC, USA.

USA Quality Criteria for Domestic Water Supplies (NAS/NAE, 1973; US EPA, 1986).

[*] 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 change from EEC to EC, formally in 1992.

Criteria and guidelines published in the South African literature are listed per constituent in the sources of information section.

Chapter 3

Characterisation of Aquaculture Water Use

Characterisation of Aquaculture Water Use

Background Information

Introduction

Aquaculture is aquatic agriculture and includes the husbandry, management, nutrition, genetics and controlled propagation of all aquatic organisms for use byhumans.

The principal groups of freshwater organisms produced in South Africa are several food fish species, eyed trout ova, trout and black bass fingerlings for stocking of angling waters, ornamental fish and plants, crocodiles and food plants (waterblommetjies). Crocodile and waterblommetjie farming has been excluded from this edition. The reason for this is that too little is known of the water quality requirements for crocodiles to develop a practical set of guidelines. Crocodile farms in South Africa are situated in most geographic regions. Similarly, too little is known of the water quality requirements of waterblommetjies to develop a specific set of guidelines. Waterblommetjies are farmed in the Western Cape Province.

As water used for aquaculture spans a wide variety of activities, it follows that the type of quality requirements for such water represents a synthesis of the needs for the various activities. A wide spectrum of problems may be encountered where water does not meet requirements.

Sources of Water

Aquaculture in South Africa can be divided into several sectors

cage culture in dams or natural lakes;
extensive farming in small earthen farm dams;
extensive and semi-intensive fish farming in purpose designed fish ponds; and
intensive farming in raceways and tanks.

Extensive and semi-intensive fish farming in ponds is dependent on an adequate supply of water. Water for aquaculture is currently obtained from diverse sources such as springs, dams, irrigation canals, rivers, ground water and purified sewage water. The choice of system is to a large extent species and site specific and determined by its commercial viability. Water quality, water availability and climatic conditions to a large extent are the physical determining factors. Intensive farming is practised either under throughflow (open) or recirculating (closed) conditions. Recirculating systems require rigorous management, and are more expensive to operate than throughflow systems, and are therefore only suitable for hatcheries or high-value products. However, a greater degree of control of environmental conditions is possible in recirculating systems in comparison to open systems. In some instances potable drinking water for domestic consumption is used for recirculating systems.

Under extensive conditions the farmer exercises little control of water quality. Stocking densities are usually low and the fish rely largely on natural aquatic organisms for food. Some supplemental feeding may take place. Under open semi-intensive pond or intensive tank culture conditions, stocking densities are appreciably higher and fish are fed on formulated feeds, which necessitates control and water quality management.

Water Quality Problems

The most important areas for the production of warm-water species (including African catfish, tilapia, carp, ornamental fish and koi carp) are the Mpumalanga lowveld and northern KwaZulu-Natal, while the cooler regions of the highveld, the western Cape and the Drakensberg are the main areas for the farming of trout. The primary environmental limiting factors for freshwater aquaculture in South Africa are the lack of suitable freshwater resources and seasonal temperature variations. Lack of suitable fresh-water is related principally to the seasonal nature of river flow. The greatest threat to freshwater aquaculture is industrial pollution of rivers, the effects of afforestation and deforestation on water quality and quantity, the poor use of agricultural and riparian land, and of herbicides and pesticides. Given the sensitivity of fish to organic and inorganic pollutants, prospective fish farmers are strongly advised to undertake a comprehensive analysis of the water they wish to use for the farming of fish, so that they can be advised on whether the water is suitable for fish farming in general and for what species in particular. In fact a complete water quality analysis is absolutely imperative before the farming of any aquatic organisms is considered. Warm-water species in general have a higher degree of tolerance to water quality perturbations than cold-water species.

Frequently, water quality problems are associated not only with the presence of a constituent, but with the interactions between constituents. Some constituents are often used to characterise a water source, and/or play a role in causing water quality related problems whereas other constituents are associated with site-specific water quality problems.

Fish Production

Rainbow trout are farmed mainly in circular tanks or raceways, although a considerable proportion is also produced by way of cage culture in dams or lakes. A small proportion is also produced in earthen ponds. Just under 1 000 metric tons were produced in 1994 with a farm gate value of ca. R 12 million. Processed products include fresh table fish, pate, smoked and sliced trout, whole smoked trout and gravelax. In the last three years there has been a move towards the production of large fish (1 - 2 kg), particularly in the Western Cape, for the smoked and sliced market. In general trout farms are small. Most farms produce between 10 and 25 tons p.a. and only a few produce more than 50 tons/year.

Some trout farms in the western Cape, on the highveld and in KwaZulu-Natal have customised their operations to produce fingerlings for recreational angling. There are three certified disease free farms in South Africa at the moment which produce eyed ova for the local and the export market. In 1994 South Africa exported approximately 42 million eyed ova and it has recently been estimated that South Africa supplies approximately 30 - 35 % of the eyed ova requirements of the UK in their summer. Trout in particular have a requirement for very high quality water and are very sensitive to even minor perturbations.

African catfish (*Clarias gariepinus*) are produced mainly on a semi-intensive basis in earthen ponds in the warmer regions of the country, although a new technology for the high-density tank culture (450 kg/m^3/9 months) of catfish has recently been developed. Average production figures in earthen ponds are in the region of 40 tons/hectare/year. The first ten tons of catfish were produced in 1987 and by 1991 production was in excess of 1 150 tons. Since then the industry has collapsed to less than 50 tons in 1994. This was largely a consequence of rising feed costs and a poor price for the fish.

The fresh-water ornamental fish industry in South Africa has become an important aquaculture sector in terms of revenue earnings and employment. It had its origins in hobbyist backyards and garages, but has now grown into a mature, highly sophisticated, market- and technology-driven industry, which in 1993 produced over 4,8 million fish and several million units of aquatic plants for aquarium keepers. Over 200 species of ornamental fish are produced for the local as well as the export market. Ornamental aquarium fish producers have a ready market for their products. While most of the fish produced in South Africa are still sold on the local market the industry has increased its exports from ca. 7 % of production in 1988 to 40 % in 1992. The farming of high quality koi carp is also gaining momentum in South Africa. Just under one million fish were produced in 1994.

An interesting development in recent years has been the revival of interest in carp and tilapia farming. When the catfish industry collapsed, the farmers found a ready market for both carp and tilapia in rural communities in South Africa, and as a consequence are now paying ever-increasing attention to these species. Twenty tons of tilapia were produced in South Africa in 1988. In 1993 production had increased to approximately 80 tons. Consumers in rural areas prefer small fish and the average size of fish produced is in the region of 50 g and the gate price (in the round) is in the region of R6.50/kg. Similarly, in 1988 less than 5 tons of common carp were produced, while the estimated figure for 1993 was 80 tons. By 1995 this market for small tilapia and carp had collapsed because of erratic demand and more lucrative warm water aquaculture opportunities. However, we predict that the production of tilapia for white fish fillets will show a significant upswing in the future as the demand for fish increases.

TABLE 1: South African aquaculture production and farm gate value for the period 1988 to 1993/4

Years	**Production in metric tons**						**Gate value (R x 1 000)**
SPECIES	1988	1989	1990	1991	1992	1993	1993/4
Rainbow Trout	600	620	950	1 220	990	1 000	12 000
Catfish	137	203	850	1 150	150	100	480
Ornamentals	15	21	23.4	25.2	32.4	28.3	3 668
Tilapia	20	20	30	40	55	80	780
Carp	5	10	20	35	48	80	399
Other fish	*	*	*	*	*	*	52
Water blommetjies	250	260	260	285	309	315	647
TOTAL TONNAGE AND FARM GATE VALUE FOR 1993						1 643	18 026

* Data not available.

Chapter 4

Information Contained in the Guidelines

Information Contained in the Guidelines

Overview

The information contained in a guideline for a particular constituent is organized in three sections.

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 aquacultural water uses;

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. These identify the type of information and can assist users in locating 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 aquacultural uses.

Occurrence

Information on the fate and occurrence of a constituent in the aquatic environment, as well as the natural and man-made sources thereof, are provided as background to help the user ascertain how widely, 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 aquacultural 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 methods 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 data sets and used for making judgements about the fitness of water for aquacultural use.

For example, if the effect is acute then statistics that estimate extreme values, such as the maximum or the 5th percentile, should be used for comparison with the water quality criteria provided, whereas if the effects are mostly chronic then 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 aquaculturists;

Improve, with the use of various treatments, the quality of water within the hatchery or the production unit by the aquaculturist.

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

Feasibility and availability of technological solutions;
Social acceptability;
Scale of the intervention required;
Availability of 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 feasible. It is expected that if that option is to be pursued that the user would obtain expert advice on water treatment.

The Effects of a Constituent

Norms

The norms 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;
Recoverable to irrecoverable.

In order to make informed judgements of the fitness of water for aquaculture 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 the hydrological characteristics of SA rivers, flow and consequently water quality can be highly variable. The effects of water quality on fish 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 fish farming.

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

Adaptation of organisms to water of a certain quality; and

Consumer perceptions.

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 aquacultural use.

Mitigation

The undesirable effects of water quality on its fitness for aquaculture can often be prevented or mitigated against through management interventions during use or at the point of use. These interventions can, for example, include the addition of chemicals or taking measures to reduce dependence on 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 when making judgements about the fitness of water for use in aquaculture.

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

Criteria

Water quality criteria for most of the constituents are provided in the form of tables in which the effects of increasing concentrations of the constituents 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 describes essentially what is considered to be ideal water quality and that water quality outside of this range may, under certain circumstances, be acceptable.

Modifications

Many site- and case-specific factors may modify the effects of water quality on specific water uses. For example, some chemical forms of a constituent may be much more toxic than others: some forms of organic mercury are 5 - 10 times more toxic than are inorganic forms.

It is therefore important that the information on site- and case-specific modifications 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, be modified in certain cases. 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 has not been possible to include all the constituents that might affect the fitness of water for aquacultural use, or to include all the relevant information on the constituents for which guidelines were developed.

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

Should the user of these guidelines require additional information, it must remembered that, besides the publications referenced in the guidelines, there is also a wealth of unpublished information available from a number of organizations and individuals in South Africa. The list of acknowledgements of people and organizations who participated in the development of these guidelines provided at the front of this document is a good starting point for accessing this information and perhaps the best initial sources are the FISHLIT and WATERLIT databases, published by NISC. The two relevant CD ROM discs are "Aquatic Biology, Aquaculture and Fisheries Resources" and "Water Resources Worldwide" respectively. These can be accessed via electronic mail at NISC@RU.AC.ZA or Fax 0461-29550.

Common and Scientific Names

List of common and scientific names used in the text

African catfish	*Clarias gariepinus*
Bluegill	*Lepomis macrochirus*
Brook trout	*Salvelinus fontinalis*
Brown trout	*Salmo trutta*
Channel catfish	*Ictalurus punctatus*
Common carp	*Cyprinus carpio*
Eel	*Anguilla spp.*
Fathead minnow	*Pimephales promelas*
Gold fish	*Carassius auratus*
Grass carp	*Ctenopharyngodon idella*
Largemouth black bass	*Micropterus salmoides*
Mozambique tilapia	*Oreochromis mossambicus*
Nile tilapia	*Oreochromis niloticus*
Perch	*Perca fluviatus*
Pike	*Esox lucius*
Rainbow trout	*Oncorhynchus mykiss*
Redbreast tilapia	*Tilapia rendallii*
Silver carp	*Hypophthalmichtys molitrix*
Striped bass	*Morone saxatilis*
Threespine stickleback	*Gasterosteus aculeatus*

Salmonids, cyprinids and cichlids are the collective common names for the fish in the families Salmonidae (e.g. trout and salmon), Cyprinidae (e.g. carp) and Cichlidae (e.g. tilapia), respectively.

Chapter 5

Water Quality Constituents

Algae

Tentative Guideline

Background Information

Introduction

Some marine and freshwater algae produce chemicals that are toxic to animals, including fish. Fish-kills caused by algal toxins (saxitoxins) have been well documented for certain marine *dinoflagellates*, which cause "red tides". Freshwater blue-green algae (cyanobacteria) of the genera *Microcystis*, *Anabaena* and *Aphanizomenon* are common in fish ponds and are known to produce compounds that are toxic to mammals and birds. However, fish-kills caused by blue-green algae appear to be rare. Water-borne toxins produced by blue-green algae are unable to cross the gill membranes of fish and therefore do not enter the circulatory system. Toxic effects can be induced when the toxin is injected into fish or possibly when fish eat the toxin-containing algal cells.

Algae are always present in the water, but only become of concern when blooms occur. Blooming occurs when high concentrations of nutrients such as nitrogen and phosphate enter the water system. The sources of these nutrients are usually agricultural fertilizers, effluents from sewage treatment plants and industry, runoff from informal settlements, overfeeding, and insufficient throughflow with a resultant build-up of nutrients in fish ponds.

As an aid in both the identification and the use of control measures, problem algae are divided into planktonic (e.g. *Microcystis,*) and filamentous (e.g. *Spirogyra, Pithophora, Chara, Nitella*) forms.

Occurrence

Algae occur in all waters and algal blooms occur in water bodies with high levels of nutrients, coupled with conducive environmental conditions (e.g. no wind, no cloud and high temperatures).

Interactions

Associated with algal blooms is a reduction in dissolved oxygen levels in the water, whereupon fish have to compete with the algae for oxygen, particularly at night. Algal blooms also reduce the amount of light penetration in the water column.

There are no known direct effects of algal blooms on fish. However, algal blooms give rise to a reduction in the amount of dissolved oxygen, which is harmful to fish.

Measurement

Blooms of single-celled algae are estimated from the concentration of chlorophyll *a*. One to five litres of water are filtered through a coarse "cell filter". The residue is kept in steam for 45 seconds to disrupt the cells, then dried and dissolved in an appropriate solvent (e.g. 90% acetone for 20 hours). To estimate the chlorophyll concentration, the solute is read using a spectrophotometer. In large dams, the values usually range between 10 and 120 µg of chlorophyll/L.

Treatment Options

Physical removal of algae by micro filtration is a viable option in small recirculating systems, but is impractical in throughflow systems.

Algicides such as cyanazine, diquat and dalapon are used to control algae; the effects of these algicides on fish have not been documented, see guidelines for Herbicides. Low concentrations of copper sulphate can be used to control algal blooms, however, continuous use thereof is not recommended due to its toxicity to fish and tendency to accumulate in sediments.

Fish ponds or tanks can be flushed with clean water. If this option is chosen it is recommended that the fish be transferred to other ponds and that some of the nutrient rich sediments be removed prior to refilling. Algal blooms in recirculating systems can be combatted by covering the tanks with black plastic or by the provision of adequate shade.

The Effects of Algae

Norms

The norms used in the guideline for algae are based on the effects of:

- The fitness of the fish species in terms of health, growth and reproduction.
- The fitness of fish flesh for human consumption.

Effects

Only one fish-kill that possibly involved blue green algal toxins has been described in the literature. Fingerling channel catfish, *Ictalurus punctatus*, were observed to be under stress after ingesting large quantities of *Microcystis* while feeding on floating feed. The fish exhibited tetany and convulsions, symptoms often seen after exposure to neurotoxins. *Microcystis* is known to produce neurotoxins as well as hepatotoxins. Relatively few fish died during this incident, and cases of fish dying from this toxin are rare.

The susceptibility of fish to infectious disease increases as water quality declines, as a result of algal blooms. There is, however, no documentation on the interrelationship between the amount of algae in the water and fish health. Further, there is no direct evidence of a reduction in growth rate of fish as a consequence of algal blooms.

Similarly, there are no data on the effects of algal toxins on fish reproduction. However, as algal blooms cause low dissolved oxygen concentrations in water, fish might not be able to utilise the habitat for breeding.

Filamentous algae (e.g., *Spirogyra*) are a problem in fish ponds as they trap larvae and fingerlings.

Excess algae cause changes in the organoleptic properties in fish. Earthy musty flavours related to geosmins are the most common "off-flavour" in *pond-raised fish*. Blue-green algae are frequently implicated as the major source of these compounds.

Mitigation

Fish with a musty flavour need to be purged in clean unpolluted water for 3 - 5 days, during which time feeding must be suspended.

Criteria

There are no known criteria for the effects of algal toxins on fish. Qualitative data consisting of visual estimates of the percentage area of a water body covered by algal scums may, however, be used to assess possible indirect effects associated with the presence of algal blooms on fish. See dissolved oxygen, carbon dioxide and total dissolved gases.

Sources of Information

BOYD C.E. 1990. *Empirical Modelling of Phytoplankton Growth and Oxygen Production in Aquaculture Ponds*. In: Aquaculture and Water Quality. (Eds). Brune D.E & J.R. Tomasso. The World Aquaculture Society, Lousiana State University. pp 606.

BROWN E.E. and J.B. Gratzek 1980. *Fish Farming Handbook*. Van Nostrand Reinhold, New York, pp. 390.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY. (1986). *Management of the Water Resources of the Republic of South Africa*. Department of Water Affairs, Pretoria.

TUCKER C.S. and E.H. Robinson 1990. *Channel Catfish Farming Handbook*. Van Nostrand Reinhold, New York, pp 454.

SCHWEDLER T.E., C.S. Tucker and M.H. Beleau 1985. *Non-infectious Diseases. In Channel Catfish Culture* (editor) C.S. Tucker. Amsterdam: Elsevier.

Alkalinity

Background Information

Introduction

Alkalinity is a measure of the capacity of water to neutralize strong acid and as such, it is a summary measure of the anionic character of water. Alkalinity is primarily attributable to the presence of hydrogen carbonate (HCO_3^-) (*also referred to as bicarbonate*), carbonate (CO_2^{3-}) and, at high pH, hydroxide (OH^-) ions. As the alkalinity of water is governed by the concentration of the conjugate base ions, which are most often bicarbonate, bicarbonate alkalinity is the most common of the three forms. At pH values less than 8.3 the hydrogen carbonate ion concentration is the predominant form whereas at pH values greater than 8.3 and 9.6 the concentrations of the carbonate and hydroxide ions, respectively, are of consequence. Bicarbonate alkalinity is just above zero at pH 4. Other ions which may also contribute to the alkalinity of water are borates, silicates, phosphates and organic bases. Alkalinity is expressed either as mg $CaCO_3$/L or as milli-equivalents per litre (mEq/L).

Occurrence

The chemical composition of rocks and soils strongly influences the natural alkalinity of water, which can range from very low values to several hundred mg/L $CaCO_3$. Ground water extracted from aquifers and water in contact with limestone have high alkalinities, while those in catchments based on igneous rock usually have low alkalinities. This however, is not the case for most waters in South Africa where high alkalinities are associated with most rock formation types, except for very weathered sandstones. Water in close proximity to intensive agriculture may have a measurable phosphate-based alkalinity. Alkalinity can be neutralised in rivers, dams and ground waters by acid inputs from mining or industrial activities, and atmospheric pollution.

Interactions

The alkalinity of water is dependent on the activity and proportion of acidic and basic ions and as such is governed by the full chemical composition of the water, as well as physical parameters such as the temperature. In oceans, rivers, and lakes the proportions and concentrations of carbonate-bicarbonate, form the primary buffering system. Hydrogen ions combine with carbonate (CO_2^{3-}) to form bicarbonate (HCO_3^-) and the further addition of H+ to bicarbonate, forms carbonic acid (H_2CO_3), a weak acid, which can be estimated using the equation:

$$2H^+ + CO_2^{3-} \rightleftharpoons H^+ + HCO_3^- \rightleftharpoons H_2CO_3 \rightleftharpoons H_2O + CO_2$$

Dissociation of carbonic acid is only partial, decreasing with decreasing pH and not contributing to the acidity of aqueous solutions less than pH 5. However, above pH 5 the acidity of carbonic acid potentially has a large effect on total acidity because of the increasing solubility of carbon dioxide as pH increases. The pH is therefore regulated; increasing pH promotes the formation of acidic products, while decreasing pH promotes the dissociation of basic ions.

Alkalinity indirectly affects the speciation of metals and the formation of metal complexes and hence, the bio-availability of metals. In alkaline waters with sufficient alkalinity, some metals form relatively non-toxic hydroxide and carbonate precipitates, and dissolved carbonate and bicarbonate complexes. Adequate alkalinity is also essential for biological filtration systems in recirculating fish culture systems. Nitrification of ammonia to nitrate and nitrite, produces acid which, unless the system is adequately buffered, may cause the pH to fall lower than 6.0, and thus negatively affect bacterially mediated nitrification processes.

Measurement

Total alkalinity is measured by titration of the water sample with a strong acid (usually hydrochloric acid), of known concentration to an end point pH of between 8 - 10. The end point of the titration is detected with a pH meter or colour change of an indicator, either phenolphthalein or methyl red. Total alkalinity may be calculated as follows:

$$\text{Total alkalinity (mg } CaCO_3\text{/L)} = \frac{\text{(mL acid) (N) (1 000)}}{\text{(sample volume in mL)}} \times 50$$

where the acid (mL) is the volume of standard acid required to titrate the sample to the methyl red end point, and N is the normality of the acid.

Data Interpretation

Alkalinity measurements should be interpreted in conjunction with the pH, as well as related water properties such as hardness and the dissolved carbon dioxide concentration. Alkalinity is represented as mg $CaCO_3$/L. This is an aggregate property and interpretation may be imprecise unless the ion composition of the water is known. Total hardness in conjunction with alkalinity is an important property in evaluating the corrosion potential of water, and should also be interpreted in relation to corrosion indices.

Treatment Options

Water quality problems associated with alkalinity are usually the result of inadequate alkalinity and therefore poor buffering capacity. Treatment normally entails increasing the alkalinity of the water by the addition of lime.

A simple method of estimating the amount of agricultural limestone required to raise soil pH to more than 7 for earth ponds with low soil pH is to measure the pH of a slurry made by mixing the soil and water in a weight: volume ratio of 1:1. The pH value is then used to obtain the liming rates from the table given below:

pH	**Agricultural limestone (Kg/Ha)**
< 5	3 000
5 - 6	2 000
6 - 7	1 000

To determine the amount of $CaCO_3$ to add to a concrete pond; titrate pond water against a standard solution of $CaCO_3$ until desired pH is reached (pH7). Scale up according to volume of water.

Limestone is not very soluble in water. The rate of dissolution will increase with decreasing particle size, although total alkalinity will not normally exceed 50 - 60 mg $CaCO_3$/L through artificial liming. Addition of lime will also increase the total hardness of the water.

Effects and Criteria

Norms

The norms used in the guideline for alkalinity are based on:

- The influence of alkalinity on the physiological functions of fish.

Effects

Although alkalinity has no effect *per se*, it is an important criterion for determining the effect and concentration of other water quality constituents and criteria, and therefore the general suitability of a water source for the culture of fish. Waters of low alkalinity (< 20 mg $CaCO_3$/L) are considered to be less suitable for fish culture due to the associated unstable water chemistry. The upper limit of alkalinity is largely defined by individual species requirements and the magnitude of the concomitant increase in pH value (see pH guideline). In general, freshwater fish in hard water (100 - 150 mg $CaCO_3$/L) tend to spend less energy on osmoregulation, which results in better growth. The upper limit of alkalinity may also be related to its effect on osmoregulation at high ion concentrations. Symptoms of osmotic stress are given in the total dissolved solids guideline.

Criteria

Table of Criteria and Effects on the Health of Fish

Alkalinity Range (mg $CaCO_3$/L)	**Effects**
0 - 20	Below optimal production
Target Water Quality Range ***20 - 100***	***Production is optimal within this range***
> 175	High alkalinity reduces natural food production in ponds Below optimal production

Sources of Information

BOYD C.E. and H.V. Daniels 1993. *Liming and Fertilization of Brackish Water Shrimp Ponds.* In Anderson, R.O. & Tave, D., (eds) Strategies and Tactics for Management of Fertilized Hatchery Ponds. Food Products Press, New York, pp 221-234.

DALLAS H.F. and J.A. Day 1993. *Effect of Water Quality Variables on Riverine Ecosystems: A Review*. Prepared for the Water Research Commission, University of Cape Town.

FROMM P.O. 1980. *A Review of Some Physiological and Toxicological Responses of Freshwater Fish to Acid Stress*. Env. Biol. Fish. 5: 79-93.

TUCKER C.S. 1993. *Water Analysis* (pp.166-197). In Fish Medicine, (Ed.) M.K. Stoskopf. W.B. Saunders Company, Philadelphia.

WILKIE M.P. and C.M. Wood 1994. *The Effects of Extreme Alkaline Water (pH 9.5) on Rainbow Trout Gill Function and Morphology*. J. Fish Biol. 45: 87-98.

WARREN C.E. 1971. *Biology and Water Pollution Control*. W.B Saunders Company, Philadelphia, 434 pp.

Aluminium

Background Information

Introduction

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 can exist in a number of forms some of which may be soluble in water and some insoluble in water. It occurs as ionised aluminium (Al_3^+), as ionised aluminium complexes, such as $Al_2^-(OH)_6$, and insoluble compounds. Aluminium is probably not an essential nutrient in any organism and is potentially one of the more toxic metals. Soluble ionised aluminium is toxic to fish and aluminium complexes have been implicated in fish-kills.

Occurrence

Aluminium is the most common metal in the earth's crust, with an average proportion of 81g/kg. Aluminium does not occur in 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 the kaolins (various aluminium silicates).

Aluminium occurs in water in two main phases, as suspended aluminium minerals, and as dissolved aluminium species. Aluminium occurs as a hydrated Al(III) cation at low pH, but hydrolyses and precipitates as insoluble aluminium hydroxides around neutral pH. In acidic waters, or where soluble aluminium complexes are present, the soluble aluminium concentration increases. Increases in acidity result in changes in the chemical structure of soils with the release of minerals such as aluminium into runoff water, which may enter lakes and fish farms. High concentrations of soluble aluminium may also be found in natural waters affected by acid rain and acid mine drainage.

Interactions

Aluminium oxide and hydroxide are amphoteric, and are usually insoluble in water around neutral pH, but dissolve under acidic or alkaline conditions. The toxicity of aluminium is strongly dependent on the degree of ionisation of aluminium present in the water. In alkaline waters, aluminium is present as soluble but inactive hydroxide complexes. At lower, near- neutral pH, aluminium often remains insoluble, complexing strongly with silica and organic acid ligands. In waters with a pH below 4, aluminium is released from complexing agents and liberated as the ion (Al^{3+}).

As such the interactions of aluminium are strongly influenced by **pH**, and the nature of available organic and inorganic complexing ligands, such as **fluoride,** which can keep aluminium in solution at neutral pH.

Measurement

The criteria refer to the dissolved aluminium concentration, 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.

Data Interpretation

Mean values should be used in the interpretation of the criteria given. The pH value, as well as the fluoride concentration should also be taken into account, since fluoride tends to form complexes with aluminium, humates, carbonates, silicates and may keep aluminium in solution at neutral pH, where it would otherwise precipitate.

Treatment Options

Aluminium toxicity can be avoided by maintaining the pH above 5.9 to allow the ions to precipitate out of solution. In addition aluminium concentrations can be reduced by precipitation after complexation with inorganic and organic ligands.

Removal of aluminium from water is expensive and in most instances, impractical for aquacultural purposes.

The conventional 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 may be very light and difficult to settle without the addition of polyelectrolytes to flocculate and increase the specific gravity of the particles. However, if the water has a high concentration of suspended clay particles, settlement is fairly fast and the addition of polyelectrolytes is unnecessary. Light particles can also be settled out in properly designed sedimentation tanks without the addition of polyelectrolytes.

- An alternative is to dose the water with a phosphate solution and remove the aluminium as insoluble aluminium phosphate;

- Exchange of sodium by aluminium in a cation exchange column along with calcium and magnesium; and

- Removal of aluminium together with other dissolved components using desalination techniques such as demineralization 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 effects of aluminium on:

- The fitness of the species of fish in terms of health, egg development and behaviour.

- The fitness of fish flesh for human consumption.

Effects

Aluminium toxicity to fish is dependent on the aluminium species and concentration, length of exposure and previous acclimation of the fish.

Acute effects

Aluminium related mortalities are usually associated with the production of mucus that clogs the gills, resulting in anoxia and a rapid loss of sodium due to impaired ion-exchange across the gill membrane. This is usually fatal, as it results in the dilution of the blood plasma ions, which leads to severe osmotic problems in tissues and interstitial fluids.

Chronic effects

These may include aluminium accumulation in the tissues, decreased locomotor activities, hyperventilation, coughing by mucus clogging of the gills, gill damage, anaemia and increased susceptibility to disease.

High concentrations of soluble aluminium are known to influence egg development and hatching. Labile aluminium concentrations between 93 and 183 µg/L has been shown to cause hatching mortalities of between 50 % - 97 % in trout. At pH 5.6, aluminium impairs uptake of calcium, potassium and sodium in juvenile brown trout.

Human consumption

Accumulation of elevated concentrations of aluminium as a result of the consumption of fish is unlikely, since most of the aluminium in fish is deposited in the liver and gills. The liver and gills should be removed if the fish are consumed whole, as is sometimes the case with Tilapia. Fish that have died from aluminium toxicity should not be consumed, since aluminium has been tentatively implicated in Alzheimer's disease.

Mitigation

Mitigatory options for heavy-metal toxicity in fish include:

- Intraperitoneal injections of calcium EDTA, administered once a day at a dose of 25 mg/kg fish mass.
- Placing fish suffering from aluminium toxicity in water containing low concentrations of aluminium at neutral pH.
- An increase in the calcium concentration of the water which may mitigate against damage to the gills because calcium competes with aluminium for binding sites on the gills.

The success of treatment is dependent on the extent of the existing damage. Extensive damage is irreversible and death is inevitable.

Criteria **Table of Criteria and Effects of Aluminium on the Health of Fish**

Aluminium Concentration (mg Al_3^+ / L)	Effects
Target Water Quality Range < 0.03	***No adverse effects on aquatic life at pH > 6.5***
0.07	Toxic to stickleback (*Gasterosteus aculaeatus*)
0.1 - 0.105	Toxic to striped bass (*Morone saxatilis*), 21-d LC_{50} for brown trout
1.5	Fatal to brown trout (*Salmo trutta*)

Note:

The TWQR given above is applicable for a pH range of more than 6.5.

The no adverse effects values of Canadian and Australian standards are 0.005 mg/L at pH above 6.5 and 0.1 at pH above 6.5.

Sources of Information

APHA 1989. *Standard Methods for the Examination of Water and Waste Water*, 17th Edition. L.S. Clesceri, A.E. Greenberg and R.R. Trussel (eds). American Public Health Association American Water Works Association and Water Pollution Control Federation, Washington DC, USA.

DALLAS H.F and J.A. Day 1993. *The Effect of Water Quality Variables on Riverine Ecosystems: A Review*. Freshwater Research Unit, University of Cape Town, Rondebosch.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY 1993. *SA Water Quality Guidelines, Volume 4*. The Government Printer, Pretoria.

EXLEY C. and M.J. Phillips 1988. Acid Rain: *Implications for the Farming of Salmonids,* In: Muir, J.F. & Roberts, R.J (eds). Recent Advances in Aquaculture, Volume 3: 227-341. Timber Press, Portland.

SAYER M.D.J., J.P. Reader and R. Morris 1991. *Embryonic and Larval Development of Brown Trout, Salmo trutta* L.: Exposure to Aluminium, Copper, Lead or Zinc in Soft, Acid Water. J. Fish Biology: 38(3) 431-455.

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

Ammonia

Background Information

Introduction

Ammonia is highly soluble and reacts with water to form ammonium ions. In water, total ammonia consists of ionised ammonia, referred to as ammonium (NH_4^+) and un-ionised ammonia (NH_3). The equilibrium between these two forms is pH- and temperature-dependent.

At high pH, ammonia exits predominantly as NH_3, as a gas in solution, and can be released to the atmosphere from the water. At low and neutral pH, ammonia is found predominantly as ammonium ion. Ammonia can also be microbiologically oxidised to nitrites and nitrates. Ammonia concentrations in water depend on the equilibrium between the rate of production, water exchange rate and oxidation by bacterial activity.

Ammonia is the primary degradation product of nitrogen metabolism in fish and is produced by metabolic activity of the nerve and muscle tissue, deamination of amino acids by the liver and by enzymic activity of the micro flora of the gut. Ninety percent of ammonia is excreted at the gills in freshwater fish. Un-ionized ammonia is toxic and readily diffuses across the gill membrane into the circulatory system, whereas ionized ammonia is a larger, hydrated and charged molecule and can only cross the membrane by active transport through charge-lined micropores of hydrophobic membrane components.

Occurrence

Uncontaminated surface waters generally have a low ammonium nitrogen concentration. This is due to normal biological degradation of protein products, but in high-density aquacultural systems with intensive feeding, much higher concentrations may accumulate.

High concentrations are found in raw (untreated) sewage. Ammonium concentrations also tend to be elevated in waters where organic decomposition under anaerobic conditions takes place. Natural waters may also contain high concentrations of ammonium due to sewage effluent, effluents from certain industries (coal or gas) and agricultural effluents (manure and fertilisers containing ammonium salts).

Interactions

The major factor controlling the toxicity of ammonia is **pH**, which, together with **temperature**, governs the proportion of un-ionised ammonia.

Un-ionized ammonia (NH_3) increases with increasing pH and temperature and may be evident under *pond culture* conditions where photosynthetic activity by phytoplankton causes a rise in pH.

Low concentrations of **dissolved oxygen** (DO) increase the toxicity of NH_3. For example, 0.014 mg/L NH_3 is toxic to rainbow trout if the DO is less than 3.8 mg/L. High concentrations of free carbon dioxide (CO_2) in water result in an increase in pH and therefore an increase in the toxicity of ammonia.

Mixtures of ammonia and various other constituents (for example, cyanide and copper) have been found to be more toxic than either alone. Increased salinity concentrations, up to 30 g/L reduce the ammonia fraction. Higher tolerance levels to ammonia may be achieved by acclimation with sub-lethal concentrations.

Measurement

The criteria are based on the un-ionised ammonia fraction and are given as mg NH_3/L.
The reference method for the determination of ammonia is the phenate colorimetric method. Where other methods are used, their characteristics relative to the reference method should be known.

The un-ionised fraction of ammonia can be calculated if the total ammonia, pH and temperature is known using the equation:

$$\% \text{ UIA} = 100 / [1 + \text{antilog } (\text{pKa} - \text{pH})]$$

where: % UIA is the percent of the total ammonia in un-ionized form, and pKa is the negative antilog of the ionization constant, which is temperature dependent.

Table of Percentage of Total Ammonia Present as Un-ionised Ammonia in Aqueous Solution at Different Temperature and pH Values, *after Boyd, 1982*.

pH	**Temperature (°C)**						
	8	**12**	**16**	**20**	**24**	**28**	**32**
7.0	0.2	0.2	0.3	0.4	0.5	0.7	1.0
8.0	1.6	2.1	2.9	3.8	5.0	6.6	8.8
8.2	2.5	3.3	4.5	5.9	7.7	10.0	13.2
8.4	3.9	5.2	6.9	9.1	11.6	15.0	19.5
8.6	6.0	7.9	10.6	13.7	17.3	21.8	27.7
8.8	9.2	12.0	15.8	20.1	24.9	30.7	37.8
9.0	13.8	17.8	22.9	28.5	34.4	41.2	49.0
9.2	20.4	25.8	32.0	38.7	45.4	52.6	60.4
9.4	30.0	35.5	42.7	50.0	56.9	63.8	70.7
9.6	39.2	46.5	54.1	61.3	67.6	73.6	79.3
9.8	50.5	58.1	65.2	71.5	76.8	81.6	85.8
10.0	61.7	68.5	74.8	79.9	84.0	87.5	90.6
10.2	71.9	77.5	82.4	86.3	89.3	91.8	93.8

The values given in the table are theoretical values in pure solution. If free metal ions are present, the equilibrium will shift.

Data Interpretation

Mean sample values should be used to compare with the criteria given. The ammonia concentration should also be interpreted in relation to **pH** and **temperature**.

Treatment Options

NH_3 ammonia concentrations can be reduced by aeration, by decreasing the pH and by biological filtration by way of nitrifying bacteria.

The volatile nature of free ammonia provides a useful treatment technique for removing ammonia from water, before its entry into the holding system. The pH of the water is increased above 11.0 by the addition of a strong alkali such as sodium hydroxide, to convert all the ammonia to the volatile free form. The water is sprayed in droplet form down through a vertical stripping tower, through which air is blown counter current to the water flow. This strips the volatile ammonia from solution into the atmosphere with the air stream, leaving ammonia residuals of less than 1.0 mg/L. The water is then made usable by re- adjusting the pH to around 7 at which any residual ammonia is likely to exist as the non-toxic ammonium ion. Air stripping of ammonia may cause a local smell nuisance if ammonia levels are significantly high. Natural zeolites, such as clinoptilolites, which absorb ammonium ions and buffer the pH, are also commonly used to reduce ammonia concentrations in recirculating aquaculture systems. The costs may, however, be prohibitive.

High concentrations of free ammonia in fish-farm effluent waters can be reduced by directing the water through reed beds or by using systems designed for tertiary treatment of sewage effluent.

The Effects of Ammonia

Norms

The norms used in the guideline are based on the effects of ammonia on:

- The fitness of the fish species in terms of health, growth, reproduction and behaviour.
- The fitness of fish flesh for human consumption.

Effects

Acute effects

High concentrations of internal ammonia affect intracellular and blood pH, and osmoregulation. This may result in reduced internal ion concentrations, increased urine flow (> 12 % of the lethal threshold concentration) and plasma renin activity (in rainbow trout) and acidemia, which adversely affects the oxygen-binding capacity of haemoglobin.

Acute ammonia toxicity occurs when the passive diffusion of NH_3 into the blood is faster than the active excretion of NH_4^+ across the gill epithelia, whereupon the ammonia concentration of the blood reaches a critical level. Acute toxicity results in hyperventilation, hyper excitability, loss of equilibrium, convulsions, coma and death, probably due to the disruption of membrane processes through the substitution of potassium ions by NH_4^+. Shortly before death the fish hang vertically in the water with their mouths at the water surface, indicating respiratory impairment and distress.

At a concentration of 0.19 mg NH_3/L the growth rate of channel catfish is significantly reduced. The growth rate of Chinook salmon is reduced at ammonia concentrations greater than 0.026 mg/L.

Chronic effects

Long-term exposure of fish to reversed water-to-blood ammonia concentrations leads to various manifestations of chronic toxicity. These include:

- Increases in the primary stress indicators in the blood, i.e. increased concentrations of cortisol and catecholamines;
- Capillary congestion and dilation; renal blood vessel damage; connective tissue inflammation and hyperplasia;
- Tissue damage of the gills (epithelial cell hyperplasia and hypertrophy; separation of epithelial cells from pillar cells which results in inflammation of the gill tissue; cellular degeneration; lamellar detachment; congestion; haemorrhage; aneurysms; karyolysis and karyorrhexis);
- Susceptibility to infection by parasites and diseases increases. Generally, juveniles are more sensitive to elevated NH_3 concentrations than are adults or eggs; and
- Reduction in egg hatching success.

Human consumption

Fish that have died of ammonia poisoning can be eaten although the flesh may be tainted due to haemorrhaging.

Mitigation

In high-density aquaculture the production rate of NH_3 is high and needs to be counteracted by the addition of fresh water or by way of efficient biological filtration techniques. The effects of ammonia can also be mitigated by decreasing the pH, keeping temperatures low (if possible) and/or increasing oxygen supply.

Criteria

Table of Criteria and Effects of Un-ionised Ammonia on the Health of Fish

Ammonia Range (mg NH_3/L)	**Effects**
Cold-water fish	
Target Water Quality Range 0.0 - 0.025	***At pH > 8.0 the upper range of the TWQR must be < 0.025. Values slightly higher may not harm the fish, if previously acclimatized to this concentration***
0.025 - 0.3	Some sub-lethal effects, especially reduced growth rate for cold-water species. Adverse physiological and/or histopathological effects may occur. Blue-sac disease in yolk sac fry of rainbow trout. The 96-hr LC_{50} for 32-day- old juvenile rainbow trout is 0.16 mg NH_3/L
0.3 - 1.10	Adverse physiological and histopathological effects occur in the range of 0.3 - 0.6 mg NH_3/L. The 96-hr LC_{50} for post-yolk-sac rainbow trout is 0.37 mg NH_3/L. The 96-hr LC_{50} for sub-adult and adult rainbow trout is in the range 0.44 - 1.10 mg NH_3/L
Warm-water fish	
Target Water Quality Range 0.0 - 0.3	***No health or sub-lethal effects***
0.3 - 0.8	Possible sub-lethal effects in warm-water fish occur in the range of 0.3 - 0.8 mg NH_3/L.
1.0 - 3.0	The 96-hr LC_{50} for larvae of common carp 1(*Cyprinus carpio*) is in the range 1.74 - 1.84 mg NH_3/L. The 96-hr LC_{50} for Mozambique tilapia (*Oreochromis mossambicus*) is in the range 2.08 - 2.53 mg NH_3/L. The 96-hr LC_{50} for African catfish larvae (*Clarias gariepinus*) is 2.30 mg NH_3/L.
6.5 ± 1.5	96-hr LC_{50} for sub-adult African catfish.
9.1 ± 1.4	96-hr LC_{50} for *Clarias gariepinus* x *Heterobranchus longifilis* hybrids.

Sources of Information

ALABASTER J.S. and R. Lloyd 1980. *Water Quality Criteria for Freshwater Fish*. Chapter 4: Ammonia (p.85-102) in London: Butterworths.

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.

BOYD C.E. 1979. *Water Quality in Warm Water Fish Ponds*. Auburn University. 359pp.

DALLAS H.F. and J.A. Day 1993. *Effect of Water Quality Variables on Riverine Ecosystems: A Review*. Prepared for the Water Research Commission, University of Cape Town.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY 1993. *South African Water Quality Guidelines. Volume 4: Agricultural Use.*

EUROPEAN INLAND FISHERIES ADVISORY COMMISSION 1986. *Report of the Workshop on Terminology, Format and Units of Measurement as related to Flow-through and Recirculation Systems*. EIFAC. Technical Paper (49) 100pp.

McKEE J.E. and H.W. Wolf 1963. *Water Quality Criteria*, 2nd Edition. California State Water Resources Control Board, Publication Nr. 3-A. California.

OELLERMANN L.K. 1995. A comparison of the aquaculture potential of *Clarius gariepinus* (Burchell, 1822) and its hybrid with *Heterobranchus longifillis* (Valenciennes, 1840), in southern Africa. PhD Thesis, Rhodes University, Grahamstown, South Africa.

TRAIN 1979. *Quality Criteria for Water*. U.S. Environmental Protection Agency, Washington DC, USA.

Arsenic

Tentative Guideline

Background Information

Introduction

Arsenic is a greyish semi-metal that occurs in three oxidation states, namely, (0), (III) and (V). In solution arsenic can exist as arsenite, As(III); arsenate, As(V) and as various organic complexes. Inorganic arsenates form arsenate salts with calcium and/or iron ions. Soluble arsenical compounds are readily taken up by living organisms and at elevated concentrations can exert toxic effects. Even a single exposure to an elevated concentration of arsenic can be detrimental. Because arsenic can be bio-accumulated, it needs to be monitored in the aquatic environment.

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 and in association with other metallic ores, and occasionally in the elemental form.
Typically, the concentration of arsenic in fresh water is less than 1 µg/L and in sea water, 4 µg/L. Elevated concentrations of arsenic occur where there is pollution from industrial sources, or where outcrops of arsenate minerals occur. New borehole water supplies in areas where arsenical minerals are known to occur should be tested for arsenic.

Inorganic arsenates have a strong tendency to bind to sediments. The toxicity of arsenic is dependent on its speciation. Arsenic compounds can range from harmless organic compounds such as arsenobetaine or arsenates to toxic inorganic ones such as arsenous oxide, arsine and trimethyl arsine.

Arsenic is used in metallurgy, in the manufacture of glassware and ceramics, and as a pesticide and wood preservative.

Interactions

To a large extent, **pH** and redox potential determine the 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 atomic absorption spectrophotometry, using the hydride method. 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 above reference method should be known.

Data Interpretation

The criteria are given in terms of mg/kg or mg/L. Once absorbed, arsenic is not readily lost, but accumulates. A single exposure to a high concentration of arsenic may have serious long-term effects. The criterion given should be treated as a maximal value not to be exceeded.

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 (addition of iron or aluminium salts at pH 7), 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, which may present disposal problems.

The Effects of Arsenic

Norms The norms used in the guideline are based on the effects of arsenic on:

- The fitness of the fish species in terms of health, growth and reproduction.
- The fitness of aquaculture products for human consumption.

Effects Most arsenic in water is precipitated on the surface of the body and gills of fish, and causes the production of mucous film, and death is usually attributable to suffocation. High concentrations of arsenic cause direct gill damage, which leads to anoxia and collapse of blood vessels. Some arsenical compounds are fat-soluble and therefore accumulate in fatty tissues, although the arsenic that commonly accumulates in fish consists of harmless stable organic arsenate compounds, such as arsenobetaine, which is absorbed readily by the digestion tract, abdominal cavity and muscle tissue. Arsenates, although not particularly toxic, have the ability to uncouple oxidative phosphorylation by replacing the phosphoryl group and thereby interfere with energy metabolism.

Fish exposed to high concentrations of arsenic show a significant increase in phagocytic cells, which may be indicative of a stress response. The fecundity of fish exposed to arsenic is not significantly affected whereas bone growth is, particularly that of collagen metabolism.

Mitigation There are no known mitigatory procedures.

Criteria The ***TWQR for arsenic*** for water bodies containing fish is ***0 - 0.05 mg/L***. In Australia it is illegal to sell any foodstuffs with a concentration of inorganic arsenic in excess of ***1 mg/kg***.

Sources of Information

ANALYTICAL METHODS MANUAL 1992. Water Affairs and Forestry, TR151. 248pp.

APHA 1992. *Standard Methods for the Examination of Water and Waste Water*, 18th Edition. American Public Health Association, Washington DC.

EDMONDS J. and K. Francesconi 1988. *WA Researchers Solve Arsenic Mystery*. Fins 21(3): 20-23.

HEPING A. 1985. *Regional Study and Workshop on the Environmental Assessment and Management of Aquaculture Development* (TCP/RAS/2253).

HAMILTON S.J. and R.J. Reash 1988. *Bone Development in Creek Chub from a Stream Chronically Polluted with Heavy Metals*. Transactions of the American Fisheries Society, 117(1): 48-54.

NACA, 1995. *Environment and Aquaculture Development*. Series No.1 Network of Aquaculture Centres in Asia-Pacific, Bangkok, Thailand, p 91-112.

SHUKLA N.P. and G.N. Pandey 1985. *Effect of Heavy Metals on Fish - A Review*. Reviews on Environmental Health, 5(1): 88-99.

Bacteria

Tentative Guideline

Background Information

Introduction Bacteria are a group of prokaryotic, single-celled organisms that mostly reproduce asexually by binary fission. Many species of bacteria are found in fish ponds and water systems. Most aquatic bacteria are free-living and perform beneficial functions such as the decomposition of organic matter. A few species are opportunistic pathogens and cause diseases in fish, particularly under conditions of stress and immune deficiency. Most bacterial diseases are contagious. If fish with bacterial diseases are not treated they are likely to die.

Occurrence Bacteria are abundant in water. Additional bacteria can be introduced into an aquacultural system by translocation of fish and contamination with transport water. Bacterial diseases of fish frequently follow stress conditions. Stress conditions may include bad handling, overcrowding of fish in ponds or tanks and poor water quality. Healthy, unstressed fish can harbour potentially pathogenic bacteria on the surface of the skin or within the intestine (and possibly other organs) without showing signs of disease.

Interactions The activities of heterotrophic bacteria are dependent on those physical and chemical interactions in the aquatic environment that determine their growth rate and survival.

Measurement Bacterial analysis of water in aquaculture is not common. However, for diagnosis of bacterial diseases only fresh fish should be used. For bacterial diagnosis, the fish surface is disinfected (70 % alcohol) and samples are taken from the blood and the kidney, streaked onto appropriate solid media and incubated for 24 - 48 hours at 28 °C. Trypticase Soy Agar medium is routinely used. Once bacterial colonies are isolated on plates it is possible to proceed with the characterization of each of the isolated types of bacteria.

Treatment Options There are many commercially available antibiotics for specific bacterial diseases. Chemicals such as malachite green and formalin are also used to treat bacterial diseases such as columnaris and pseudomonas (see criteria).

The Effects of Bacteria

Norms The norms used in the guideline for bacteria are based on the effects of bacteria on:

- The fitness of the fish species in terms of health, growth, reproduction and survival.
- The fitness of fish flesh for human consumption.

Effects

Symptoms of most bacterial diseases include fish not feeding well and swimming erratically. Stressed fish are highly susceptible to outbreaks of pathogenic bacteria.

Low levels of dissolved oxygen, thermal stress, high concentrations of nitrogenous metabolites and improper handling are the principal causes which render fish susceptible to bacterial diseases. Growth rate is impaired, fish lose condition and ultimately die if not treated.

There is no known information in the literature on the effect on humans of eating fish with bacterial infections. It is however, fair to assume that it would be unhealthy and the market value of such fish would be significantly affected.

Mitigation

When fish are stressed their tolerances to bacterial infection and diseases decrease. It is therefore important to ensure that fish are well maintained and are not exposed to adverse water quality conditions or improper handling.

Criteria

Table of Bacterial Diseases, Pathologies and Treatments for Some Fish Species

Common Name	Species affected	Bacteria & character	Symptoms & Pathology	Prevention & Treatment *
Bacterial gill disease	Most fresh-water fish world-wide	Flavobacteria	Asphyxia	- Avoidance of overcrowding - Quaternary ammonium disinfectants
Bacterial haemorrhagic septicaemia	Most fresh-water fish world-wide	*Aeromonas hydrophila* Gram-negative bacteria	Haemorrhages on skin, skin ulcers; death	- Avoidance of infection - Oxytetracycline
Cold-water disease of salmonoids	Trout	*Cytophaga psychrophila* Gram-negative bacteria	Skin ulceration	- Oxytetracycline - Sulfamethazine
Columnaris, tail rot, mouth fungus	Most fresh-water fish world-wide	*Flexibacter sp.*	Cottonmouth, skin lesions, tail rot	- Oxytetracycline - Sulfamethazine
Enteric septicaemia	Channel catfish, tilapia	*Edwardsiella ictaluri*	Haemorrhages on skin	- Oxytetracycline
Fin and body rot	Common disease of most fresh-water fish	*Flexibacter columnaris*	Fin necrosis	- Avoid crowding & water pollution - Antibiotics
Fish furunculosis	Trout, goldfish	*Aeromonas salmonicida*	Boils, ulcer of goldfish	- Sulfamerazine - Oxytetracycline - Furoxone
Hagerman redmouth disease	Trout	RM bacterium (an enterobacterium)	Small pinpoint haemorrhages	- Oxytetracycline - Vaccine
Kidney Disease	Trout	*Corynebacterium sp.*	Exophthalmia, skinhaemorrhages, enlarged kidney	- Avoidance of exposure - Sulfamethazine
Mycobacteriosis	Most fresh-water fish world-wide	*Mycobacterium piscium,* *M. fortuitum*	Skin lesions, debility, wasting, colour change	- Avoidance of infection
Nocardiosis	Same as mycobacteriosis but less common	Nocardia	Same as mycobacteria	- Avoidance of infection
Pseudomonas	Common to most fresh-water fish world-wide	*Pseudumonas fluorescens*	Haemorrhagic septicemia, haemorrhages & ulcers	- Antibiotics

Ulcer disease	Trout	*Hemophilus piscium*	External ulcers	- Oxytetracycline
Vibriosis	Common to most fresh-water fish world-wide	*Vibrio anguillarium*	Haemorrhages septicemia	- Oxytetracycline - Furnace - Oral immunization

* Treatment options are highly variable (see Stoskopf 1993)

Sources of Information

BROWN E.E. and J.B. Gratzek 1980. *Fish Farming Handbook*, Van Nostrand Reinhold, New York, pp. 390.

DAS S.M. 1989. *Handbook of Limnology & Water Pollution*, South Asian Publishers, New Delhi, pp. 174.

PAPERNA I. 1980. *Parasites, Infections and Diseases of Fish in Africa*. Food and Agriculture Organisation of the United Nations. CIFA Technical Paper No. 7.

STOSKOPF M.K. 1993. *Fish Medicine*, W.B. Saunders Company, Harcourt Brace Jovanovich, pp. 873.

TUCKER C.S. and E.H. Robinson 1990. *Channel Catfish Farming Handbook*, Van Nostrand Reinhold, New York, pp. 454.

CHART H. and C.B. Munn 1980. Experimental Vibrosis in the Eel (*Anguilla Anguilla*), In: *Fish Disease*, (Eds) Ahne W. Third Cooperative Programme of Research on Aquaculture Session, Springer-Verlag Berlin, pp. 250.

Bacteria

Escherichia coli

Tentative guideline

Background Information

Introduction *Escherichia coli* (*E.coli*) is usually found in the intestinal tract of man and other warm-blooded animals. It is rarely found outside the intestines, except where faecal pollution has occurred (e.g. in sewage). This bacterium has been known to cause diarrhoea, a disease that may have fatal consequences for children. *E. coli* is the most resistant of all coliforms and pathogens.

Occurrence Aquaculture in domestic waste water has been in practise for a long time. Although it has high nutrient value for fish growth, domestic waste water carries a variety of human pathogens. Fish grown in waste water harbour micro-organisms, some of which are pathogenic and may infect consumers and handlers.

Interactions *E.coli* is not pathogenic to fish. In India, for instance fish are cultured in sewage ponds, with no detrimental effects.

Measurement Samples of water or fish are cultured on agar plates at 30 °C, and *E.coli* enumerated as counts (colony forming units)/100 mL of water sample or as cells/gram of tissue sample.

Treatment Options Fish contaminated with *E. coli* should be treated with antibiotics and purged in clean water. If this is not done, recontamination is likely. Since *E.coli* are difficult to treat, it is important to maintain a high standard of hygiene in and around the fish ponds. Fish fillets can also be treated with a dilute chlorine solution.

Effects and Criteria

Norms The norms used in the guideline for *E.coli* are based on:

- The fitness of the species in terms of fish health, growth, reproduction and survival.
- The fitness of fish flesh for human consumption.

Effects There is no information in the scientific literature to show that *E.coli* affects the growth, reproduction, health or survival of the fish. Because waste water is not generally used for fish production in South Africa, little attention has been given to the health aspects involved. The published information is limited to either studies of fish cultivated in sewage or natural waters; no known comparitative studies have been done.

Pathogenic bacteria, including *E.coli* are rapidly destroyed by temperatures higher than 70 °C and contaminated fish do not pose a threat to human health if well cooked. However, one of the associated health hazards is the presence of antibiotic residues in food and the potential for resistant strains to develop that pass on or confer resistance factors to human bacteria such as *Salmonella typhi*, which causes typhoid. Fish can hold waterborne pathogens in the intestine for a long time. If farm animals excrete such resistant pathogens and the excrement is used in fish ponds, the pathogens can be retained in the fish and passed on to humans later. Similarly, if fish are treated with lower than therapeutic levels of antibiotics, this can allow bacteria in fish to develop resistance.

Criteria

Fish-flesh destined for human consumption should not exceed a limit of 10 *E.coli*/g of fish flesh.

Sources of Information

GAIGHER I.G. and T.E. Cloete 1980. *Human Health Aspects of Fish Production in Waste Water in South Africa*, In: Grobbelaar, J.U., C.J. Soeder, D.F. Toerien (Ed). Proceedings of a Workshop on Biological Systems and Waste Treatment, University of the Orange Free State Publications, Series C, No. 3.

PAL D. and C.K. Dasgupta 1991. Interactions of Some City Sewage Bacteria with an Indian Major Carp, *Cirrhinus mrigala*. Journal of Aquatic Animal Health, 3: 124 -129.

PAL D. and C.D. Gupta 1992. *Microbial Pollution in Water and its Effects on Fish*. Journal of Aquatic Animal Health, 4: 32 - 39.

Cadmium

Tentative guideline

Background Information

Introduction

Cadmium is a soft, bluish-white metal chemically similar to zinc and highly toxic to living organisms. The presence of cadmium in the aquatic environment is of concern because it bio-accumulates. Cadmium has low solubility under conditions of neutral or alkaline pH and is highly soluble under acidic conditions, where toxic concentrations can easily arise from the dissolution of cadmium from cadmium-plated materials.

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. It is found naturally in unpolluted surface and ground waters at geochemically low concentrations as a result of leaching from rocks. Cadmium is not usually found in water at concentrations above 1 µg/L, unless the water has been subject to pollution from cadmium-containing industrial effluents. There is often a low concentration of cadmium in soils, sandstones and shales as a result of leaching from ground water. Cadmium is also present in some phosphate fertilisers. Surface waters can be contaminated by rain containing airborne particulate matter contaminated with cadmium from exhaust emissions as a result of the burning fossil fuels.

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. Cadmium is also a by-product in refining copper and zinc, small quantities remaining in the refined product.

Interactions

Cadmium interacts strongly with **zinc** due to the chemical similarity of the two metals. Cadmium has intermediate ionic properties between those of **zinc** and **mercury**. In aqueous solution reduction cannot occur in water containing dissolved oxygen. The hydrated ion $Cd(H_2O)_6^{2+}$ is stable in aqueous solution, is not readily hydrolysed and is far less amphoteric than the corresponding zinc ion. Cadmium also interacts with **selenium**.

Organo-cadmium compounds are far less important in the environment than those of mercury. Cadmium can form a wide variety of soluble complexes. The humic complex is usually the most important in water containing organic matter (derived either from decayed vegetation or from sewage effluent). Complexes with carbonate, sulphate, chloride and hydroxide ions and with chelating agents such as ethylenediaminetetracetic acid (EDTA) and nitiloacetic acid (NTA) may occur. The free uncomplexed ion occurs in soft, unpolluted, low-pH waters. Most cadmium in rivers is transported on solid particles.

The following factors influence the lethal concentration of cadmium.

Temperature: cadmium toxicity is increased at high water temperatures;

The dissolved oxygen concentration: survival decreases in water containing low dissolved oxygen concentrations;

pH: high pH increases bioaccumulation of cadmium;

Water **hardness**: a negative relationship exits between the logarithm of cadmium toxicity and the logarithm of water hardness. Increased hardness reduces bioaccumulation and toxicity of cadmium to fishes;

Additive (synergistic) effects with other metals: additive toxicities have been found for the following combinations of metals: **copper** and cadmium; and cadmium and **mercury**; and

Infra-additive effects with other metals: cadmium toxicity is lowered in the presence of sublethal concentrations of **zinc**.

There is no difference in the toxicity of cadmium in water with or without suspended solids.

Measurement

The criteria are given in terms of the soluble cadmium concentration, in units of µg/L. The reference method for the measurement of cadmium is atomic absorption spectrometry. Where the detection limit is higher than the criteria values, standard procedures for sample concentration should be used. If other methods of analysis such as neutron activation analysis, x-ray fluorescence, flame photometry and optical emission spectrometry 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 dose and frequency of exposure should also be taken into account because cadmium tends to bio-accumulate.

As cadmium toxicity is dependent both on **water hardness** and **pH**, it is imperative that both these variables are measured when assessing the effects cadmium will have on a fish population.

Treatment Options

Cadmium may be removed from solution by adsorption. Cadmium is adsorbed on humic materials to a far greater extent than onto clay or silica particles. Cadmium in water supplies can also be 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 and this may present disposal difficulties.

The Effects of Cadmium

Norms

The norms used in the guideline are based on the effects of cadmium on:

- The fitness of the fish species in terms of health, growth, reproduction and behaviour.

Effects

Most chemical forms of cadmium are similarly toxic and irreversible damage occurs when fish are exposed to high concentrations. Gill tissue is initially damaged by detachment of the epithelial layer with consequent hypertrophy and hyperplasia of the interlamellar epithelium. Pathological changes have been found in the kidney and intestinal tract, and respiratory and extrarenal functions are impaired. Damage to ion regulating mechanisms by cadmium is more likely to be the cause of death than is respiratory impairment or damage to the nervous system.

Cadmium concentrations in bluegill sunfish accumulate maximally in the kidney, liver, gill and gut and to a lesser extent in the spleen and not significantly in the bone or muscle. Equilibria between tissue and water concentrations of cadmium is established within 30 - 60 days in both sunfish and largemouth bass and 80 days for rainbow trout. When returned to the unpolluted water, normal tissue cadmium concentrations are reached in all organs in 80 days. Accumulation of cadmium also occurs in fish fed with food containing cadmium.

Growth, reproduction and behaviour

Data correlating growth rate and cadmium concentration are sparse, although a 28-day growth effect has been observed in salmon. The presence of cadmium increases excitability and mortality in male salmonids during spawning. Hyperactivity, regardless of the sex of the fish, has been reported in bluegill sunfish and largemouth black bass. Significant avoidance behaviour is evident in all fish.

Acclimation occurs in embryos and juveniles exposed to low concentrations of cadmium. Eggs of the common carp exhibit decreased swelling, delayed hatching and a decrease in the survival of embryos.

Salmonid fish species have been found to be more sensitive than cyprinids to cadmium whereas non-salmonids are more tolerant. Thus only water bodies with low cadmium concentrations will contain trout.

Mitigation

No available information.

Criteria

The Target Water Quality Ranges for soluble cadmium for different water hardness values are given in the table below

Water hardness (mgCaCO3 /L)	***Target Water Quality Range for soluble cadmium (µg/L)***	**Effects**
0 - 60	**≤ *0.2***	No adverse effects
60 - 120	**≤ *0.8***	No known adverse effects
120 - 180	**≤ 1.3**	No known adverse effects
180	**≤ *1.8***	No known adverse effects

Modifications

Values should be lowered if dissolved oxygen concentrations are low or if other metal toxicants are present.

Sources of Information

ALABASTER J.S and R. Lloyd 1982. *Water Quality Criteria for Fresh Water Fish*, 2nd Edition. Butterworth Scientific, London, 361pp.

BIRGE W.J., R.D. Hoyt, J.A. Black, M.D. Kercher and W.A. Robinson, 1993. *Effects of Chemical Stresses on Behaviour of Larval and Juvenile Fishes and Amphibians*. American Fisheries Society Symposium, 14: 55-65.

CANADIAN GUIDELINE, 1987. *Canadian Water Quality Guidelines*, Canadian Council of Resource and Environment Ministries, Ottowa.

KOYAMA J., K. Yamawaki, M. Maita, K. Wakabayashi, Y. Ileda and H. Ozaki 1985. *The Effects of Cadmium on the Activities of Tissue Enzymes of Fish*. Bulletin of the Japanese Society of Scientific Fisheries, 51: 1 255-1 260.

NAKAGAWA H. and S. Ishio 1989. Effects of Water Hardness on the Toxicity and Accumulation of Cadmium in Eggs and Larvae of Medaka *Oryzias latipes*. Nippon Suisan Gakkaishi, 55: 321-326.

NAKAGAWA H. and S. Ishio 1989. Effects of Water pH on the Toxicity and Accumulation of Cadmium in Eggs and Larvae of Medaka *Oryzias latipes*. Nippon Suisan Gakkaishi, 55: 327-331.

WITESKA M., B. Jezzerska and J. Chaber 1995. *The Influence of Cadmium on the Common Carp Embryos and Larvae*. Aquaculture, 129: 129-132.

Carbon Dioxide

Background Information

Introduction

Carbon dioxide (CO_2) is the third most common atmospheric gas. It is colourless, odourless and highly soluble in water. Aqueous carbon dioxide exists either as dissolved free CO_2 or in the ionised hydrated form as carbonic acid (H_2CO_3), which dissociates into hydrogen (H^+) and bicarbonate (HCO_3^-) ions. Further dissociation of bicarbonate releases carbonate (CO_3^-) and hydrogen (H^+) ions. The total carbon dioxide in water is the sum of all forms of CO_2 given in the equation below:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3 \rightleftharpoons 2H^+ + CO_3^=$$

An equilibrium exists between the various forms of CO_2 which is determined by pH. A decrease in pH promotes the formation of gaseous CO_2 while an increase in pH favours ionisation to bicarbonate and carbonate ions.

Occurrence

Dissolved carbon dioxide exists in all water and is derived from both biotic and abiotic sources. It is one of the primary by-products of respiration, produced by all organisms, and as such the concentration of CO_2 depends to some extent on the biomass of organisms in the water body. Inorganic carbonate and bicarbonate in the form of hardness and alkalinity can also significantly contribute to carbon dioxide gas in solution, although this is dependent on concentration, temperature and pH. Carbon dioxide does not occur above a pH of 8.3.

High levels of dissolved CO_2 in surface waters are mostly the result of low pH. Accumulation of CO_2 in the water as a result of metabolic processes may in part reduce the ambient pH, although other factors are also implicated. Low pH causes metabolic carbon dioxide to form CO_2 gas. In addition, the equilibrium between carbon dioxide, hydrogen carbonate and carbonate is altered so that the assimilation of CO_2 gas is promoted.

Water extracted from certain underground sources may have high levels of carbon dioxide in addition to high concentrations of carbonates.

Interactions

Apart from the interaction of **pH** with carbon dioxide in solution, gaseous CO_2 fluctuates with metabolic rate. For example, increases in metabolism due to post feeding, elevate CO_2 concentrations. In systems with high plant densities, elevated CO_2 concentrations may occur during plant respiration. **Temperature** also affects the rate of metabolism of organisms and hence the dissolved gas carrying capacity of the water and may therefore also exert some effects on the concentration of gaseous CO_2.

Measurement

Concentrations of individual dissolved gases are expressed in units of mg/L or mL/L, or as percentage saturation or partial pressure. The usual procedure for the determination of carbon dioxide is titration to the phenolphthalein end-point (pH 8.3), with a standard base solution (sodium hydroxide or sodium carbonate).

Total carbon dioxide in water can be calculated indirectly from pH, based on the fact that as carbon dioxide concentration increases, there is a concomitant decrease in pH, see Golterman (1969) in sources of information.

Data Interpretation

Mean sample values should be used to compare with the criteria given. The concentration of CO_2 should be interpreted in conjunction with pH and temperature.

Treatment Options

Water that contains significant concentrations of free carbon dioxide tends to be corrosive. This can be corrected by the addition of hydroxyl ions by dosing with sodium hydroxide or calcium hydroxide. The hydroxyl ions combine with the carbon dioxide to form bicarbonate ions in solution.

The dosing would normally be controlled according to pH.

Alternatively, where the addition of chemical reagents needs to be minimized, it is possible to remove free carbon dioxide from solution by simple aeration of the water or spraying the water vertically downwards through a stripping tower, using a counter current stream of air to remove the carbon dioxide. A pH correction is usually necessary to avoid the water re-dissolving free carbon dioxide.

Both forms of treatment require specialized equipment and some skill in application and control.

The Effects of Carbon Dioxide

Norms

The norms used in the guideline are based on the effects of carbon dioxide on:

- The fitness of the fish species in terms of health, growth, reproduction and behaviour.

Effects

Since carbon dioxide resulting from metabolic processes leaves organisms by diffusion, an increase in external carbon dioxide concentration decreases the diffusion gradient, resulting in internal accumulation of the gas. This effectively prevents excretion of bicarbonate ions from the gills. The higher the concentration of carbonic acid, specifically the bicarbonate ion (HCO_3^-), in water surrounding fish, the greater the inhibition of excretory function, resulting in accumulation of metabolic wastes. This alters the ratio of oxygen to carbon dioxide in all body tissues, including the brain, where slight anoxia produces anaesthesia. The presence of free carbon dioxide depresses the affinity of fish blood for oxygen.

Acute effects

High concentrations of carbon dioxide (hypercapnia) give rise to a reduced rate of oxygen transportation in the blood and the formation of calcareous deposits in the kidney (nephrocalcinosis). Acute reactions of fish to CO_2 include:

- Avoidance reactions;
- Changes in respiratory movements at low concentrations; and
- Interference with gas exchange at high concentrations, which may result in narcosis and death.

Chronic effects

Chronic exposure to intermediate levels of carbon dioxide (55 mg/L) reduces growth and increases food conversion ratios in rainbow trout. Continuous exposure to concentrations of 12 - 60 mg/L may result in the development of nephrocalcinosis in rainbow trout, the prevalence and severity of which increases with increasing CO_2 concentrations.

Under controlled conditions carbon dioxide may be successfully used as a fish anaesthetic that does not produce any contaminating residues, thereby rendering fish acceptable for immediate human consumption.

Mitigation

Reduction of gaseous carbon dioxide concentrations is facilitated through control of pH. Possible mitigatory options are to reduce the metabolic contribution of CO_2, by decreasing the stocking and aquatic plant density. Agitation and aeration of the water also effects a reduction in free carbon dioxide.

Recovery from the effects of CO_2 accumulation by fish is achievable, if anoxia is reversed. This is best achieved by transferring the fish to fresh water or by diluting the concentration of bicarbonate ions.

Criteria **Table of Criteria and Effects of Dissolved Carbon Dioxide (DC) on some Fish Species**

Species	DC Concentration	Exposure	Effect
Target Water Quality Range	***< 12 (mg/L)***	***Continuous***	***No adverse effects. Protective to most fish species***
Rainbow trout	12 - 60 (mg/L)	Continuous	Causes nephrocalcinosis
Channel catfish	40 - 50 (mg/L)	Periodic	No effect
Rainbow trout	55 mg/L	Chronic	Reduced growth and increased food conversion
	120 - 150 (mg/L)	1.5 min	Loss of equilibrium in fingerlings
	240 - 265 (mg/L)	2.2 min	Loss of equilibrium in adults
Common carp (adult)	25 - 75 (mm Hg*)	10 min	No effect
	100 (mm Hg)	10 min	Anaesthesia
	125 (mm Hg)	10 min	10 % mortality
	150 (mm Hg)	10 min	20 % mortality
	175 (mm Hg)	10 min	70 % mortality

* mm Hg represents a partial pressure. The values in the table have not been converted to mg/L as no correlating pH or temperature values were provided.

Sources of Information

FISH F.F. 1943. *The Anaesthesia of Fish by High Carbon Dioxide Concentrations*. Trans. Am. Fish. Soc., 72: 25-29.

GOLTERMAN H.L. 1969. *Methods for Chemical Analysis of Fresh Water*. Blackwell Scientific Publications, Oxford, pp. 136-147.

POST G. 1979. *Carbonic Acid Anaesthesia for Aquatic Organisms*. Prog. Fish-Cult., 41: 142-144.

YOKOYAMA Y., H. Yoshikawa, S. Ueno and H. Mitsuda 1989. *Application of* CO_2*-anaesthesia Combined with Low Temperature for Long-Term Anaesthesia*, In: Carp. Bull. Jpn. Soc. Sci. Fish., 55: 1 203-1 209.

YOSHIKAWA H., Y. Ishida, S. Ueno and H. Mitsuda 1988a. *Changes in Depth of Anaesthesia of the Carp Anaesthetised with a Constant Level of* CO_2. Bull. Jpn. Soc. Sci. Fish., 54: 457-462.

YOSHIKAWA H., Y. Ishida, S. Ueno and H. Mitsuda 1988b. *The Use of Sedating Action of* CO_2 *for Long-term Anaesthesia,* In: Carp. Bull. Jpn. Soc. Sci. Fish., 54: 545-551.

Chloride

Tentative guideline

Background Information

Introduction

Chloride is the anion of the element chlorine. Chlorine seldom occurs in nature, but is usually found as chloride. The chlorides of alkaline and alkaline earth metals are all highly soluble in water, for example, sodium, potassium, calcium and magnesium.

Chloride is of concern in water supplies used for aquaculture because the anions are essential for osmotic, ionic and water balance in all fishes.

Occurrence

Chloride is a ubiquitous aqueous anion. The natural origins of chloride in inland waters are attributable to leaching of salts from underlying rock strata (mostly sedimentary rocks of marine origin) from which springs arise or over which the river flows. Near coastal areas chlorides are derived from rainwater containing dissolved salts from the sea.

In many fresh-waters the proportional concentration of anions is carbonates > sulphates > chlorides. However, where ground water may come in contact with salt- rich deposits the anion sequence is reversed, and is chlorides > sulphates > carbonates. A similar anion sequence is usually found for very soft waters such as coastal waters, and for almost all saline waters and waters flowing over highly leached rocks low in calcium and magnesium, whether coastal or inland.

Typically, the 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 water may arise from irrigation return flows, sewage effluent discharges and various industrial processes. With repeated re-use or recycling of water, the chloride concentration increases with each cycle and can only be removed by energy-intensive desalinating processes.

Interactions

Chloride contributes to the concentration of **total dissolved solids** (**TDS**) and to the **salinity** of water. At high concentrations, chlorides interact with metals to enhance corrosion by accelerating oxidation. Chlorides are particularly aggressive to stainless steels, resulting in stress corrosion and cracking.

Measurement

The criteria are given in terms of the chloride concentration, in units of mg/L. The reference method for the determination of dissolved chloride is usually by colorimetry using the ferricyanide 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. Chloride concentrations should be interpreted in conjunction with the major cations (sodium, potassium, calcium and magnesium) and anions (sulphates and bicarbonates).

Treatment Options

Chlorides are highly soluble in water and cannot be precipitated at concentrations normally present. Conventional methods for demineralisation or desalinisation used to reduce the TDS concentration can be used to reduce chloride concentrations.

Chloride can also be removed from water by **electrolysis** to form chlorine gas liberated at the anode. Electrolysis is not effective where the conductivity and chloride concentration are low.

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

anion exchange resin beds, in which all significant anions will be 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 guideline are based on the effects of chloride on:

- The fitness of the fish species in terms of health, growth and reproduction.

Effects

Chloride has little effect on fish health or behaviour and is not considered a problem in inland waters. At high concentrations near the coast, some freshwater fish may show symptoms similar to those given for salinity.

Criteria

Due to insufficient data, a TWQR for chloride has not been set in this guideline. Most fresh- water species are able to survive at 600 mg Cl^-/L, but production is not optimal.

Sources of Information

APHA 1992. *Standard Methods for the Examination of Water and Waste Water*, 18th Edition. American Public Health Association, Washington DC.

CANADIAN GUIDELINE, 1987. *Canadian Water Quality Guidelines*, Canadian Council of Resource and Environment Ministries, Ottowa.

Chlorine

Tentative Guideline

Background Information

Introduction

Chlorine is a powerful, commonly available oxidizing agent that easily dissolves in water. It is found in various forms such as elemental chlorine, hypochlorites, and chloramines, and hypochlorite-based compounds such as calcium hypochlorite and dichloroisocyanurates.

Occurrence

Chlorine is used extensively as a biocide for disinfecting and sterilizing drinking water. Chlorination is also used in the textile and paper and pulp industries for bleaching, in cooling towers for its slimicidal properties and in sewage treatment to reduce odour, the density of "ponding algae" on filter beds, and bacteria in effluents discharged to surface waters.

Interactions

Chlorine can be described as *free, available, active* or *residual*. When present as chloramines it is referred to as *bound available chlorine*.

Free available chlorine is present as an equilibrium mixture of chlorite ions (OCl^-) and hypochlorous acid (HOCl). Bound available chlorine is in the form of chloramines or other compounds with a N-Cl bond. The total available chlorine is the sum of free and combined available chlorine.

When elemental chlorine (Cl_2) or hypochlorite ions are added to water at pH values greater than 5, rapid chemical reactions occur resulting in the formation of hypochlorous acid (HOCl) in equilibrium with hypochlorite ions (OCl^-) according to the following reactions:

$$Cl_2 + H_2O \rightleftharpoons H^+ + Cl^- + HOCl$$
$$HOCl \rightleftharpoons H^+ + OCl^-$$

$$Ca(OCl)_2 \rightarrow Ca^{2+} + 2OCl^-$$
$$H^+ + OCl^- \rightleftharpoons HOCl$$

Elemental chlorine is extremely *fugitive* and can essentially be ignored. The chemical species causing poisoning is most probably hypochlorous acid, the toxicity of any solution will depend on **pH**. Below pH 7.5, at all temperatures at which most fish species are found, the greater part of the chlorine present will be in the toxic form.

When chlorine is added to water containing ammonia it will, in the absence of other oxidizable substances, initially form chloramine (NH_2Cl), chlorimine (NHC_2l), nitrogen trichloride (NCl_3) or a mixture of these compounds, according to the following reactions:

$$NH_4^+ + HOCl \rightarrow NH_2Cl + H_2O + H^+$$

$$NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$$

$$NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$$

Formation of the more highly substituted derivatives is favoured by an increased acidity of solution and an increased ratio of chlorine to ammoniacal nitrogen. In waters with normal pH values only a small amount of nitrogen trichloride (known to cause chronic systemic effects) is formed.

Chloramines slowly reach an equilibrium with a small concentration of hypochlorous acid, which accounts for their toxicity to fish. Since sewage effluents always contain ammonia, the effects of chlorine must not be considered without taking into account the effects of chloramines which though less toxic than chlorine, are more persistent. Hypochlorous acid and the hypochlorite ion slowly decompose forming chloride ions and oxygen, a process accelerated by sunlight.

Chlorine can react with thiocyanide to produce lethal concentrations of hydrogen cyanide and/or hydrogen chloride.

Little data are available on the effect of temperature on chlorine toxicity, although it does seem that there are higher mortalities with increased water temperature and lowered dissolved oxygen concentrations.

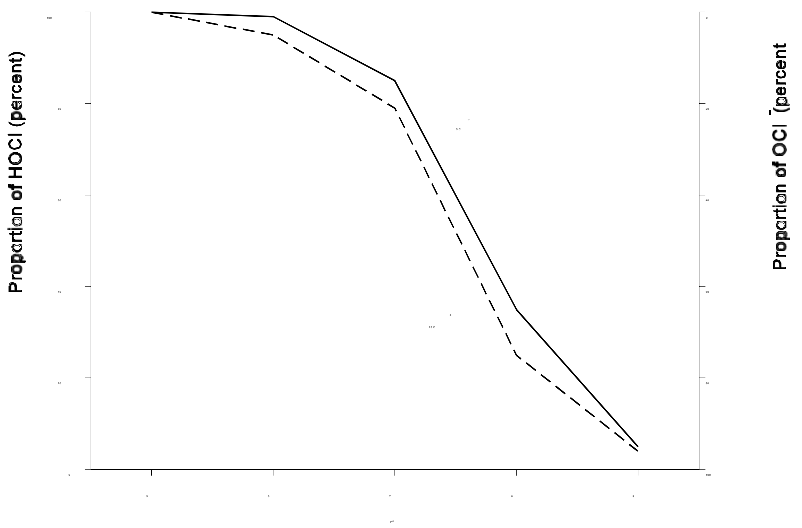
The amounts of total chlorine corresponding to temperature and pH are given in the table below:

Table of the approximate Total Concentrations of Chlorine corresponding to 4 µg HOCl/L

Temperature (°C)	Concentration (µg/L)			
	pH 6	pH 7	pH 8	pH 9
5	4	5	11	75
25	4	5	16	121

Note:

A lower limit must be applied if phenolic compounds are present.



Proportion of HOCl and OCl^- in solution at temperatures of 5 °C and 25 °C and pH values between 5 and 9. [*] After Alabaster and Lloyd, 1982.

Measurement

The criteria are given in terms of the total chlorine concentration in units of µg HOCl/L. The reference method for the determination of chlorine and chloramine concentrations is amperometric titration.

Data Interpretation

The relationship between hypochlorous acid and hypochlorite ions is highly **pH** dependent (Figure 1). At low pH values, chlorine is more toxic than at high pH values. The relationship between ammonia and ammonium ions should also be taken into account when calculating chloramine concentrations.

Treatment Options

Chlorine can be removed by adsorption with activated carbon and neutralized with reducing agents such as sodium thiosulphate or ferrous salts. Neutralization can be checked with starch-iodide chlorine test paper with orthotolidine solution. The toxic effects of any added chemicals must however be checked. Chlorine can never completely be removed, and the residual levels should be below the TWQR.

The Effects of Chlorine

Norms

The norms used in the guideline are based on the effects of chlorine on:

- The fitness of the fish species in terms of health, growth, reproduction and behaviour;
- The fitness of fish flesh for human consumption.

Effects

Chlorine oxidizes plant and animal enzymes containing sulphydryl (-SH) groups, thus destroying enzymatic activity because of the strength of the resultant covalent bond. Fish are unlikely to recover after exposure to chlorine. Monochloramine exposure results in anoxia due to the oxidization of haemoglobin to methaemoglobin and disruption of erythrocyte membranes. Increased numbers of erythrocytes are formed and this increases blood viscosity, hindering normal vascular circulation.

Growth, reproduction and behaviour

Non-salmonid fish tend to be more chlorine-tolerant than salmonid species and smaller species tend to be more susceptible to chlorine than larger species.

Egg mortality is increased in the presence of chlorine, with newly hatched larvae being more susceptible than eggs. Spawning at high densities has been shown to have been is reduced in chlorinated water and in cases where spawning did occur, there was a reduction in spawning frequency and egg number.

Rainbow trout have demonstrated avoidance behaviour to chlorinated water. Fish have been shown to acclimatize slightly to low chlorine concentrations, but there are, still mortalities.

Human consumption

Concentrations of chlorine as low as 1 µg/L in the presence of phenols are likely to taint the flesh of fish, rendering it unsuitable for human consumption. It is therefore necessary to take special precautions when cleaning tanks with chlorinated products.

Mitigation

Mitigatory procedures for the effects of chlorine on fish are unknown.

Criteria

Table of Criteria and Effects of Chlorine on some Fish Species

Target Water Quality Range (µgHOCl/L)	Effects	
	Salmonids	Cyprinids
< 2	*No known adverse effects*	-
< 10	-	*No known adverse effects*

Sources of Information

ALABASTER J.S and R. Lloyd 1982. *Water Quality Criteria for Freshwater Fish*, 2nd Edition. Butterworth Scientific, London, 361pp.

WANG M.P and S.A. Hanson 1985. *The Acute Toxicity of Chlorine to Freshwater Organisms: Time-concentration Relationships of Constant and Intermittent Exposures.* American Society for Testing and Materials Special Report, 891: 213-232.

WHEATON F.W. 1977. *Aquacultural Engineering*. John Wiley & Sons, New York, 708pp.

Chromium(VI)

Background Information

Introduction

Chromium(VI) is a highly oxidized state of metallic chromium. It occurs as a yellow-coloured dichromate salt under neutral or alkaline conditions and as an 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) and have a much lower toxicity index than chromium(VI). They therefore do not constitute as serious a health hazard as does chromium(VI).

Occurrence

The most common ore of chromium is chromite, in which chromium occurs in the trivalent state. Chromium enters the environment through the natural weathering of chromite ores. Minerals containing chromium(VI) do occur, but are not common. The most elevated concentrations of chromium(VI) found in the environment are the result of industrial pollution. Because chromium(VI) is highly water-soluble, it is very mobile in the environment and readily moves through the soil profile, resulting in contamination of 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 above 0.01 mg/L. Higher concentrations may occur wherever operations using chromium(VI) compounds are located.

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

Chromic acid and 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

Chromium most commonly occurs in its trivalent or hexavalent oxidative states. The proportion of the two states is dependent on the amount of **organic matter** and the **dissolved oxygen** concentrations in the water. Hexavalent chromium is considered to be 100 times more toxic to fish than trivalent chromium.

The equilibrium between chromium(VI) and its reduced forms is strongly influenced by **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

It is necessary to assume that all chromium present is chromium(VI).

The criterion is given as soluble chromium in units of µg/L. The reference method for the determination by chromium(VI) is by diphenyl carbazide spectrophotometry. Whenever chromium(VI) 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. Chromium(III) is calculated by subtraction from chromium(VI). Where other methods are used, their characteristics relative to the reference type method should be known.

Data Interpretation

The criterion given should be interpreted as the maximal allowable value and should not be exceeded.

The following factors influence the lethal concentration of chromium.

pH: acute toxicity to chromium(VI) in rainbow trout decreases with decreasing pH in the range of 7.8 - 6.5. Only the gills are affected at pH 6.5.

Total hardness: toxicity decreases with an increase in the total hardness of water. Chromium(III) is more toxic in soft water than hard water.

Treatment Options

Chromium(VI) is the most soluble of the chromium species and its removal requires pre-treatment of chromium(VI) to a more easily precipitable species. This can be achieved by the addition of ferrous sulphate to the water 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 ferric salts, followed by settlement and filtration. The process needs careful monitoring to ensure effective removal of chromium. The expense under culture conditions is very high.

Removal with **reverse osmosis** or **ion exchange.** This process is suitable under recirculating conditions, but not for pond culture conditions.

Alternative methods are available for adsorbing chromium(VI) onto ferric hydroxide precipitates. These, however, are not as efficient as methods that 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, presenting disposal difficulties.

The Effects of Chromium(VI)

Norms

The norms used in the guideline are based on the effects of chromium on:

- The fitness of the fish species in terms of health and growth.

Effects

Fish are considerably less sensitive to chromium than aquatic plants and invertebrates Chromium is a carcinogen and causes chromosomal aberrations. The effects of chromium exposure are more dependent on the dose than on the duration of exposure. Fish exposed to chromium have significantly reduced growth rates. Accumulation of chromium is greatest in the liver and kidneys, but also occurs in the testes, brain and blood. The kidney and myocardium tend to accumulate chromium irrespective of its oxidative state, even though chromium(VI) is more permeable than chromium(III).

The toxicological action of chromium is different from other heavy metals as it has a hexavalent form which enables it to cross cell membranes resulting in both external and internal tissue damage.

The toxilogical action of chromium is different from other heavy metals as it has a hexavalent form which enables it to cross cell membranes resulting in both external and internal tissue damage.

Exposure to chromium to freshwater teleosts results primarily in the irritation of the gill surface and anaemia and leucopenia which is secondary to internal tissue damage.

As with most other toxins, salmonid fishes tend to be more sensitive to chromium than do non-salmonid fishes.

Mitigation There are no known mitigatory measures against the effects of chromium toxicity to fish.

Criteria Since chromium bio-accumulates, the TWQR set for aquaculture is also protective of all fresh water fish species.

Concentration Range (µg/L)	**Effects**
Target Water Quality Range ***< 20***	***No adverse effects on fish and other aquatic biota***

Sources of Information

ANALYTICAL METHODS MANUAL 1992. Water Affairs and Forestry, TR151. 248pp.

APHA 1992. *Standard Methods for the Examination of Water and Waste Water*, 18th Edition. American Public Health Association, Washington DC.

CANADIAN GUIDELINE, 1987. *Canadian Water Quality Guidelines*, Canadian Council of Resource and Environment Ministries, Ottowa.

CHIAUDANI G. and G. Premazzi 1988. *Water Quality Criteria in Environmental Management*. Commission of the European Communities, Directorate General Science, Research and Development, Joint Research Center, Luxemborg, Report No. EUR 11 638EN, 78pp.

HELLAWELL J.M. 1986. *Biological Indicators of Freshwater Pollution and Environment Management.* Elsevier Applied Science, London, 546pp.

UKLA N.P. and G.N. Pandey 1985. *Effect of Heavy Metals on Fish - A Review*. Reviews on Environmental Health 5(1): 88-99.

WEPENER V, J.H.J. van Vuren and H.H. du Preez 1992. *The Effect of Hexavalent Chromium at different pH values on the Haematology of Tilapia sparmanii (Cichlidae*). Comparative Biochemistry and Physiology, 101C: 375-381.

Copper

Background Information

Introduction

Copper occurs in three oxidation states, as metallic copper(0), cuprous copper(I) and cupric copper(II). Copper is a micronutrient, forming an essential component of many enzymes involved in redox reactions. The toxicity of copper depends on the solubility and chemical species of the copper present in water. Free cupric copper ions (Cu^{2+}) are considered most toxic, and complexed forms least toxic, to aquatic organisms.

Copper is an essential trace element for plants and animals. Copper toxicity in closed aquaculture systems is rare, but may occur where dissolution of copper from copper or bronze plumbing fixtures has occurred. Copper may also be introduced into aquaculture systems as a treatment for protozoan infections, control of algae or as a molluscicide. If the treatment doses are not calculated accurately and alkalinity is not taken into account, copper poisoning may occur. A combination of pH, alkalinity, and water hardness, as well as the presence of inorganic and organic complexing ligands, controls the availability of free cupric ions and therefore the toxicity of copper.

Occurrence

Many minerals containing copper are known; some of these such as malachite, azurite and turquoise are important semi-precious minerals. 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 copper concentration in surface waters is usually low, typically about 0.003 mg/L, whereas in acidic waters, copper readily dissolves and substantially higher concentrations may occur. The concentration of copper in sea water is about 0.002 mg/L. Copper is readily adsorbed onto particles and precipitated into sediments at alkaline pH. Re-mobilisation of copper to the underlying water occurs on acidification. Copper also bio-accumulates in certain plants, animals and fish.

Copper has excellent conducting properties and so one of the most important industrial uses of copper is in the electrical industry. Elevated concentrations of copper may result from effluent discharges from industries such as paper mills and steel works, and from electrical industries. The ability of the cupric ion to act as a toxin depends on its solubility and its interactions with other water constituents (see below).

Interactions

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

Copper toxicity is decreased in water with high alkalinity, since the cupric ion combines with the carbonate ion (CO_3^{2-}) to form insoluble copper carbonate ($CuCO_3$), which precipitates out of solution. At alkalinities of less than 50 mg $CaCO_3$/L the toxicity of copper increases as there is insufficient carbonate present in the water to form a salt complex with the toxic cupric ion. Copper toxicity is further increased by a reduction of **water hardness**, **low dissolved oxygen** levels and a low **temperature**. The presence of chelating agents such as EDTA and NTA, humic acids, amino acids and suspended solids will decrease copper toxicity as the free ions are readily complexed with inorganic and organic substances and are therefore not biologically available to act as toxins. Combinations of copper with some heavy metals, such as nickel and zinc, appear to have additive effects, increasing the toxicity of copper. Molybdenum and sulphate have antagonistic effects, reducing copper toxicity.

Measurement

The criteria are given in terms of the total copper concentration, expressed as mg/L. Total dissolved copper is measured after acidification of the 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 maximal values should be used to compare with the criteria given. Copper concentrations should also be interpreted in relation to pH, and to the concentration of ammonia because ammonia can solubilise copper at alkaline pH and facilitate uptake by fish.

Treatment Options

Copper in solution is most conveniently removed from water by:

flocculation with alum or ferric salts at pH 6 - 7; this reduces the soluble copper concentration to a low level; or
using lime to raise the pH and precipitate the insoluble copper carbonate and hydroxide complexes; precipitation is followed by settlement and filtration as in conventional treatment of water.

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

However, either of the two options given above would normally be too expensive to implement under aquaculture conditions.

The Effects of Copper

Norms

The norms used in the guideline are based on the effects of copper on:

- The fitness of the fish species in terms of health, behaviour and reproduction.

Effects

Clinical signs of acute copper toxicity are usually evident 24 - 48 hours after exposure and are dependent on pH, temperature and the copper concentration.

Acute effects

Acute copper toxicity in fish causes severe mucus clogging of the gills and extensive gill damage, as well as hepatic and renal disorders. Symptoms of copper poisoning include anorexia, oedema and protrusion of scales.

Chronic effects

Long-term exposure of fish to low levels of copper results in haematological effects such as erythrocytopia and hyperglycaemic changes in the nervous and immune systems, rendering the fish more susceptible to infectious diseases.

Growth, reproduction and behaviour

Fish affected by copper become dark in colour, lethargic and indifferent to external stimuli. If exposure persists the fish become uncoordinated and disoriented. The fish may become extremely colourful just before death since copper causes the melanophores to relax.

The early life-stages of fish are more sensitive to copper than are adults. Concentrations of 0.02 - 0.04 mg Cu/L have been shown to impair hatching rates of rainbow trout and Atlantic salmon eggs in soft waters. Continuous exposure to 0.015 mg Cu/L reduces growth of juvenile brown trout. At pH 5.6, copper ions impair calcium, sodium and potassium uptake of fry of brown trout.

The behaviour of natural populations of fish is also affected by trace amounts of copper. Sensitive fish populations may restrict themselves to certain areas of streams where copper concentrations are lowest. Although this may reduce exposure to copper, it limits spawning and interferes with feeding habits.

Mitigation

Copper fittings in recirculating systems can be coated with Teflon®, vinyl, polypropylene, neoprene or epoxy to prevent copper poisoning. If copper poisoning does occur, the source of the exposure must be identified and removed from the system. For practical purposes, no copper (or other metal) fittings should be used in recirculating aquaculture systems.

Treatment of infections and algae with copper should be carried out under controlled conditions. The alkalinity of the water must be taken into account when calculating the required concentrations and copper must be introduced into an aquacultural system over a period of about three days. This allows the fish to adapt to the increasing copper concentration by producing a substance which facilitates the internal storage of copper without toxic effects.

If copper reaches toxic concentrations, the pH may be lowered to between 4.4 and 4.7 (if possible) and complexing agents added to reduce the availability of Cu^{2+} ions. Further, the calcium ion content of the water can be increased to reduce the availability of copper ions. Since calcium ions compete with copper ions for binding sites on the gills, calcium may reduce uptake of copper ions through competitive binding.

An increase in temperature and dissolved oxygen will also reduce the toxic effects of copper.

Criteria

Table of Criteria and Effects of Copper on the Health of Fish

Copper concentration (mg Cu/L)	**Effects**
0.001	Decreased growth during early ontogeny of salmonids. 100 % death of coho salmon juveniles after 39 days of exposure
Target water quality range < 0.005	***No known adverse effects***
0.002 - 0.006	Canadian guidelines
0.006	*Upper limit for continuous exposure in soft water*
0.009	96-hr LC_{50} for striped bass (*Morone saxiatilis*)
0.014	Safe limit for salmonids
0.03	*Upper limit for continuous exposure in hard water*
0.02 - 0.04	Impaired hatching in rainbow trout
0.048	96-hr LC_{50} for Atlantic salmon (*Salmo salar*)
0.07	Avoidance behaviour observed in rainbow trout
1.29 - 1.38	LC_{50} for African Catfish (*Clarias gariepinus*)
0.46	96-hr LC_{50} for goldfish (*Carassius auratus*)
0.6	96-hr LC_{50} for carp (*Cyprinus carpio*)

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.

DALLAS H.F. and J.A. Day 1993. *The Effect of Water Quality Variables on Riverine Ecosystems: A Review.* Freshwater Research Unit, UCT.

DETHLEFSEN V. and K. Tiews 1985. *Review on the Effects of Pollution on Marine Fishlife and Fisheries in the North Sea.* J. Applied Ichthyology, 1(3):97 - 118.

EXLEY C. and M.J. Phillips 1988. *Acid Rain: Implications for the Farming of Salmonids*, In: Muir, J.F. & R.J. Roberts (eds). Recent Advances in Aquaculture, Volume 3: 227-341. Timber Press, Portland.

GLUBOKOV A.I. 1990. *Growth of Three Species of Fish during Early Ontogeny under Normal and Toxic Conditions.* J. of Ichthyology, 30(2): 51-89.

SAYER M.D.J., J.P. Reader and R. Morris 1989. *The Effect of Calcium Concentration on the Toxicity of Copper, Lead and Zinc to Yolk-sac Fry of Brown Trout, Salmo trutta L., in Soft, Acid Water.* J. Fish Biol. 35(3)323-332.

STOSKOPF M.K. 1993. *Fish Medicine*, W.B. Saunders Company, Mexico.

VAN DER MERWE M., J.H.J. van Vuren and H.H. du Preez (1993). Lethal copper concentration levels for *Clarias gariepinus* (Burchell, 1822) - A Preliminary Study. *Koedoe* 36(2): 77 - 86.

VAN VUREN J.H.J., M. van der Merwe and H.H. du Preez (1994). The Effect of Copper on the Blood Chemistry of *Clarias gariepinus* (Claridae) (1994), Ecotoxicology and Environmental Safety 29, 187-199.

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*, 2nd Edition, Volume 1: Recommendations. World Health Organization, Geneva.

Cyanide

Tentative Guideline

Background Information

Introduction

Cyanide salts ionize in water to release cyanide ions (CN^-), which hydrolyse to form hydrocyanic acid (HCN). Hydrocyanic acid is the most toxic form of cyanide.

Occurrence

Cyanide is widespread in surface and ground water, where it originates from industrial wastes such as mine drainage. Cyanogenic blue-green bacteria are a natural source, releasing cyanide after death. Cyanide toxicity is rare in intensive farming practices but may be an annual problem in fish raised in net-pens in large reservoirs. This usually occurs during the mid-summer months when water temperatures are at a maximum and algal growth is prolific. Cyanide is also used illegally for the capture of marine coral-reef fishes for the aquarium trade.

Interactions

There is a paucity of information regarding the interactions of cyanide with other water constituents. Mixtures of cyanide and ammonia have been found to be more toxic than either alone.

Measurement

The criteria for cyanide are given in units of mg/L. The reference method for measuring cyanide is acid distillation followed by colorimetry. Where colorimetry is not sufficiently sensitive, high performance ion exchange chromatography should be used.

Data Interpretation

Single-sample maximal values should be used to compare with the criteria given.

Treatment Options

Prevention of cyanide contamination is the most practical option. Cyanide contamination can be avoided through careful selection of farming locations. Water in the area must not be polluted by industrial wastes and the site should not be subject to blooms of potentially toxic algae. Biological production of cyanide from blue-green algae can be prevented through minimizing the organic load in the water and by the use of a commercial chemical that restricts the sunlight needed by cyanogenic blue-green bacteria.

The Effects of Cyanide

Norms

The norms used in the guideline for cyanide are based on:

- Fitness of the fish species in terms of health, behaviour, growth, reproduction and lethal tolerance levels.

Effects

Cyanide toxicity is not easily diagnosed and the condition is usually indicated by sudden mortalities associated with eutrophication and mass production of blue-green bacteria. Mortalities in fish stocks exposed to sublethal concentrations of cyanide may not occur immediately, although most of the fish will eventually die as a result of starvation or liver failure. Atrophy of the alimentary tract may occur.

Cyanide interferes with oxygen metabolism; fish respond to cyanide poisoning by increasing the water flow over their gills and by decreasing their heartbeats (bradycardia). Other effects of cyanide on fish may include liver degeneration, histopathological damage to intestines, and degeneration of the stomach lining, concomitant with a loss of appetite and disorientation.

Sublethal levels of cyanide poisoning may reduce fish growth and inhibit reproduction, probably as a result of alterations in lipid metabolism in the liver.

The lethal threshold levels for cyanide in fish range from 30 - 150 µg/L HCN. Salmonids exhibit a greater sensitivity (10-fold) to cyanide poisoning than do cyprinids and ictalurids.

Mitigation The effects of cyanide poisoning are mostly irreversible, although prolonged bathing of the fish for up to 5 days in methylene blue (3 mg/L) may reduce the toxic effects.

Criteria **Table of Criteria and Effects of Cyanide on the Health of Fish**

Cyanide Concentration (mg HCN/L)	**Effects**
Target Water Quality Range ***< 0.02***	***No known adverse effects***
0.1	LC_{50} for perch and roach Lethal to trout when exposed for 8 hours
0.2	Lethal to catfish when exposed for 8 hours

Note: The guideline for cyanide is tentative because the TWQR is based on very limited information.

Sources of Information

McALLISTER D.E. 1987. *A Test for Cyanide Caught Fish*. Sea Wind: Bulletin of Ocean Voice International, 1(4): 6-9.

RUBEC P. and V.R. Pratt 1986. *Scientific Data Concerning the Effects of Cyanide on Marine Fish.* Algoa Marine Aquarists' Society Newsletter (Port Elizabeth), 15: 24-35.

STOSKOPF M.K. 1993. *Fish Medicine*. W.B. Saunders Company, Philladelphia, USA.

Dissolved Oxygen

Background Information

Introduction

Dissolved oxygen (DO) is the oxygen present in a dissolved form in water. Under equilibrium conditions there is a relationship between the amount of dissolved oxygen and the partial pressure of oxygen in the atmosphere. The equilibrium solubility of oxygen, termed the *saturation solubility*, is governed by atmospheric pressure, water temperature and total dissolved solids.

Oxygen is one of the principal limiting factors in aquatic respiration and metabolic reactions and as such, it is a significant water quality constituent that may limit production under aquaculture conditions. Low DO concentrations indicate eutrophication and biological overloading in aquaculture systems.

Occurrence

In unpolluted surface waters and rain water the DO concentration is normally close to, or at, saturation. Typically, the saturation values for dissolved oxygen in water at sea level (atmospheric pressure 760 mm Hg) are 14.16 mg/L at 0 °C, 12.8 mg/L at 5 °C, 10.1 mg/L at 15 °C and 9.09 mg/L at 20 °C. Where water contains oxygen depleting substances, such as easily oxidised organic matter, the DO concentration will be below the equilibrium value. In highly polluted water the DO concentration may be zero. Water with no or very little DO is referred to as anaerobic.

Oxygen is dissolved into water at the water air interface. This process is slow but under aquacultural conditions can be enhanced by agitation (using paddle wheels or other agitators), aeration (using compressed air generated by blowers or compressors) or by supplying pure oxygen into the water. During photosynthesis, aquatic plants release oxygen into the water, but due to the high algal oxygen demand at night and the production of CO_2, the aquatic system does not necessarily benefit therefrom. Furthermore, the rate of photosynthesis and therefore the amount of O_2 released by plants, is controlled by temperature, light, nutrient concentration and turbidity.

Interactions

Dissolved oxygen is labile and can easily be reduced by carbon compounds to form carbon dioxide. Heating of water also lowers the solubility of oxygen and reduces the DO concentration. The DO concentration of water is strongly affected by the presence of oxidisable matter and as such, is affected by the **dissolved organic carbon (DOC)**, the **biochemical oxygen demand (BOD)** and **organic and inorganic nitrogen** concentrations. Other factors that also affect the DO concentration are **temperature** and pressure. Increasing the DO concentration in aquaculture systems increases the carrying capacity of ponds or fish tanks.

Measurement

The criteria are given in terms of the DO concentration in units of mg/L. The reference method for the determination of the DO concentration is the Winkler method, which is the most precise titrimetric method for DO measurements in most waste water, effluent and stream samples. However, this method is time consuming. DO can be estimated using DO meters. Where other methods, such as the electrode or "oxygen probe" are used, their characteristics relative to the reference method should be known. Online monitoring and an alarm system may assist in monitoring DO levels in aquacultural systems.

In aquacultural systems the DO concentration is often expressed as the percentage saturation of DO, using the equation:

$$\% \text{ saturation} = (Cm/Cs) \times 100,$$

where Cm is the measured DO concentration and Cs is the saturation level concentration of the DO of the water after correction for atmospheric pressure and water temperature.

DO is sometimes also expressed in mL/L which can be converted to mg/L by multiplying by the coefficient 1.43. This factor is valid at 25 °C and 760 mmHg pressure.

Data Interpretation

Single-sample values should be used to compare with the criteria given, and should be within the TWQR. The DO concentration should also be interpreted in relation to interacting variables such as DOC, Kjeldahl nitrogen, BOD, temperature and atmospheric pressure. For example, the solubility of oxygen decreases with increasing salinity; for every 9 000 mg/L increase in salinity the DO solubility decreases by 5 %. DO solubility is also severely affected by temperature; at 760 mm Hg at 10 °C, fresh water can hold 11.29 mg/L, while at 30 °C, the value decreases to 7.56 mg/L.

Treatment Options

Low DO concentrations can be rectified by aeration or agitation or by direct oxygenation using pure oxygen and specially designed diffusers. Under pond-culture conditions low DO concentrations can be remedied by an immediate increase in waterflow or by the use of paddlewheels or venturi agitators.

Oxygen supersaturated water is not desirable for larviculture. Supersaturation can be rectified by vigorous aeration and/or by placing dry straw (to absorb oxygen) on larval rearing ponds.

The demand for oxygen by fish increases exponentially with temperature, doubling or trebling for each 10 °C rise in temperature. While it is nearly impossible to maintain a constant temperature in fish ponds, in hatcheries it is vital to maintain optimum temperatures with as little fluctuation as is possible.

The Effects of Dissolved Oxygen

Norms

The norms used in the guideline for dissolved oxygen are based on:

- The fitness of the fish species in terms of health, growth and production, reproduction and behaviour.
- The fitness of fish flesh for human consumption.

Effects

Low DO concentrations cause stress in fish, resulting in reduced appetite, poor growth and production and an increase in susceptibility to infectious diseases. Symptoms include gulping of air at the water surface, stress coloration and an increase in swimming activity.

Hatching success of fish eggs and larval survival is severely affected by low DO concentrations. Larval deformities have been observed under low DO concentrations and growth of carp is impaired if the DO decreases to 25 % of the saturation level. Symptoms include micro-, mono- or anopthalmia, and hydration of the embryonic yolk sac and of the pericardium.

Fish kept at low DO concentrations show reduced fecundity and reduced egg and sperm viability.

Gametogenesis is also impaired. Mass mortalities of fish may result under confined aquaculture conditions at low DO concentrations.

High DO concentrations (> 20 mg/L) are toxic to fish and cause physiological dysfunctions (including gas bubble disease) and developmental abnormalities in fertilised eggs and larvae.

Generally, the limiting DO concentration range is between 1 and 3 mg/L and the "normal" concentrations range is greater than 3 mg/L, with a mean concentration of 5 mg/L.

African catfish are obligate air breathers and therefore more tolerant of low DO levels.

Fish which have died of asphyxiation, on condition that they are fresh, can be consumed by humans.

Mitigation See Treatment Options.

Criteria

Table of Criteria and Effects of Dissolved Oxygen on the Health of Fish

Dissolved oxygen concentration (mg/L)	Effects
Cold-water species (e.g. salmonids)	
0 - 2	Lethal to trout
2.13 - 2.5	Minimum DO concentration for brown and rainbow trout at 18 and 25 °C respectively
4	Respiratory stress in rainbow trout
5 - 6	Critical DO concentration for incubating and hatching of salmonid eggs
Target Water Quality Range 6 - 9	***Optimal growth and production and no stress at temperatures ranging between 14 and 18 °C***
16 - 21	Maximum safe concentration at 25 and 12 °C respectively.
> 21	Supersaturation causes mortalities
Intermediate species (e.g. Carp and Black bass)	
0.5	Lethal for carp
0.8 - 2.3	Critical minimal concentration for carp and black bass, respectively
2.5 - 5	Growth of carp impaired and decreased food conversion efficiency in black bass. Hatching and larval survival of black bass impaired
Target Water Quality Range 5 - 8	***Optimal DO concentration for growth of carp and bass***
> 20	Supersaturation causes mortalities, increases frequency of disease and causes gas-bubble disease
Warm-water species (e.g. Tilapia and African catfish)	
0 - 0.3	Tilapia fry and adults survive short exposure. Catfish can survive for longer periods
0.3 - 0.75	Lethal to tilapia if exposed to long. Growth of African catfish impaired
1 - 5	Growth of tilapia impaired. Growth of adult African catfish not impaired
Target Water Quality Range 5 - 8	***Optimal DO concentration for growth of warm water fish***
> 20	Supersaturation causes mortality, particularly in larval and early juvenile African catfish

Modifications Critical DO concentrations are difficult to assign because the responses are not all-or-nothing; rather there is a continuum of effects as DO concentrations change. Further complications arise as a consequence of low DO concentrations, as the effects depend on exposure time, fish size and health, and water temperature.

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.

BOYD C.E. 1979. *Water Quality in Warm-Water Fish Ponds*. Auburn University, 359pp.

COLT J. and K. Orwicz 1991a. *Aeration in Intensive Culture*, In: Brune D.E. and J.R. Tomasso (ed). Aquaculture and Water Quality, The World Aquaculture Society, Los Angeles, 605pp.

COLT J. and K. Orwicz 1991b. *Modelling Production Capacity of Aquatic Culture Systems under Freshwater Conditions.* Aquaculture Engineering, 10(1991) 1-29pp.

HERRICKS E.E. and L.L. Osborne 1985. *Water Quality Restoration and Protection in Streams and Rivers,* In: Gore J.A. (ed). The Restoration of Streams and Rivers, Butterworth Publishers, 280pp.

JONES J.R.E. 1964. *Fish and River Pollution*. Butterworth & Co Ltd, London., 203pp.

SIMCO B.A., J.H. Williamson, G.J. Carmichael and J.R. Tomasso 1986. *Culture of Non-salmonid Freshwater Fishes*, In: Stickney R.R. (ed) CRC Press, Florida, 201pp.

STICKNEY R.R. 1986. *Tilapia*, In: Stickney R.R. (ed). Culture of Non-salmonid Freshwater Fishes, CRC Press, Florida, 201pp.

TRAIN 1979. *Quality Criteria for Water*. U.S. Environmental Protection Agency, Washington DC, USA.

TUCKER C.S. and E.D. Robinson 1990. *Channel Catfish Farming Handbook*. Van Nostrand Reinhold, New York, 454pp.

WICKINS J.F. 1981. *Water Quality Requirements for Intensive Aquaculture*, In: Tiewes, K. (ed). Aquaculture in Heated Effluent and Recirculating Systems. Proceedings of the Eifac-Symposium, Heeneman Vaerlagsgesellschaft, Berlin, 513pp.

Herbicides

Tentative guideline

Background Information

Introduction

Organic herbicides are a diverse group of synthetic organic chemicals used to control the growth of plants considered to be weeds. Herbicides (and fungicides) have a broad spectrum of organic and inorganic active ingredients and as such exhibit different ranges of toxicity, levels of biodegradation and persistence in the soil. Generally herbicides, unlike some other biocides, do not persist in aquatic systems.

Some herbicides have a broad action and are therefore also toxic to animals and micro-organisms. The herbicides discussed in this guideline are those commonly used in South Africa.

Occurrence

Herbicides enter aquatic systems directly or indirectly. Some herbicides are added directly to water to control the growth of aquatic weeds. Leaching and runoff from agricultural soils, and effluent from industrial areas, are indirect and direct sources of pollution respectively.

Interactions

Some herbicides are inactivated (degraded) in the environment by biological, chemical and physical means. The rate of inactivation depends upon the nature of the herbicide and the environmental conditions. However a limited number of herbicides undergo molecular changes in the environment that result in a decreased toxicity compared to that of the parent molecule. The transformation of 2,4-Dichlorobenzophene to 2,4-Dichlorophenoxyacetic acid, being an example.

Measurement

Herbicides are measured in units of µg/L (for water) or mg/kg (for soil and animal flesh) using instrumental chromatographic techniques after suitable sample preparation and concentration techniques.

Synthetic organic molecules break down into several products, some of which are persistent but present in minute quantities.

Data Interpretation

Single-sample maximal values should be used to compare with the criteria given.

Treatment Options

Once a herbicide is present in an aquacultural system, it is best removed by drainage of the system, followed by replacement with unpolluted water.

The Effects of Herbicides

Norms

The norms used in the guideline for herbicides are based on:

- LC_{50} data for various fish species.
- The fitness of fish flesh for human consumption.

Effects

The effects of herbicides on fish are poorly documented. Effects may range from sublethal behavioural changes to death. There is no information on the effects of herbicides on the growth and reproduction of fish.

Mitigation

There is no known information on the treatment of fish following exposure to herbicides.

Criteria

Table of Effects and Concentrations (96 hr LC_{50}) for Various Organic Herbicides

Herbicide	Concentration	Fish Species
Acephate	100	Rainbow trout
	1 100	Rainbow trout
	1 000	Bluegill
Amitrols	160	Channel catfish
Atrazine	0.23	Gold fish
Cyanazine	9.0	Rainbow trout
	17.4	Channel catfish
	22.5	Bluegill
Dichlon	100	Rainbow trout
Dinitramine	590	Brown trout
	1 180	Carp
	1 370	Channel catfish
Dinoseb	5	Rainbow trout
Diquat	245	Bluegill
Endothall	230	Rainbow trout
	150	Channel catfish
	343	Bluegill
Ethofumesate	0.8	Rainbow trout
	2.5	Bluegill
Garlon 4	1.2	Trout (spp.)
	2.3	Tilapia
	3.1	Carp
Glyphosate	130	Rainbow trout
	97	Channel catfish
	135	Bluegill
Molinate	0.21	Rainbow trout
	0.32	Bluegill
MSMA	31.1	Gold fish
	> 100	Rainbow trout
	12	Bluegill
	26.8	Channel catfish
Nitralin	30	Rainbow trout
	62	Bluegill
Paraquat	15	Channel catfish
	13	Bluegill

Human Consumption

Fish that have been grown in water contaminated with herbicides are in general not fit for human consumption. Many of the residues of herbicides bioaccumilate and therefore strict production standards need to be observed. Standards are given in the table below.

Table of Maximum Residue Limits (wet weight) for Herbicides in Food Stuffs intended for Human Consumption

Herbicide	Maximum residue limit (mg/kg)
Acephate	1 - 3
Acifluorfen	450
Benomyl	0.1 - 3.0
Dichlobenil	500
Endothall	38 - 51
Monuron	2 300 - 3 700
MCPA	1 000
Paraquat	157
Pendimethalin	1 250

Sources of Information

ASHTON F.M. 1982. *Persistence and Biodegradation of Herbicides*, In: Matsumura, F. and C.R.K. Murti (Eds). Biodegradation of Pesticides, Plenum Press, New York, 312pp.

DALLAS H.F. and J.A. Day 1993. *The Effect of Water Quality Variables on Riverine Ecosystems: A Review*. Fresh Water Research Unit, University of Cape Town, Rondebosch, 7 700.

JOHNSON W.W. and M.T. Finley 1980. *Handbook of Acute Toxicity of Chemicals to Fish and Aquatic Invertebrates*. United States Department of The Interior, Fish and Wildlife Service, Washington, DC, 98pp.

LIVINGSTONE R.J. 1977. *Review of Current Literature Concerning the Acute and Chronic Effects of Pesticide on Aquatic Organisms.* CRC Critical Review of Environmental Control, 7: 325-351.

PALMER R.W. 1994. Detrimental Effects of Fenthion (Queletox) used to Control Red-billed Quelea (Quellea *quelea*) on Rheophilic Benthic Macroinvertebrates (Invertebrates) in the Orange River. South African Journal of Aquatic Sciences, 20 (1/2) 33-37.

SERVIZI J.A., R.W. Gordon and D.W. Martens 1987. Acute Toxicity of Garlon 4 and Roundup Herbicide to Salmon, *Daphnia*, and Trout. Bulletin of Environmental Contamination and Toxicology, 39: 15-22.

SHEEDY B.R., J.M Lazorchak, D.J. Grunwald, Q.H. Pickering, A. Pillia, D. Hall and R. Webb 1991. *Effects of Pollution on Freshwater Organisms*. Journal of Water Pollution Control Federation, 63: 619-696.

VERMEULEN J.B., S. Sweet, M. Krause, N. Holling and N. Annette 1990. *A Guide to the Use of Pesticides and Fungicides in the Republic of South Africa*. Department of Agriculture Development.

Iron

Background Information

Introduction

Pure iron is silvery in colour but usually appears as greyish black or brown as a result of oxidation. Iron is found in three oxidation states, namely, 0, II and III, of which III is the most common. In water, iron can be present as dissolved ferric iron Fe(III), as ferrous iron Fe(II), or as suspended hydrated ferric oxides. Biologically, iron is an essential micronutrient required by all living organisms, although at high concentrations it is toxic and inhibits enzyme function.

Since iron is not readily absorbed through the gastro-intestinal tract of vertebrates, it is not commonly associated with toxicity as a result of the consumption of contaminated fish.

Occurrence

Iron is the fourth-most abundant element on earth and constitutes 5 % 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 occasionally also be found in the elemental form, as either terrestrial or 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 waters, is in the range of 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. At neutral or alkaline pH, under oxidising conditions, the dissolved iron concentration is usually in the µg/L range but under reducing conditions, soluble ferrous iron may be formed and substantially higher concentrations, in the mg/L range, may be encountered. Where the pH is less than 3.5, the dissolved iron concentration may be several hundred mg/L, as may be the case with acid mine drainage. Elevated iron concentrations may also occur from effluents of industries such as the fertilizer and herbicide industries, as well as steel works and petroleum refineries.

Interactions

The behaviour of iron in water and the transformations that occur between particulate iron hydroxides, and ferrous and ferric iron in solution, are governed by the pH, alkalinity and redox potential of the water. Waters low in pH generally carry high concentrations of dissolved ferrous ions, while under alkaline conditions these ions precipitate out of solution. The cycling of iron between the dissolved and precipitated phases may result in the co- precipitation of many trace metals such as **arsenic**, **copper**, **cadmium** and **lead**. The concentration of dissolved iron is also dependent on **turbidity**, the amount of **suspended material**, the concentration of **aluminium** and the occurrence of several heavy metals, notably **manganese**.

Microorganisms such as *Gallionella* spp. play an important role in the natural cycling of the dissolved and precipitated phases of iron at the water-sediment interface.

Since reduced forms of iron are readily oxidized, high concentrations of the reduced form may cause oxygen depletion in water.

Measurement

The criteria are given in terms of the soluble iron concentration, in units of mg/L. The reference method is atomic absorption spectrophotometry (AAS) using an air-acetylene flame. Filtration followed by acidification of the sample prior to AAS analysis is required. 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. Turbidity, pH and alkalinity measures must also be taken into account in the interpretation of iron concentrations.

Treatment Options

Iron can be removed from water using oxidizing processes that convert the iron into an insoluble hydroxide or hydrated oxide, removable by filtration. The following treatment approaches are used.

> The water can be **aerated** by devices such as fountains, cascades, or mechanical aeration;
>
> The addition of lime to the water will raise the pH of acidic water and facilitate the oxidation of iron by air in the water, followed by settlement of the iron oxide;
>
> Elevated levels of iron in water may be reduced by maintaining a neutral pH;
>
> The water can also be **chemically oxidized** by dosing with chlorine, hydrogen peroxide, ozone or other strong oxidants. On an industrial scale, chlorine is commonly used as the chemical oxidant. Post-treatment, high levels of residual chlorine or ozone should be avoided since these are lethal fish.

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

The Effects of Iron

Norms

The norms used in the guideline for iron are based on:

- The fitness of the fish species in terms of health, behaviour and life stage.

Effects

Indirect lethal effects of iron have been attributed to precipitated iron forms. For example, direct precipitation of ferric hydroxide on the gills of fish or incubating eggs interferes with the transport of oxygen across the gill epithelium and chorion respectively. Ferric hydroxide suspensions have been shown to reduce growth of coho salmon alevins. Susceptibility of fish to ferric hydroxides appears to depend on the species of fish as well as the life stage involved. For example, fathead minnows and coho salmon alevins are more sensitive to ferric hydroxides than are brook trout alevins. Highly sensitive fish are affected by iron hydroxide suspensions earlier in their life histories than are species of lower susceptibility.

Dissolved iron causes damage to the epithelial membranes of gills but does not appear to involve extensive disruption of sodium balance. Respiratory distress is thought to contribute to mortalities associated with iron toxicity. Fish dying of iron toxicity show listlessness, weak and erratic opercular movements and pale colour. Elevated levels of iron are also known to increase the susceptibility of fish to infectious disease.

Mitigation

There is no known treatment for fish suffering from iron toxicity. Fish should be moved to water with a low iron content. Alternatively, the pH and alkalinity should be raised to facilitate precipitation of iron. Precipitated iron is considered less toxic than free ferrous iron. Since high concentrations of iron may cause oxygen depletion in the water, aeration should be increased.

Criteria

Table of Criteria and Effects of Iron on the Health of Fish

Iron Concentration (mg Fe/L)	**Effects**
Target Water Quality Range ***< 0.01***	***No known adverse effects on fish***
0.2 - 1.75	General lethal threshold concentration for fish 48hr LC_{50} for brook trout (pH 7.0) is 0.41 mg/L 48hr LC_{50} for brook trout (pH 6.0) is 0.48 mg/L Reduced growth in coho salmon juveniles at 1.27 mg $(FeOH_3)$/L

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.

DALLAS H.F. and J.A. Day 1993. *The Effect of Water Quality Variables on Riverine Ecosystems: A Review*. Freshwater Research Unit, Uct.

DETHLEFSEN V. and K. Tiews 1985. *Review on the Effects of Pollution on Marine Fishlife and Fisheries in the North Sea.* J. Applied Ichthyology, 1(3): 97-118.

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

GONZALEZ R.J., R.S. Grippo and W.A. Dunson 1990. The Disruption of Sodium Balance in Brook Charr, *Salvelinus fontinalis* (Mitchell), by Manganese and Iron.
J. Fish Biol. 37(5): 765-774.

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

SMITH E.J and J.L. Sykora 1976. *Early Developmental Effects of Lime-neutralized Iron Hydroxide Suspensions on Brook Trout and Coho Salmon.* Transactions of the American Fisheries Society, 105(2): 308-312.

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

WHO 1993. *Guidelines for Drinking-water Quality*, 2nd Edition, Volume 1: Recommendations. World Health Organization, Geneva.

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

Lead

Background Information

Introduction

Lead has two oxidation states, Pb^{2+} and Pb^{4+}, of which Pb^{2+} dominates in the aquatic environment. In water with a pH $\leq$ 6, HCO_3^-, SO_4^{2-} and Cl^- are the most common lead counter-ions, while $PbCO_3$ predominates in fresh water with pH $\geq$ 9. $PbCl_2$, $PbCO_3$ and $Pb(OH)_2$ are found in sea water. Various lead sulphides are formed under anaerobic conditions in sediments. Alkyl-lead compounds may also be formed but are not stable.

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 elemental state is rare. Lead tends to accumulate in sediments and soils. Lead absorbed by vertebrate organisms is to a large extent deposited in the bony skeleton.

Typically, the concentration of lead in:

surface waters, is less than 0.010 mg/L;
sea water, is no greater than 0.003 mg/L; and
contaminated water, can be several mg/L. Dissolution of lead from lead pipes occurs particularly in soft water low in calcium carbonate.

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

Interactions

Lead interacts with **pH**, **alkalinity** and **hardness** and is most soluble in acidic, soft waters. Lead oxide and lead hydroxide are highly soluble, and the presence of lead in oxygenated waters can be particularly dangerous. It is for this reason that lead piping and fittings are not recommended for aquaculture systems.

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

Measurement

The criteria are given in terms of the total lead concentration, in units of µg/L. Alternatively, lead may be measured by atomic absorption spectrophotometry. If other methods are used, their characteristics relative to the reference type methods should be known.

Data Interpretation

Mean values should be used to compare with the criteria given and should be interpreted as maximal values, not to be exceeded. The concentration of lead, as is the case with any other metals, must be interpreted according to the species present.

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. (Lime increases the pH of the water, reducing the solubility of lead).

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. Fish farms should not be set up in areas where lead contamination occurs.

The Effects of Lead

Norms

The norms used in the guideline for lead are based on:

- The fitness of the fish species in terms of health and behaviour.
- The fitness of fish flesh for human consumption.

Effects

Acute lead toxicity in fish causes renal disorders that result in interference with sugar metabolism. Lead disrupts haemoglobin synthesis and also interferes with the uptake of calcium and potassium through the gills.

Long-term exposure of fish to low levels of lead causes toxic changes in the immune system of fishes, making them more susceptible to infectious diseases. Spinal deformities may occur after prolonged exposure to 125 µg Pb^{2+}/L.

Fish affected by lead poisoning become disorientated, often undergoing spiral movements. Once ventilation and mucous production is increased, the skin may become pale or dark, depending on species. In some species, for example channel catfish, the skin may begin peeling off after prolonged exposure.

In general, juveniles are more sensitive to lead toxicity than are eggs or adults.

Toxic effects in humans as a result of the consumption of lead from seafood are not commonly encountered, unless the fish are reared near an industrial discharge site.

Mitigation

Calcium ions are thought to compete with metal ions for binding sites on the gills of fish. Increased calcium concentrations therefore reduce lead toxicity through "competitive inhibition", which limits lead uptake. Adequate dietary calcium also tends to suppress the uptake and accumulation of lead in skeletal tissue.

Criteria **Table of Criteria and Effects of Lead on the Health of Fish**

Lead Concentration (mg Pb/L)	Effects
Target Water Quality Range ***< 0.01***	***No adverse effects on fish health; TWQR for soft water***
0.03	Maximum acceptable upper concentration for brook trout. General upper limit for continuous exposure
0.03 - 0.3	Spinal deformities after prolonged exposure
0.3 - 2.15	96hr LC_{50} for rainbow trout 1.2 mg/L; for African catfish (*Clarias spp.*) 1.72 mg/L; for Nile tilapia 2.15 mg/L

Modifications An increase in alkalinity and pH reduces the solubility and therefore the availability of lead ions.

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.

DETHLEFSEN V. and K. Tiews 1985. *Review on the Effects of Pollution on Marine Fishlife and Fisheries in the North Sea.* J. Applied Ichthyology, 1(3): 97-118.

FERGUSON J.E. 1991. The Heavy Elements: Chemistry, Environmental Impacts and Health Effects. Pergamon Press, New York.

GESAMP (IMO/FAO/UNESCO.WMO/WHO/IAEA/UN/UNEP). Joint Group of Experts on the Scientific Aspects of Marine Pollution. Review of Potentially Harmful Substances: Cadmium, Lead and Tin. Reports and Studies (22).

MAZID M.A. 1995. *Regional Study and Workshop on the Environmental Assessment and Management of Aquaculture Development*. NACA Environment and Aquaculture Development. Series No.1 p 61-82.

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

MUIR J.F and R.J. Roberts 1988. *Recent Advances in Aquaculture*, Volume 3. British Library Cataloging in Publication Data, Great Britain.

OLADIMEJI A.A. and B.O. Offem 1989. *Toxicity of Lead to Clarias Lazera, Oreochromis Niloticus, Chironomus Tentans and Benacus sp.* Water, Air & Soil Pollution, 44(3-4): 191-201.

SAYER M.D.J., J.P. Reader and R. Morris 1989. The Effect of Calcium Concentration on the Toxicity of Copper, Lead and Zinc to Yolk-sac Fry of Brown Trout, *Salmo trutta* L., in Soft, Acid Water. J. Fish Biol. 35(3): 323-332.

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.

WHO 1984. *Guidelines for Drinking-water Quality*, 2nd Edition, Volume 1: Recommendations. World Health Organization, Geneva.

YONG TONG and E.T. Garside 1987. Pre-exposure and Subsequent Resistance to Lead in Yearling Brook Trout, *Salvelinus fontinalis*. Can. J. Fish. Aquatic. Sci. 44: 1 089-1 091.

Manganese

Background Information

Introduction

Manganese is a grey-white brittle metal and is found in several oxidation states, namely, -III, -I, 0, I, II, III, IV, V, VI and VII. It is an essential micronutrient involved in proteoglycan synthesis in vertebrates, but is neurotoxic in excessive amounts. At typical concentrations encountered in surface waters, manganese has aesthetic rather than toxic effects as it produces a slight green discolouration of the water.

Occurrence

Manganese is a relatively abundant element, constituting approximately 0.1 % of the earth's crust. Commonly occurring minerals that contain 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 Mn(II) ion, in acidic water with a pH of less than 5, and may be stabilised by complexation with 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:

fresh-waters, 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 waters, where manganese has been mobilised from the sediments. Elevated concentrations of manganese may occur in rivers as a result of effluent discharges from industries producing fertilizers and herbicides. Industrial uses of manganese include:

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

Interactions

The aquatic chemistry of manganese is similar to that of **iron** and the two elements tend to behave similarly in their dissolution from sediments under anaerobic conditions and re-precipitation under aerobic conditions. Manganese, once in solution, is more readily stabilised by complexation than is 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

Manganese is measured as total manganese, in units of mg/L. The reference method for the determination of manganese is atomic absorption flame spectrometry or inductively coupled optical emission spectrometry. 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

Single-sample values should be used to compare with the criteria given. The occurrence of elevated manganese concentrations in surface waters is typically cyclic unless directly due to pollution by manganese-bearing effluents. Transient episodes of elevated manganese concentrations in pipelines can result in a long-standing manganese problem through precipitation followed by gradual release. Point-of-use analyses should be done in conjunction with those of the source water.

Treatment Options

Manganese is commonly removed from water by increasing the pH. This allows the ions to precipitate out of solution as hydroxides. If an oxidizing process is used the manganese is converted into insoluble oxides, removable by filtration. At pH ;: 9, manganese is oxidized by dissolved oxygen in water. If this is not possible to achieve, a **strong oxidizing agent** is used. (The reaction is considerably more difficult to achieve than with iron). Agents commonly used include:

Chlorine
Hydrogen peroxide
Potassium permanganate
Ozone

Where the oxidant used leaves a residual, as is the case with chlorine or ozone, the residual should be removed before the water is used for aquaculture.

The action of oxidation-reduction enzymes produced by or extracted from microorganisms such as Chlamydobacteriaceae, Crenotrichaceae, Gallionellaceae and bacteria such as *Pseudomonas maganoxidans* and *Metallogenium symbioticum*, may in the future play an important role in the biological removal of manganese from water.

The Effects of Manganese

Norms

The norms used in the guideline for manganese are based on:

- The fitness of the fish species in terms of health and behaviour.

Effects

High concentrations of manganese interfere with the central nervous system of vertebrates by inhibiting dopamine (a neurotransmitter) formation as well as interfering with other metabolic pathways.

Sodium regulation in fish is disrupted by manganese and may ultimately cause death. An increase in calcium appears to reduce the toxic effects of manganese, indicating competition between calcium and manganese for binding sites on the gill epithelium. High levels of manganese ions do however inhibit the uptake of calcium by the gills. Sublethal gill damage has been observed in some fish exposed to 0.1 - 0.5 mg Mn/L. Manganese is lethal to stickleback (*Gasterosteus aculeatus*) when exposed to 40 mg/L Mn^{2+}.

Manganese accumulates in the liver of fish.

Mitigation

Manganese toxicity may be reduced by increasing the pH of the water to above 5. This allows for the manganese ions to precipitate out of solution, thereby reducing the biological availability to fish. An increase in calcium ions will also serve to reduce the toxicity of manganese ions by competing with them for binding sites on the gill epithelium.

Criteria

Table of Criteria and Effects of Manganese on the Health of Fish

Manganese Concentration (mg Mn/L)	**Effects**
Target Water Quality Range ***< 0.1***	***No known adverse effects; recommended minimal value for pond culture***
0.1 - 0.5	Sublethal effects
> 0.5	Increasing risk of lethal effects

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.

DALLAS H.F. and J.A. Day 1993. *The Effects of Water Quality Variables on Riverine Ecosystems: A Review*. Freshwater Research Unit, University of Cape Town.

EXLEY C. and M.J. Phillips 1988. *Acid Rain: Implications for the Farming of Salmonids*, In: Muir, J.F. and R.J. Roberts (eds). Recent Advances in Aquaculture Volume 3: 227-341. Timber Press, Portland.

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

GONZALEZ R.J., R.S. Grippo and W.A. Dunson 1990. The Disruption of Sodium Balance in Brook Charr, *Salvelinus fontinalis* (Mitchell), by Manganese and Iron.
J. Fish Biol. 1990, 37(5): 765-774.

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

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

Mercury

Background Information

Introduction

Mercury is a metal of rare geological occurrence. Concentrations in the environment are normally very low. Mercury occurs in three oxidation states in the natural environment, namely, as the metal, as mercury(I) and as mercury(II). It is also found as organo-mercurials, 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 mercury-organic complexes are severely neurotoxic. The non-ionic inorganic forms of mercury, for example, $HgCO_3$, are least toxic to vertebrates as they are not readily absorbed by the gastro-intestinal tract, while free ionic forms, for example, Hg^{2+} and organic forms are very toxic. The most serious mercury toxin is methylmercury (CH_3Hg^+) because it accumulates in the food-chain. In fish, methyl mercury accounts for 80% of the total mercury concentrated. Intake can occur via air, food or water. Food, particularly fish and fish-products, are usually the major source of exposure of humans to mercury.

Occurrence

The principal source of mercury in the environment is 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 organo-mercurial compounds. Atmospheric mercury can enter terrestrial and aquatic ecosystems through particle deposition and precipitation.

Mercury concentrations in surface water are generally less than 1 µg/L, 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, it may occur at high concentrations in water bodies subject to industrial pollution. The proportion of organically complexed mercury is dependent on the amount of organic material present; humic species form the bulk of the organically bound mercury in fresh-water. Several industrial activities contribute significantly to the presence of mercury in the environment. Major sources are the chlor-alkali and paint and fungicide industries. Mercury is also used in dentistry, in pulp and paper manufacturing processes, vehicle and aircraft plating, steel, non-ferrous metals, inorganic and organic chemicals, in thermometers and electrical equipment and in some therapeutic medicinal compounds.

Mercury has a strong affinity for -SH and -OH functional groups. It is 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. The methods used must measure both the dissolved and particulate forms of mercury, particularly if water contains finer particulates, where most of the mercury tends to be concentrated. The reference type method for the determination of mercury is by flameless atomic absorption spectrometry (AAS). Acid digestion of the sample is required before analysis by AAS.

Data Interpretation

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

Mercury in water can occur in different forms, for example in the dissolved state, as suspended particles and as complexes with other substances. Both the method of analysis and the treatment of water samples before analysis will determine how much mercury in each of the above categories is included in the analysis.

Treatment Options

Current technology capable of removing inorganic mercury includes:

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

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 onto 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 guideline for mercury are based on:

- The fitness of the fish species in terms of health and behaviour.
- The fitness of fish flesh for human consumption.

Effects

An increase in mercury concentrations above safe limits (1 µg/L) inhibits enzyme activity and causes an increase in abnormal cell division. Mercury has also been implicated in chromosomal damage and central nervous system dysfunction. Other effects of mercury include disturbances in sugar metabolism and oedema leading to rapid death.

Fish exposed to mercury show abnormal behaviour, such as disorientation, as well as increased mucous secretions and darkening of the back of the body, on projections and on gill-covers. The disorientation exhibited by the fish suggests that mercury toxicity is related to its severe effects on the central nervous system and muscle.

The **least effective concentration** (LEC) of mercury has been shown to affect the blood chemistry of fish and manifests as an increase in blood clotting time, a reduction in the oxygen carrying capacity of the blood and a reduction in the number of red blood cells.

Mercury is bioaccumulated in fish and shellfish mainly in the form of methyl-mercury. The United States Food and Drug Administration (FDA) has set the maximum allowable concentration of mercury in food-fish tissues of 0.5 mg mercury/kg of fish tissue.

Mitigation Dietary selenium reduces the toxic effects of methyl-mercury accumulation in fish. An increase in water pH to greater than 8 facilitates the precipitation of mercury ions out of solution. *However, such high pH values are not suitable for many freshwater fish.*

Criteria **Table of Criteria and Effects of Mercury on the Health of Fish**

Mercury Concentration (µg Hg/L)	Effects
Target Water Quality Range < 1	***No adverse effects on fish populations***
1	Growth impairment in coho salmon and Siberian sturgeon during early development
100 - 170	48hr LC_{50} for sea bream, 96hr LC_{50} for fathead minnow (*Pimephales promelas*)
170 - 210	LEC for *Heteropneustes fossilis* and *Channa punctatus*
280	96hr LC_{50} for rainbow trout

Sources of Information

DETHLEFSEN V. and K. Tiews 1985. *Review on the Effects of Pollution on Marine Fishlife and Fisheries in the North Sea*. J. Applied Ichthyology, 1(3): 97-118.

DELAMORRE P.H. and M. Truchet 1984. *Comparative Study of Mercury and Cadmium Exposure in a Freshwater Fish (Brachydanio rerio*). Histological Microanalysis of Cd-induced Mineral Concretions. Vie Milieu, 34 (2/3): 79-86.

DHANEKAR S., S. Shrivastava, K.S. Rao and S.S. Pandya 1988. Ichthyological Notes. *Studies on Toxic Effects of Least Effective Concentration of Mercury on Fish: A Haematological Study.* Matsya, 11: 75-77.

GLUBOKOV A.I. 1990. *Growth of Three Species of Fish During Early Ontogeny Under Normal and Toxic Conditions*. J. of Ichthyology, 30(2): 51-89.

Nitrate

Background Information

Introduction Nitrate (NO_3^-) is the end product of two bacterially mediated processes in the nitrification of ammonia. Nitrification is the sequential oxidation of ammonia to nitrite and nitrite to nitrate. Oxidation of nitrite is performed by aerobic, autotrophic bacteria of the genus *Nitrobacter*. Nitrate is also used by a number of species of facultative anaerobic bacteria as an exogenous terminal electron acceptor during the oxidation of organic compounds under anaerobic conditions. During this process nitrate is denitrified to nitrogen, possibly via the nitrite intermediate. 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 most often accumulates in aquaria and closed-water recirculation fish culture systems, since it is the final product in the nitrification of ammonia and enters the water in fish excretory products.

Occurrence Mineral deposits of nitrates are rare due to the high solubility of nitrates in water, 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 unimpacted fresh waters are typically less than 5 mg/L of nitrate- nitrogen (22 mg NO_3/L nitrate). A significant source of nitrates in natural water results from the oxidation of plant and animal debris and from the decomposition of animal and human excrement. Treated sewage wastes, effluents from food-related industries and agricultural runoff all contain elevated concentrations of nitrate.

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.**

The biological production of nitrate relies on oxidation of nitrite by bacteria. The *Nitrobacter* group responsible for this process are sensitive to fluctuations in temperature, dissolved oxygen and antibiotic compounds (see nitrite guideline). Nitrate is also one of the primary inorganic nutrients required by aquatic plants. High concentrations of nitrate are implicated in the eutrophication of water bodies.

Measurement The criteria for nitrate are given in terms of the concentration of nitrate-nitrogen in units of mg/L. The reference method for the estimation of nitrate, is colorimetry. All nitrate is reduced to nitrite by cadmium reduction followed by diazotisation. The procedure involves passing the sample through a column containing cadmium loosely coated with metallic copper. The nitrite produced, as well as any nitrite initially present, is determined by diazotising with sulfanilamide in the presence of a coupling agent, as described in the procedure for determining nitrite. A separate determination is made of any nitrite initially present in the sample and subtracted from that found after cadmium reduction, to obtain the concentration of nitrate-nitrogen. Where other methods are used, their characteristics relative to the reference method should be known.

Data Interpretation

Analysis of nitrate concentrations can be used indirectly to assess the suitability of water as a supply for large-scale fish culture. Concentrations of nitrate in excess of 10 mg/L may indicate pollution of water by industrial or agricultural wastes which may contain toxic substances, even though nitrate at this concentration is not toxic. Under fish culture conditions the ratio of nitrite to nitrate can provide an indication of the efficiency of biological filtration.

Transient elevations of nitrate and nitrite concentrations above non-exceedance limits are of less importance than are continuous 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 or contaminated systems.

Treatment Options

High concentrations of nitrate in fish-farm, agricultural and industrial effluent can be reduced by directing water through reed beds or by using aquatic macrophytes in biological filters.

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 also be removed, depending on the nature of the resin used. This method should only be considered for recirculating conditions.

On a commercial scale the process described requires competent operation, control and maintenance and is generally not viable under culture conditions. The most cost- effective way to reduce nitrate levels in aquaculture is the use of macrophytes.

The Effects of Nitrate

Norms

The norms used in the guideline for nitrate are based on:

- The fitness of the fish species in terms of health and growth.

Effects

Nitrate is the least toxic of the inorganic nitrogen compounds to fish. Acute lethal concentrations of $NaNO_3$ for freshwater fish are comparable to lethal NaCl concentrations, indicating that toxicity of nitrate is related to its effect on osmoregulation at high ion concentrations. Symptoms of osmotic stress are given in the salinity guideline. Little is known of the effects of long term exposure of fish to low concentrations of nitrate, although it is generally considered to be negligible.

Mitigation

High nitrate concentrations in closed recirculating fish culture systems may be reduced by partial water exchange.

Criteria **Table of Criteria and Effects of Nitrate on the Health of Fish**

Nitrate Concentration (mg NO_3-N/L)	Effects
Target Water Quality Range ***< 300***	***No known adverse effects***
1 000	Below the 96-hour LC_{50} values for most fish

Modifications The presence of high nitrate concentrations in natural waters is indicative of organic waste effluent, and therefore contamination of fish flesh by metals and bacteria, such as *E. coli*, should be considered.

Sources of Information

ALABASTER J.S. and R. Lloyd 1980. *Water Quality Criteria for Freshwater Fish*. FAO, United Nations, Butterworths, London, 297pp.

TUCKER C.S. 1993. *Water Analysis* (p.166-197). In Fish Medicine, (Ed.) M.K. Stoskopf. W.B. Saunders Company, Philadelphia.

Nitrite

Background Information

Introduction

Nitrite is an intermediate product of inorganic oxidation and of the bacterially mediated processes, nitrification and denitrification, which involve transformations of nitrogen in soil and water. During nitrification, two groups of highly aerobic, autotrophic bacteria, mainly *Nitrosomonas* spp. and *Nitrobacter* spp., oxidise ammonia to nitrite, and nitrite to nitrate. Nitrite is also an intermediate in the process of denitrification and usually involves a number of species of common facultative anaerobic bacteria which use nitrate as an exogenous terminal electron acceptor during the oxidation of organic compounds under anaerobic conditions.

Occurrence

As nitrite is an intermediate product of both nitrification and denitrification it does not usually accumulate, and concentrations of nitrite-nitrogen in inland waters are usually less than 0.1 mg/L. However, high nitrite concentrations are sometimes found in surface waters polluted with nitrogen-containing wastes, such as sewage or runoff from agricultural lands.

Nitrite is more likely to be detected in fish culture systems than is nitrate and is usually the result of inefficient nitrification in systems with high nitrogen loading rates, in the form of feed protein, and high stocking densities. In closed recirculating fish culture systems biological filters convert ammonia to nitrite and nitrite to nitrate. In properly designed and operating recirculating systems, nitrite does not accumulate as it is converted to nitrate as it is produced.

Interactions

Nitrification, being an oxidation reaction, is dependent on the presence of **dissolved oxygen.** Under conditions of low dissolved oxygen, not conducive to the oxidation of nitrate, nitrite tends to accumulate. Nitrite can also be produced from the reduction of nitrate. Accumulation of nitrite may also be attributable to differential colonisation of bacterial species. For example, the ammonia-oxidising *Nitrosomonas* group of bacteria tend to colonise filters and ponds faster than the nitrite-oxidising *Nitrobacter* group. This is particularly evident when conditioning filters, filling ponds or during recolonisation following antibiotic treatment of fish. *Nitrobacter* spp. are sensitive to environmental perturbation, particularly **temperature** changes. A rapid decrease in water temperature may result in the sudden accumulation of nitrite. Seasonal variations in nitrite concentrations in ponds subject to low winter water temperatures may be a result of this effect.

Measurement

The criteria are given in terms of the nitrite-nitrogen concentration, in units of mg/L. The reference method for the determination of nitrite is spectrophotometry, with prior derivatisation of nitrite by acidification to convert nitrite to nitrous acid, which reacts with a diazotising reagent to form a diazonium salt. The diazonium salt is coupled with an aromatic compound to form highly coloured azo dyes. Modifications of this method, using a chromotropic acid as the coupling agent, are used in test kits. Should other methods be used, the characteristics relative to the reference method should be known.

Data Interpretation

Nitrite concentrations should also be interpreted in conjunction with **salinity**, **alkalinity**, **pH**, **dissolved oxygen** and **temperature** measurements.

Treatment Options

High concentrations of nitrite can be reduced by aeration of the water. However, as the presence of nitrite is symptomatic of poor biological filtration, water quality management practices should be reviewed to provide long-term solutions. Feeding practices and carrying capacity should be adjusted. Adequate time should be allowed for bacterial colonisation of filters and sediments under low nitrogen loading prior to stocking to capacity. Where feasible, maintenance of constant water temperature may prevent fluctuations in nitrite concentration. For recirculating the aquacultural system, a daily water exchange of 10 % is recommended as an effective way in which to combat nitrite build-up.

The Effects of Nitrite

Norms

The norms used in the guideline for nitrite are based on:

- The fitness of the fish species in terms of health, growth and behaviour.

Effects

Nitrite in solution enters the circulatory system of fish through the gills. The amount of permeable nitrite depends on the fish species and environmental pH. Nitrite in the blood oxidises the ferrous ion (Fe^{2+}) in the haemoglobin to the ferric ion (Fe^{3+}). The resulting product, methaemoglobin, is incapable of reversibly combining with oxygen and therefore oxygen transport is impaired. Methaemoglobin has a characteristic brown colour that is noticeable when the concentration in the blood exceeds 20 - 30 % of the total haemoglobin. This characteristic symptom has given nitrite poisoning the common name of *brown blood* disease.

The toxic effects of nitrite result from impairment of oxygen transport and cause anoxia. Exposure to low concentrations of nitrate manifest as stress responses, resulting in lower productivity, activity and growth, and poor health. Higher concentrations result in acute anoxia, loss of equilibrium and mortality.

Mitigation

The concentration of methaemoglobin formed in the blood is dependent on the rate at which nitrite enters the blood and the rate at which it can be reduced back to haemoglobin by the body. This occurs spontaneously or by enzymatic action. Reduction of the environmental nitrite concentration allows for the natural re-establishment of equilibrium. The addition of rock salt as a source of chloride ions facilitates rapid recovery by inhibiting the uptake of nitrite.

Criteria **Table of Criteria and Effects of Nitrite on the Health of Fish**

Nitrite Concentration (mg NO_2-N /L)	Effects
Target Water Quality Range 0 - 0.05	***No known adverse effects; The TWQR is protective for salmonids and most other species***
0.06 - 0.25	Toxic to salmonids (LC_{50} for *Oncorhynchus mykiss*) **This range is considered safe for a number of warm-water fish**
7.0	LC_{50} for *Ictalurus punctatus*
10 - 15	LC_{50} for *Oreochromis* and *Tilapia* spp; Tolerated by *Clarias gariepinus* adults
86	LC_{50} for *Lepomis macrochirus*
140.2	LC_{50} for *Micropterus salmoides*

Modifications The effect of temperature, pH and chloride concentration all govern the rate of uptake of nitrite by fish and therefore its toxicity. Under closed-systems, nitrite levels should ideally be monitored on a continuous basis (every second day)

Sources of Information

LEWIS W.M. and D.P. Morris. *Toxicity of Nitrite to Fish: A Review*. Trans. Am. Fish. Soc. 115: 183-195.

PALACHEK R.M. and J.R. Tomasso 1984. Toxicity of Nitrite to Channel Catfish (*Ictalurus punctatus*), Tilapia (*Tilapia aurea*) and Largemouth Bass (*Micropterus salmoides*): Evidence for a Nitrite Exclusion Mechanism. Can. J. Fish. and Aqua. Sci. 41: 1 739-1 744.

TUCKER C.S. 1993. *Water Analysis* (p.166-197). **In** Fish Medicine, (Ed.) M.K. Stoskopf. W.B. Saunders Company, Philadelphia.

Nuisance Plants

Background Information

Introduction

Aquatic and semi-aquatic plants are a conspicuous feature of the littoral zone. They trap and consolidate sediments and, in so doing, promote the development of the benthic substrate. Thus, they provide a substratum for invertebrates which are used as food for larval and juvenile fish. Plants also provide refuge for fish larvae and juveniles.

Aquatic plants occur naturally in river systems and it is inevitable therefore that some species may get into fish ponds. Because of higher nutrient levels in fish ponds, nuisance plants can become problematic.

Description

Nuisance aquatic plants may be indigenous or invasive, and only become detrimental to fish when they cover large areas of the pond.

As an aid in both identification and in the use of control measures, aquatic weeds (or nuisance plants) may be divided into groups based upon their size, growth habit and shape:

1. Submerged weeds (e.g. *Potamogeton pectinatus, Elodea, Ceratophyllum, Utricularia*);

2. Emersed weeds (e.g. *Nymphaea, Hydrocotyle*);

3. Marginal weeds (e.g. *Juncus, Typha latifolia, Carex, Sarpus, Sparganium, Phragmites australis*, grasses).

4. Floating weeds (e.g. *Pistia, Eichhornia, Trapa, Lemna, Salvinia, Azolla*).

Occurrence

Plants can become a nuisance in rivers that have some form of nutrient enrichment (eutrophication - usually a consequence of over-regulation).

Azolla is confined to slow-moving waters and small farm dams.

Eichhornia crassipes, the water hyacinth, is a noxious aquatic weed found throughout the warmer regions of the world. It was first introduced into South Africa in the early part of the century and has since spread throughout most of the country's water systems.

Interactions

Aquatic nuisance plants do not directly kill fish, but this may occur by means of indirect processes. When the growth of nuisance plants is out of control they can quickly cover the water surface of fish ponds. This prevents light from penetrating the water, thereby halting photosynthesis and thus causing a decrease in **dissolved oxygen**, which will have a detrimental effect on fish.

Measurement

There is no defined method for measuring aquatic plants; an estimate of the proportion of the water body covered, may be used.

Treatment Options

Several techniques have been tried and tested to control aquatic weeds in ponds for aquaculture. These are:

Biological Methods

Fish are often used as a means of biological control of aquatic weeds. *T. rendallii* and *Ctenopharyngoden idella* have been used successfully to control filamentous algae and higher plants.

The weevils *Neochetina eichhorniae* and *N. bruchi* have been used successfully in the biological control of the water hyacinth. The adults of these weevils attack the plant and feed by removing tissue from the leaf pseudolamina and petioles.

Mechanical Methods

Cutting of submersed aquatic plants has been fairly successful, but needs to be repeated periodically. By deepening the pond edges, suitable habitats for the growth of rooted aquatic plants are removed. Beating with a cane pole or agitation of floating algae masses has eliminated filamentous algae. Shading of ponds with dyes has partially controlled filamentous algae and submersed weeds.

Herbicidal Methods

There is a range of herbicides that is used to control nuisance aquatic plants. An example of this is diquat (midstream). Diquat in the presence of light, oxygen and green plant tissue causes the plant to produce a chemical reaction which destroys chlorophyll producing cells.

Herbicides are toxic to fish. However, the toxicity of various herbicides is highly variable. Some herbicides have been used to control nuisance plants under aquaculture conditions. However, this practise is not recommended.

Data Interpretation

Qualitative, depending on abundance. Dissolved oxygen levels should be taken into account where the surface area covered by aquatic plants is extensive. (Guideline).

Effects and Criteria

Norms

The effects of nuisance aquatic plants on the following norms are considered:

> The fitness of the fish species in terms of health, growth, reproduction, survival and tolerance.

Effects

Fish health is decreased by dense growth of aquatic plants, as low DO levels are caused by such conditions. Decaying plant material has a high BOD and the detritus covers the benthos. Predatory fish that hunt visually are affected as there is a loss of light due to the plant cover. (There is little in the literature in this regard).

Fish growth will be affected if the fishes' feeding areas have been covered by thick mats of aquatic plants. (However, there is very little information the literature in this regard).

Fish numbers will decline due to loss of habitat and food resources. Sediments of decomposing aquatic plants may lead to changes in the diversity of fish species in rivers and to the predominance of undesirable bottom feeders. A case in point is the Eastern Cape rocky, *Sandelia bainsii* (Anabantidae) in the Blaauwkrantz River that are threatened by the aquatic plant *Azolla*.

Criteria Less than 10 % of the surface area of a fishpond should be covered by aquatic plants.

Sources of Information

ASHTON P.J. 1977. Factors Affecting the Growth and the Development of *Azolla filiculoides* Lam, In: Proceedings of the Second National Weds Conference, (Eds.) Balkema A.A., Cape Town: 240-268.

ASHTON P.J. and F.R. Schoeman 1988. *Thermal Strafication and the Stability of the Meromixis in the Pretoria Salt Pan*, South Africa. Hydrobiologia 158: 253-265.

BROWN E.E. and J.B. Gratzek 1980. *Fish Farming Handbook*. Van Nostrand Reinhold, New York, pp. 390.

DEPARTMENT OF WATER AFFAIRS (DWA) 1986. Managements of the Water Resources of the Republic of South Africa. DEPARTMENT OF WATER AFFAIRS, Pretoria.

DAVIES B.R, J.H. O'Keeffe and C.N. Snaddon 1993. *A Synthesis of the Ecological Function Conservation and Management of the South African River Ecosystem*. Water Research Commission Report Number TT62/93. Pretoria.

SULLIVAN C., J. Saunders and D. Welsh 1988. Phytoplankton Transport of the River Murray, 1980-1985. Water Quality Report 2, Murray-Darling Basin Commission, Canberra.

BASHIR M.O., Z.E. El Abjar and N.S. Irving 1984. Observations on the Effect of the Weevils *Neochetina eichhorniae* (Warner) and *Neochetina bruchi* on the Growth of Water Hyacinth, In: Limnology and Marine Biology in the Sudan, (Eds). Dumont H.J., A.I. el Moghraby and L.A. Desougi. Dr W. Junk Publishers, The Hague, pp. 363.

Parasites

Background Information

Introduction

The ichthyoparasitic fauna of South Africa is best grouped systematically. Parasites fall into 5 major taxa, namely, **protozoans**, **trematode worms**, **nematode worms**, **cestode worms** and **crustaceans**. Further division of these groups to a species level is unnecessary since the etiology within genera is essentially the same.

- **Protozoa** (single-cell organisms)

  Order: *Flagellata (possess one or more flagella)*

  Genera

  Ichthyobodo (syn. *Costia*)
  Four flagella (2 long and 2 short); free-swimming and sessile forms of similar size (7 - 15 μm long). Free-swimming form rounded; sessile forms oval. Sessile form attached to host by small tubules.

  Hexamita
  Causes "hole-in-head disease".

  Order: *Ciliata (body of organism wholly or partially covered in cilia)*.

  Genera

  Ichthyophthirius (white-spot disease)
  Predominant sign is appearance of white spots over the fish, although in some cases these are limited to the gills. Large (30 - 1 000 μm in diameter); entire body covered by dense rows of cilia; distinguished by a large horseshoe-shaped macronucleus. Free-swimming infective forms are actively motile, and about 30 - 45 μm in diameter.

  Chilodonella:
  Round (50 - 70 μm in diameter); incomplete covering of cilia arranged in several parallel rows; macronucleus round.

  Trichodina and *Trichodinella*
  Circular but ventrally flattened; distinctive denticular ring; usually 40 - 60 μm in diameter.

  Heteropolaria (syn. *Epistylis*)
  Goblet-shaped with ciliation limited to wide oral zone; colonial with individuals budding from an attachment "stem".

- **Trematoda (flukes)**

  - Monogenetic trematodes
  Direct development on host; may have free-swimming larval forms.

Genera

Dactylogyrus
Small (0.3 - 1.5 mm) elongated worms with posteriorly situated sclerotonoid anchor hooks used for attachment; anterior head region functions as additional holdfast organ and is also the site of a distinct muscular pharynx; two pigmented eyes.

Gyrodactylus
Small (0.3 - 1.2 mm) transparent worms with no eyes; anchor hooks located posteriorly; frequently contains embryos with well developed hooks *in utero*.

- Digenetic trematodes

Development is metagenetic, implying a change of host. Fish may be either intermediate or definitive hosts.

Genera

Diplostomum
Infect fish in metacercarial stage to form visible cysts (2 - 3 mm), distributed over skin and in eyes; the lens of fish may be pigmented (black spot disease) or unpigmented.

Clinostomatus and *Euclinostomatus*
Metacercarial infections produce large (2 - 4 mm) cysts under scales, on skin or within muscular and visceral tissue. Larvae released from cysts are large (5 - 6 mm) yellow grubs.

- **Cestoda (tapeworms)**

Genera

Bothriocephalus
Large (up to 20cm) segmented worms with elongated scolices. Gut parasites with copepods as the intermediate hosts.

- **Nematoda (round worms)**

Genus

Contracaecum
Red or white roundworms 20 - 45 mm long; short oesophagus distinct from the intestine; prevalent in southern Africa.

- **Crustacea**

Families

Argulidae (fish lice)
Disk-shaped with rounded carapace; transparent white, green or brown; 3 - 8 mm long.

Lernaeidae (anchorworms)
Head has horn-like structures for embedding under skin of fish; rest of body long (5 - 22 mm); lightly coloured egg sacs attached to posterior end of body.

Occurrence

Generally parasites are highly cosmopolitan and are found in most southern African waters (distribution detailed in Van As and Basson (1984). All natural waters tend to harbour low levels of parasitic infestation which, with few exceptions, are seldom manifested to any great extent. Under intensive aquacultural conditions there is a much higher prevalence of parasites, particularly of protozoans and monogenetic trematodes.

Interactions

Chronic parasitic infestation of fish is usually correlated with adverse environmental conditions which place fish under stress. The concomitant loss of appetite associated with stress increases vulnerability to diseases caused by bacteria and fungi. This in turn renders fish more susceptible to secondary infestation by parasites. Hyper infection by protozoans has been observed in wild populations of Mozambique tilapia when temperatures decline to below 18 °C during winter months. However, low temperatures may also reduce the reproductive capacity of parasites. Other factors such as low dissolved oxygen concentrations, high ammonia levels, high stocking densities, increased organic loading and handling stress all contribute to susceptibility to parasitic infections.

Generally larval and early juvenile fish are more susceptible to parasite infestation, than are adults. Epizootic infections are particularly morbid in fry and fingerlings and often result in heavy mortalities at these stages of development. Integumentary damage by physical means or by fungi (*Saprolegnia*) and ectoparasites (*Ichthyophthirius, Gyrodactylus* and *Argulus*) accelerate and facilitate secondary infection by protozoans.

Measurement

Microscopic examination of gills, skin and internal organs of the fish.

Data Interpretation

Fish are graded as either parasite free or infected. Chronic infection requires treatment.

Treatment Options **Table of Treatment Options for some Fish Parasites**

Parasite	Treatment	Concentration (parts/million)	Time	Species
Protozoa (except *Ichthyophthirius*)	Formalin	15 - 50	Single addition to water	Common carp Tilapia
Ichthyophthirius	Formalin	200	1 hour emersion	All species
	Malachite green	0.1 - 0.15	Single addition	All species
	Malachite green/ formalin mix	malachite (0.05) + formalin (50)	Single addition	All species
Monogenetic Trematodes	Organo-phosphates (Dipterex, Neguvon)	0.25 - 0.5	Single addition	All species
	Bromex	0.12	Single addition	Common carp
Digenetic Trematodes	Elimination of vector (molluscs) Copper sulphate	10 (hardwater) 3 (softwater)	Until vector is eliminated	Common carp Tilapia
Cestodes	Praziquantel	3	Single addition	Ornamental fish
Crustacea	Organo-phosphates (Dipterex, Neguvon)	0.25 - 0.5	6 hour emersion	All species

Most of the above treatment options refer to once off treatment of parasite infestation. Emersion or dipping is more commonly used for persistent infestation or treatment of isolated fish. Time intervals and concentrations for treatment can be found in most fish disease texts (see sources of information).

The Effects of Parasites

Norms

The norms used in the guideline for parasites are based on:

- The fitness of the fish species in terms of health, growth, reproduction and survival
- The fitness of fish flesh for human consumption.

Effects

For fish under conditions of low stress, most parasite infestation is asymptomatic. Virtually all fish host latent protozoan and monogenetic trematode parasitofauna but are able to mount a sufficient immune response to prevent the manifestation of pathological symptoms. In the case of moderate digenetic trematode infestation, fish may harbour up to 40 cysts per individual. Such infestation has no effect with little if any pathological change seen in tissues containing metacercarial cysts. Infestation by larger parasites, such as lernaeid copepods and cestodes, can occur on healthy fish and are generally detrimental.

Parasite hyper-infection frequently results in high mortality of fish of all ages. Increases in pathogen numbers, especially of highly contagious parasites such as *Ichthyophthirius*, often result in the infection of all individuals. In addition, infestation by one parasite increases susceptibility to others. Many of the gross symptoms (described under diagnosis) of parasitic infestation result in reduced growth performance, and alterations in behaviour.

Presence of necrotic tissue makes fish undesirable for human consumption even though human infection by fish parasites (particularly in southern Africa) is rare. The presence of metacercarial cysts renders fish largely unmarketable.

Mitigation

Quarantine of fish should be mandatory for the movement of any fish. However, very little is known about quarantine time periods. All fish imported into South Africa should be accompanied by a health certificate. It is interesting to note that four economically detrimental fish parasites were introduced into South Africa by the importation of exotic species. The potential for further introduction of exotic parasites is growing with the ever increasing volume of fish being imported. The labile nature of parasitic infections generally makes detection of infected fish difficult, although samples of fish may be sacrificed and examined.

Under aquaculture conditions the best means of prophylaxis is the maintenance of good water quality. Behavioural observations also provide an indication of parasite burdens, for example, "flashing". Removal and isolation of hyper infected individuals may also reduce the extent of a parasitic outbreak.

Table of Effects of some Fish Parasites

Site	Effects (Pathology)	Parasite	Hosts
Skin and fins	Changes in skin colour; loss of refraction of colour into greyish white sheen. Dermal haemorrhages, red sores and eroded scales. Excessive mucus production	Protozoa: *Ichthyobodo, Trichodina, Heteropolaria, Chilodonella, Ichthyophthirius* Trematoda: *Gyrodactylus*	All fish
	White spots (pustules). Fish observed flashing	Protozoa: *Ichthyophthirius*	All fish
	Black spots (cysts)	Trematoda: *Diplostomum*	All fish
	Thick, greyish-white fluff in sores	Trematoda: *Gyrodactylus*	All fish
	Large cysts containing yellow worms	Trematoda: *Clinostomum, Euclinostomum*	All fish
	Necrotic lesions containing red or white roundworms	Nematoda: *Contracaecum*	All fish
	Circular, red, crater-like depressions May be haemorrhagic or ulcerating Small disc-like animals on skin surface (fish lice)	Crustacea: *Argulus, Dolops*	Warmwater fish
	Distinct lesion, maybe inflamed and haemorrhagic. Long-rod shaped parasites (anchor worms)	Crustacea: *Lernea*	Limited to Cyprinids
Gills	White spots (pustules)	Protozoa: *Ichthyophthirius*	All fish
	Black spots (cysts) combined with thickening and deformation of the gill filaments	Trematoda: *Diplostomulum*	Warmwater fish
	Filaments pale or covered with whitish patches of tissue	Trematoda: *Dactylogyrus*	Warmwater fish
Viseral tissue	Black cysts on internal organs	Trematoda: *Diplostomulum*	*W*armwater fish
	Large cysts containing yellow worms	Trematoda: *Clinostomum* *Euclinostomum*	Warmwater fish
	Swelling of abdomen; emaciation; worms present in gut	Cestoda: *Bothriocephalus*	Mainly cyprinids
	Red or white worms in abdominal cavity	Nematoda: *Contracaecum*	Warmwater fish
Somatic tissue	Black cysts in muscle tissue	Trematoda: *Diplostomulum*	Warmwater fish
	Large cysts containing yellow worms	Trematoda: *Clinostomum* *Euclinostomum*	Warmwater fish
Eyes	Whitening of the lens (cataract)	Trematoda: *Diplostomum*	Warmwater fish

Modifications Quantitative studies of cycles of parasitic infections in natural populations of fish in South Africa are scarce. Research efforts would aid to a better understanding of fish parasitic infections.

Sources of Information

DE MOOR I.J. and M.N. Bruton 1988. *Atlas of Alien and Translocated Indigenous Aquatic Animals in Southern Africa*. South African National Scientific Programmes Report, 144: 26-40.

CONROY D.A. and R.L. Herman. *Textbook of Fish Diseases*. T.F.M. Publications, Jersey City, New Jersey, 302 pp.

PAPERNA I. 1980. *Parasites, Infections and Diseases of Fish in Africa*. CIFA Technical Paper 7: 216 pp.

STOSKOPF M.K. 1993. *Fish Medicine*. W.B. Saunders Company, Philadelphia.

VAN AS J.G. and L. Basson 1984. *Checklist of Freshwater Fish Parasites from Southern Africa*. S. Afr. J. Wildl. Res. 14: 49-61.

PCBs

Tentative guideline

Background Information

Introduction

Polychlorinated biphenols are toxic, non-polar and extremely stable lipophilic halogenated aromatic hydrocarbons. Due to their extremely persistent and bioaccumulative nature it is imperative that PCB concentrations are monitored in water containing cultured aquatic organisms. PCBs are extremely stable organochlorines and accumulate in fatty tissues. They are extremely difficult to remove from both water bodies and aquatic organisms.

Occurrence

PCBs were commonly used as a heat-exchange mechanism in transformer oils before being banned in the 1970's. However, they are still detectable in water bodies today. This is attributable to leakage from discarded transformers into water supplies.

Interactions

PCBs are a class of 209 compounds. The main commercial compounds, known as Aroclors, are mixtures of PCBs.

Measurement

PCBs are measured by gas chromatography after solvent extraction.

Data Interpretation

The detection of any PCB levels should be regarded as serious.

Treatment Options

No information is available or known for the treatment of water contaminated by PCBs.

The Effects of PCBs

Norms

The norms used in the guideline for PCBs are based on:

- The fitness of the species in terms of fish health and growth.
- Fitness of products for human consumption.

Effects

Fish absorb PCBs through their gills and from food. Due to the extremely bioaccumulative nature of PCBs they cannot be eliminated.

It has been shown that PCBs can stimulate the metabolism of sex hormones in fishes. Hormones synthesised by the hepatic pancreatic microsomes include progesterone, estradiol and testosterone. This can have pronounced effects on the reproductive potential of the fish.

Due to the biomagnification of PCBs up the food chain, PCBs are a health threat to humans consuming contaminated fish.

Mitigation PCBs cannot be eliminated. The source of pollution should be located and action should be taken to eliminate it.

Criteria There is no known quantitative information available on PCB levels that are "safe" and do not exert adverse effects on fish or from the consumption of fish flesh. Therefore, it is recommended that fish cultured in water with even extremely low PCBs not be consumed.

Sources of Information

APHA 1992. *Standard Methods for the Examination of Water and Waste Water,* 18th Edition. American Public Health Association, Washington DC.

Pesticides

Background Information

Introduction Pesticides are chemicals used in the control of pests, usually on agricultural crops and for vector-borne diseases. There are many different classes of pesticides. Essentially all pesticides used today are organic molecules that have been artificially synthesised. They have been used in increasing quantities to cope with the ever growing demand for food.

Broadly, pesticides can be divided into three groups, namely organochlorines, organophosphates and carbamates. The table below gives an indication of some of their properties.

Characteristic	Organochlorines	Organophosphates	Carbamates
Potential for entry into fresh water	strong	strong	moderate
Solubility in water	very low	low	low
Aquatic toxicity	high	moderate	moderate
Aquatic persistence	prolonged	short	short
Bioaccumulation potential	strong	weak	weak

Occurrence Pesticides enter aquatic systems directly or indirectly. Indirect pollution of aquatic systems includes leaching, runoff from agricultural lands, industrial effluent and from sewage. An example of direct pollution of aquatic systems in South Africa is the use of Fenthion, which is sprayed on reed beds to kill the red-billed quelea.

Interactions **Bioaccumulation**

Certain pesticides concentrate and accumulate in fishes and other organisms either through direct contact with the surrounding environment, or indirectly through the food chain. A classic example of pesticide accumulation through the food chain is that of DDT, a chemical now banned throughout many parts of the world, but still used in Southern Africa.

Residues

Residue concentrations are the static levels of a pesticide in the aquatic environment and may be measured in water, soil and biota. Residue concentrations of a pesticide accumulate in the fatty tissue of fish. However, the interpretation of numerical data, in terms of physiological or biochemical effects is not clear and sublethal effects of residue levels is even less clear.

Measurement

The reference method for the determination of pesticides is gas chromatography; units are expressed as mg/L (if the pesticide is dissolved in water) or mg/kg (if the pesticide is in the soil or solid state). Synthetic organic molecules break down into many products, some however, are persistent and difficult to measure. Measuring pesticides and their breakdown products is also extremely costly.

Data Interpretation

Single-sample value should be used to compare with the criteria given.

Treatment Options

Once pesticides are present in a culture system, it is best to completely drain the system and to remove the top layer of mud and refill with unpolluted water. Even though the active ingredients of pesticides may break down within a short period of time, others like DDT persist for very long periods of time.

The Effects of Pesticides

Norms

The norms used in the guideline for pesticides are based on:

- The fitness of the species in terms of health, reproduction and behaviour.
- The fitness of fish flesh for human consumption.

Effects

Although poorly defined, the effects of pesticides range from lethal to sublethal, to behavioural changes in fish and to fish death if the concentration of the pesticide reaches lethal levels. There is no definitive information on the effect of pesticides on growth and reproduction on fish.

Very little data exists on the sublethal effects of pesticides on fish health, however pesticides have been shown to stress fish, which in turn make fish more susceptible to diseases.

The respiratory function of bluegill (*Lepomis macrochirus)* is affected by Dieldrin (an organochlorine) at a concentration of 0.1 mg/L.

Mitigation

Once fish have been exposed to pesticides, little is known about how the effects may be reversed. Crops are now being genetically engineered to be pest resistant, which will hopefully reduce the need for pesticides in future.

Farmers and fishermen need to be educated as to the efficient use and danger of these chemicals. For example, the spraying of DDT onto drying fish to keep the flies away is still practised in some southern African countries.

Criteria **Table of Target Water Quality Ranges for Various Pesticides**

Substance	TWQR (µg/L)
Aldrin	≤ 0.01
Chlordane	≤ 0.025
DDT	≤ 0.0015
Dieldrin	≤ 0.005
Dursban	≤ 0.001
Endosulfan	≤ 0.003
Endrin	≤ 0.002
Guthion	≤ 0.01
Heptachlor	≤ 0.005
Lindane	≤ 0.015
Malathion	≤ 0.1
Methyoxychlor	≤ 0.02
Mirex	≤ 0.001
Parathion	≤ 0.008
Toxaphene	≤ 0.002
2,4-dichlorophenol	≤ 4.0

Table of the Effects (LC_{50}) of Various *Organochlorines* on some Fish Species

Pesticide	Concentration (µg/L)	LC_{50} (hours)	Species
Aldrin	25	96	Goldfish
	1 700 - 2 700	24 - 96	Channel catfish
	13	96	Bluegill
BHC	790	96	Bluegill
Chlordane	22	96	Bluegill
DDT	27	96	Goldfish
	8	96	Bluegill
	1.7	96	Rainbow trout
	80 - 250	24 - 96	Nile tilapia
Dieldrin	37	96	Goldfish
	8	96	Bluegill
Endosulfan	3.8 - 8.7	24 - 96	*Clarias* spp.
	3.5 - 5.3	24 -96	Mozambique tilapia
Endrin	1.96	96	Goldfish
	140	48	Carp
	0.6	96	Bluegill
	0.41	96	Rainbow trout
Heptachlor	230	96	Goldfish
	19	96	Bluegill
Toxaphene	5.6	96	Goldfish
	3.5	96	Bluegill
	50	24	Rainbow trout

Table of Effects (LC_{50}) of *Carbamate* on some Species

Pesticide	Concentration (µg/L)	LC_{50} (hours)	Species
Sevin	40 - 710	50	Crustaceans
	5 600	96	Bluegill

Table of Effects (LC_{50}) of *Organophosphate Pesticides* on Fish Species

Pesticide	Concentration (µg/L) for 96 hours	Target species
Fenthion	1 290 - 1 930	Rainbow trout
	500 - 2 550	Carp
	1 250 - 2 060	Channel catfish
	1 775 - 6 536	Goldfish
	1 080 - 1 770	Bluegill

Many of these chemicals are poisonous to humans, especially those that accumulate in fish (DDT). The following table provides maximum permissible levels of pesticides in food for human consumption.

Table of Maximum Residue Limits of Pesticides in Food Stuffs destined for Human Consumption

Pesticide	Maximum residue limit (mg wet weight/kg)
Acephate	1.0 - 3.0
Aldicarb	0.1 - 1.0
Carbaryl	0.5 - 2.5
Cyromazine	0.5
Demeton-S-methyl	0.1 - 0.4
Dicrotophos	0.1
Dimethoate	0.1 - 2.0
Disulfoton	0.05 - 0.1
Fenamiphos	0.05 - 0.1
Fenthion	0.1 - 1.0
Formothion	0.1 - 2.0
Furathiocarb	0.05
Heptenophos	0.05
Isazofos	0.05 - 0.1
Methomyl	0.02 - 0.1
Mevinphos	0.2
Monocrotophos	0.05 - 0.2
Omethoate	0.05 - 2.0
Oxamyl	0.05
Oxydemetonmethyl	0.2 - 0.5
Phorate	0.05
Terbufos	0.05 - 0.1
Vamidothion	0.4

Sources of Information

DALLAS H.F. and J.A. Day 1993. *The Effect of Water Quality Variables on Riverine Ecosystems*: A Review. Fresh Water Research Unit, University of Cape Town, Rondebosch 7 700.

HELLAWELL J.M. 1896. *Biological Indicators of Freshwater Pollution and Environmental Management.* Elsevier Applied Science, London, 546pp.

JONES J.R.E. 1964. *Fish and River Pollution*. Butterworth & Co Ltd, London, 203pp.

JOHNSON W.W. and M.T. Finley 1980. *Handbook of Acute Toxicity of Chemicals to Fish and Aquatic Invertebrates*. United States Department of The Interior, Fish and Wildlife Service, Washington DC, 98pp.

LIVINGSTONE R.J. 1977. *Review of Current Literature Concerning the Acute and Chronic Effects of Pesticides on Aquatic Organisms*. CRC Critical Review of Environmental Control, 7: 325-351.

McKEE J.E and H.W. Wolf 1963. *Water Quality Criteria*. The Resource Agency of California, 2nd Edition. State Water Quality Control Board Bd., Publication No. 3A, 584pp.

PALMER R.W. 1994. *Effects of Fenthion on Benthic Invertebrates*. South African Journal of Aquatic Sciences, 20 (½).

SHEEDY B.R., J.M. Lazorchak, D.J. Grunwald, Q.H. Pillia, D. Hall and R. Webb 1991. *Effects of Pollution on Freshwater Organisms*. Journal of Water Pollution Control.

THOMPSON C.Q. and J.W. Jr. Tucker 1989. *Toxicity of the Organophosphate Insecticide Fenthion, Alone and with Thermal Fog Carriers, to an Estuarine Copepod and Young Fish.* Bulletin of Environmental Contaminants and Toxicology, 43: 789-796.

VERMEULEN J.B., S. Sweet, M. Krause, N. Holling and N. Annette 1990. *A Guide to the Use of Pesticides and Fungicides in the Republic of South Africa*. Department of Agriculture Development.

pH

Background Information

Introduction

pH is a measure of the acidic or basic character of a solution. It is effectively the negative logarithm of the hydronium ion (H_3O^+) activity expressed as moles/L (mol/L). The hydronium ion is commonly referred to as the hydrogen ion (H^+); and its activity is estimated by the hydrogen ion concentration. Water ionizes slightly, yielding hydronium and hydroxyl ions (OH^-) and when the activities of the ions is equal (each at 10^{-7} mol/L) the solution is neutral. At 25 °C, neutrality is represented by a pH value of 7. The ionization constant of water is dependent on temperature, therefore the exact point of neutrality varies with water temperature. For example, the point of neutrality at 0 °C is pH 7.5. Values of pH below neutrality indicate an increase acidity or a predominance of hydrogen ions and those above neutrality signify increasing basicity or a predominance of hydroxyl ions. A decrease of pH by one unit represents a tenfold increase in the concentration of hydrogen ions, while any increase in pH by one unit signifies a tenfold increase in the activity of hydroxyl ions.

Occurrence

The pH of natural water ranges from less than 4 - greater than 12, but usually falls between 6 - 9. Most ground water contains dissolved carbon dioxide, bicarbonate and carbonate and has pH values between 5 - 8. However, ground water in contact with silicate minerals is poorly buffered, has a higher carbon dioxide concentration and consequently has a lower pH than water from carbonate rock deposits. Ground water of high pH value (> 8.5) is often associated with high sodium carbonate content. In common, with ground water, the pH of surface waters is dependent on the physico-chemical properties of geological formations, such as soils and rocks, with which it comes into contact. Low pH values are caused by the presence of mineral acids and are typical of streams and dams in igneous regions, for example, the Drakensberg. Such waters have a low carbonate concentration and therefore are poorly buffered. Low pH values are also found in waters that are rich in organic acids produced by decaying vegetation. Low pH values may also be derived from anthropogenic sources such as effluents from industry and acid precipitation. Usually precipitation is acidic because it contains carbon dioxide, but in areas where the atmosphere is polluted by industrial emissions of sulphur dioxide or nitrogen oxides, the pH of rain may be further decreased as these oxides form strong acids when in contact with water. The pH of surface water rich in aquatic vegetation may vary diurnally as photosynthetic activity affects dissolved carbon dioxide concentrations.

In closed recirculating fish culture systems, pH generally decreases with time since acid is produced during nitrification of ammonia to nitrate. In poorly buffered systems, the pH may decrease to 6 or less. Increased pH in recirculating systems is often indicative of poor biological filtration. Under pond culture conditions there are often diurnal fluctuations in pH, the intensity of the fluctuation is often dependent on the density of phytoplankton.

Interactions

Measurement of pH is fundamental when assessing a potential water supply for fish, or when evaluating fish health problems as the effect of pH is often manifested through the likelihood or severity of other water quality problems. The most important interaction of pH is that with alkalinity. The interaction of these two factors largely determine the ionic character of the water. Poorly buffered waters, i.e. those with low carbonate and bicarbonate alkalinity, are more susceptible to variation in pH and therefore changes in water quality. Ionisation, solubility and the chemical species of many aquatic toxins are pH controlled. For example, the toxicity of heavy metals, such as zinc, copper and aluminium, is more common in acidic waters because they are more soluble and prone to speciation. The influence of pH on ionisation is most marked in ammonia where increases of 2 pH units may result in a tenfold increase in the dissociation of the harmless ammonium ion to highly toxic ammonia. The degree of ionisation of carbon dioxide and hydrogen sulphide is similarly affected by pH, although increased toxicity is the result of decreased pH.

Measurement

Measurement of pH is by colorimetric or potentiometric methods. Colorimetric measurement uses weak organic acids and bases whose colour changes with pH. Commonly used indicators show a distinct colour change over a range of 1 pH unit. Many portable test kits are based on colorimetric pH measurement, however the low resolution of this method limits its application to more general purposes.

Data Interpretation

Measurements of pH should be interpreted in conjunction with the concentrations of metals, nitrogenous metabolites, carbon dioxide and sulphide.

Treatment Options

Integral to the control of pH variation is the buffering capacity of the water. Increasing the alkalinity, by addition of lime or calcium carbonate, of soft and/or acidic water increases the buffering capacity as well as increasing pH (see alkalinity guideline for liming rates). In closed recirculating fish culture systems the inclusion of a calcium carbonate/aragonite buffer is essential to combat acidification during nitrification of ammonia to nitrate. In cases of extreme pH decrease in recirculating systems, water may be neutralised by gradual addition of sodium hydroxide. Extremely high pH values, such as those following filter collapse, may be neutralised by the addition of hydrochloric or concentrated ethanoic (acetic) acid. Removal of the sources of hydrogen or hydroxyl ion activity should also be considered, particularly if the un-ionised form is gaseous and can be removed by aeration (e.g. ammonia and carbon dioxide).

Effects and Criteria

Norms

The norms used in the guideline for pH are:

- The presence and physiological requirement of dissolved anions (e.g. hardness and alkalinity).
- Physiological changes, behavioural changes and the effects on reproductive success.

Effects

The tolerance range of most freshwater fish falls between pH 6 - 9, provided other criteria, particularly ammonia concentration, are optimal. Toxic effects of pH above and below this range generally arise from disturbances in internal ion homeostasis. Extreme environmental pH fluctuations alter blood pH, thereby altering the physiological ability of fish to control diffusive ion efflux, and a reduced capacity for ion influx across the gill epithelium. The net effect, at both high and low pH, is a persistent decline in plasma concentrations of sodium and chloride ions. As these ions are fundamental for active transport of excretory products, the capacity to eliminate these from the body is inhibited. The accumulation of excretory products is ultimately a component of the toxic syndrome. The actual product that accumulates depends on whether blood pH is depressed or elevated.

The toxic effects of low pH largely stem from the effects on calcium metabolism, which is integral to the internal regulation of sodium-, chloride- and hydrogen-ion concentrations. Effects of acid stress may involve interference with reproductive physiology and hence result in reproductive failure. pH depression below 6.5 results in an upset in calcium metabolism controlling ovum maturation and causes faulty protein deposition in developing oocytes. The high level of deformity amongst developing fish exposed to low pH is also attributed to alterations in calcium metabolism and bone remineralisation. Exposure of fish to pH levels less than 5 results in the alteration of gill membranes and/or coagulation of gill mucus in both juvenile and adult fish. Damage to gill membranes impairs gas exchange, ion regulation, diffusive loss of ions and excretion. As a consequence of the reduced oxygen uptake, fish compensate by increasing their ventilation rates and breathing at the surface of the water. In severe cases of acid stress, mortality is normally due to hypoxia resulting from the combined effects of alterations in blood chemistry and structural damage to the gills. The drastic loss of sodium- and chloride-ions under these conditions causes circulatory failure as arterial blood pressure increases in response to increased blood viscosity and mobilization of catecholamines. Concomitant with loss of ionic balance is an increase in blood pH, leading to acidosis. Under such conditions the affinity of haemoglobin for oxygen is much reduced, resulting in blood anoxia.

The toxic effects of high pH stem from a reduced capacity to eliminate ammonia. The precise mechanism by which ammonia accumulates is not fully understood. However, it is thought that under alkaline conditions the ammonium ion (NH_4^+) interferes with the Na^+/H^+ exchanger by acting as a counter-ion for either Na^+ or H^+ ions.

The response of fish to long-term exposure to sublethal elevation or depression of pH results in elevated stress levels, which are manifested as poor growth and reduced resistance to disease. Behavioural alterations such as reduced feeding and activity may also contribute to lower production.

Criteria

Table of Criteria and Effects of pH on the Health of Fish

pH	Effect
Target Water Quality Range 6.5 - 9.0	Most species will tolerate and reproduce successfully within this pH range and production is optimal
2.2	Lowest tolerance limit of *Oreochromis mossambicus* (acute exposure)
3.0 - 3.5	Lower tolerance limit of *Cyprinus carpio* (acute exposure)
< 4.0	Lethal to most salmonids: histological damage to gills, precipitation of gill mucus, blood circulatory failure Stress response in *Cyprinus carpio*
4.0 - 4.5	Lethal to *Oncorhynchus mykiss* if exposure continuous
9.0	Upper tolerance level for most species
9.5 - 10	Upper tolerance level of *Oncorhynchus mykiss*

Mitigation

Recovery of fish from pH stress relies on restoration of the internal ionic balance. This may be facilitated by adjustment of environmental pH to optimal values. The addition of rock salt at a concentration of 5 g/L will reduce osmotic stress as well as mitigating against the effects of excretory toxins such as ammonia. In cases of acid damage to gills, chemotherapeutic treatment may need to be considered because acid stress is known to reduce immune responses.

Modifications

The ability of euryhaline fish to increase chloride cell activity, may increase their tolerances to high pH levels.

Sources of Information

FROMM P.O. 1980. *A Review of Some Physiological and Toxicological Responses of Freshwater Fish to Acid Stress*. Env. Biol. Fish. 5: 79-93.
RYAN P.M. and H.H. Harvey 1980. Growth Responses of Yellow Perch, *Perca flavescens* (Mitchill), to Lake Acidification in the La Cloche Mountain Lakes of Ontario. Env. Biol. Fish. 5: 97-108.

TUCKER C.S. 1993. *Water Analysis* (p.166-197). In Fish Medicine, (Ed.) M.K. Stoskopf. W.B. Saunders Company, Philadelphia.

WILKIE M.P. and C.M. Wood 1994. *The Effects of Extreme Alkaline Water (pH 9.5) on Rainbow Trout Gill Function and Morphology*. J. Fish Biol. 45: 87-98.

WOOD C.M. and D.G. McDonald 1982. *Physiological Mechanisms of Acid Toxicity to Fish,* In: Acid Rain/Fisheries. Proceedings of An International Symposium on Acidic Precipitation and Fishery Impacts in North Eastern North America. American Fisheries Society, pp197-226.

WARREN C.E. 1971. *Biology and Water Pollution Control*. W.B Saunders Company, Philadelphia, pp434.

Phenols

Tentative guideline

Background Information

Introduction Phenol itself is an organic compound consisting of a hydroxyl group attached to a benzene ring. Hydrogen atoms of the benzene ring may be substituted by functional groups such as chlorine, nitro-groups, or amino-groups. Such compounds comprise a whole host of substituted phenols, collectively known as the *phenol group* or *phenols.* Phenolic wastes contain monohydric phenols, creosol isomers and xylenol isomers together with other substances. Of the monohydric phenols, phenol itself (C_6H_5OH) is the most common. Phenols may be absorbed by fish and taint the flesh with phenol-like flavours.

Occurrence In natural water phenols are only found in very low concentrations, usually in the µg/L range or less. Phenols are produced as byproducts in many industrial processes where organic chemicals are used. Phenols are also manufactured industrially as disinfectants, pesticides and as starting materials in a wide variety of synthetic organic processes. Phenolic wastes arise from the distillation of wood and coal, and from oil refineries, chemical plants, pulp and paper industries, livestock dips and human and animal wastes. Phenols are often present in sewage at levels between 0.07 and 0.1 mg/L.

Phenols are generally biodegraded in water by bacteria. The rate of biodegradation of substituted phenols differs widely. When water containing phenol is chlorinated for disinfection purposes, a range of chlorophenols are formed. See Chlorine Guideline.

Interactions Phenols tend to be a reactive group of compounds because the hydroxyl group is highly electrophilic. Apart from reacting with other organic compounds in reactions typical of organic alcohols, they may also form organo-metallic complexes. If the specific reactivities of the many substituted functional groups of phenols is taken into account, then the range of possible interactions of the phenol group is extensive.

The following factors influence the lethal concentrations of phenols.

Temperature: an increase in temperature increases the resistance of fish to phenols;
Dissolved oxygen: low concentrations of dissolved oxygen decreases the lethal concentration of phenols;
Total hardness: with increasing of total hardness, phenol LC_{50} values increase substantially; and
Salinity: sensitivity to phenols increases with an increase in salinity.

Measurement The criteria are based on the total concentration of phenols, and the method chosen should therefore measure the phenols as a group. These are usually analysed colorimetrically with 4-amino antipyrine. Individual phenols may also be measured chromatographically.

Data Interpretation Mean values should be used in applying the criteria given.

Treatment Options

Phenolic compounds are not effectively removed from water using conventional water treatment techniques. Methods most commonly used include:

Oxidation: phenols can be destroyed by the action of strong oxidising agents, such as ozone. Chlorine should not be used since it combines with phenols to form strongly-tasting chlorophenols. Care has to be taken to remove residuals;

Adsorption: trace concentrations of phenols can be removed by filtering the water through a granular activated-carbon column. The activated-carbon column can be washed with a sodium hydroxide solution to remove the adsorbed phenols as phenates. Disposal of this solution may pose difficulties.

The Effects of Phenols

Norms

The norms use in the guideline for phenols are based on:

The fitness of the fish species in terms of health, growth, reproduction and behaviour.

The fitness of fish products for human consumption.

Effects

Fish exposed to phenols rapidly become excited, become sensitive to external stimuli and show increased respiration. There may be colour changes and there is an increased secretion of mucous. Haemorrhaging occurs with necrotic and degenerative changes in several tissues (skin, muscle, gills and liver) and abnormal circulatory patterns develop, bypassing damaged tissue. At high phenol concentrations (> 6 mg/L) there is damage to blood-producing tissues and destruction of red blood cells. Phenols also have marked neurotropic action, leading to deterioration of the nervous system. There is also a deterioration in mobility and in reaction rates, as a result of the suppression of retinal activity.

Phenol exposure also results in an increased frequency of chromosomal aberrations. The ovaries of common carp are affected, resulting in decreased steroid genesis with a decreased gonadosomatic index, which may result in a reduced reproductive output.

Smaller fish are more tolerant to phenols than are larger fish, and resistance to phenols decreases with increasing body weight. There is also a reduction in fish growth and fish are more susceptible to secondary pathogens such as the fungi, *Saprolegnia* and *Ichthyophthirius* (whitespot).

Chronic evasive behaviour is exhibited by fish of all sizes. Fish exposed to phenols select higher temperatures than normal, conditions that are known to increase the resistance of fish to phenols. Salmonid fishes will not be present in waters even with low phenol concentrations.

Human Consumption

Short-term exposure to low phenol concentrations does not taint fish flesh. Flesh tainting can occur, however, when fish feed on invertebrate or plant food items exposed to phenols. Low phenol concentrations, in the presence of chlorine, form chlorinated phenols, which taint flesh. Phenolic taints have been known to persist for several weeks, even after keeping the fish in clean water.

Mitigation Fish showing symptoms of phenol poisoning should be placed in clean water. Fish will recover if cellular and enzymatic damage is not too acute.

Criteria **Table of Criteria and Effects (24 hour LC_{50}) of Phenols on some Fish Species**

Phenol Concentration (mg/L)	**Effect**
Target Water Quality Range ***< 1***	***Ensures long-term survival of salmonid species***
< 2	Ensures long-term survival of non-salmonid species
7.5	24 hr-LC_{50} for 3-year Rainbow trout
11	24 hr-LC_{50} for 1-year Rainbow trout
11.7	24 hr-LC_{50} for Brown trout
25	24 hr-LC_{50} for Common carp

Modifications When the temperature is below 5 °C the concentrations given in the above table should be **divided by 2** to ensure fish survival. Allowance must also be made for the presence of other chemicals, such as free chlorine.

Sources of Information

ALABASTER J.S and R. Lloyd 1982. *Water Quality Criteria for Freshwater Fish*, 2nd Edition. Butterworth Scientific, London, 361pp.

ALSABTI K. 1985. Frequency of Chromosomal Aberrations in the Rainbow Trout, *Salmo gairdneri* Rich., Exposed to Five Pollutants. Journal of Fish Biology, 26: 13-19.

BIRGE W.J., R.D. Hoyt, J.A. Black, M.D. Kercher and W.A. Robinson 1993. *Effects of Chemical Stresses on Behaviour of Larval and Juvenile Fishes and Amphibians*. American Fisheries Society Symposium, 14: 55-65.

KUMAR V. and D. Mukherjee 1988. *Phenol- and Sulphide-Induced Changes in the Ovary and Liver of Sexually Maturing Common Carp*. Aquatic Toxicology (Amsterdam), 13(1): 53-60.

RAZANI H., K. Nanba and S. Murachi 1986. Acute Toxic Effect of Phenol on Zebrafish *Brachydanio rerio*. Nippon Suisan Gakkaishi, 52(9): 1 547-1 552.

RAZANI H., K. Nanba and S. Murachi 1986. Chronic Toxic Effect of Phenol on Zebrafish *Brachydanio rerio*. Nippon Suisan Gakkaishi, 52(9): 1 553-1 558.

SOLBE J.F., V.A. Cooper, C.A. Willis and M.J. Mallett 1985. *Effects of Pollutants in Fresh Water on European Non-salmonid Fish*, I: Non-metals. Journal of Fish Biology, 27A: 197-207.

Phosphorus

Background Information

Introduction

Phosphate is a generic term for the oxy-anions of phosphorus, namely orthophosphate (PO_4^{3-}), hydrogen phosphate (HPO_4^{2-}) and dihydrogen phosphate ($H_2PO_4^{2-}$). These three ions exist in equilibrium with one another and the position of the equilibria is governed by the pH. Phosphorus is also found in various condensed phosphates, such as metaphosphate and polyphosphates, as well as in complex organic molecules. It occurs most commonly in the dissolved form as the inorganic HPO_4^{2-} ion.

Occurrence

Phosphorus occurs as minerals, usually in different forms of phosphate salts, the most common of which are the complex salts of calcium phosphate in the apatite group. As phosphate is a basic component of living tissues, elevated phosphate levels can be found where large quantities of organic matter are decomposing. Significant quantities of phosphate are found in animal and human excreta, and consequently in sewage and fish farm effluent. Phosphate often accumulates in intensive recirculating fish rearing systems due to the high phosphate content of fish feed. Approximately 5 - 15 g of phosphate are produced for each kilogram of dry pelleted food fed to trout; moist and trash-fish-based diets produce higher levels of waste products. Phosphate salts are a constituent of detergents and are used for inhibiting corrosion. Large quantities of phosphate are applied as fertilizers in agriculture, and runoff from these areas often contains elevated concentrations of phosphate. Typical phosphate concentrations in surface waters range from 1 µg/L in unpolluted water to 300 µg/L or more in nutrient- enriched waters.

Interactions

Phosphate is an important plant nutrient, stimulating growth of both algae and aquatic macrophytes. Enrichment of water with organic phosphates and nitrates results in an excessive growth of plants and other organisms, leading to eutrophication and increased biological oxygen demand. Seasonal variations in phosphate concentrations may occur as the result of growth and senescence of aquatic plants. However, much phosphorus may be unavailable as it is adsorbed onto suspensoids or bonded to particles of iron, aluminium and calcium. Aquatic sediments therefore often act as phosphorous sinks, although anoxic or high-flow conditions may cause the release of soluble-reactive-phosphate (SRP).

Measurement

The criteria for phosphorus are given in terms of the soluble orthophosphate concentration in units of mg/L. Phosphate concentrations are commonly measured as total phosphorus (TP) and ortho-phosphate (PO_4-P). The reference method for phosphate-phosphorus determination is the heteropoly acid/phosphomolybdic acid/ascorbic acid reduction method. This analysis involves conversion of the phosphorus forms of interest to orthophosphate, followed by colorimetric measurement of the dissolved orthophosphate. Dissolved phosphate is routinely measured on filtered samples (0.45 µm).

Data Interpretation

Phosphate concentrations should be interpreted in conjunction with the concentrations of nitrate, total suspended solids (turbidity) and dissolved oxygen. Site-specific conditions should also be taken into account.

Treatment Options

At present there is no practical method for removing dissolved phosphate. Phosphate-stripping by ion exchange is possible but is very expensive. Absorption and assimilation by aquatic plants has been used with limited success in temperate climates. Removal of phosphate by this method has been found to be at best sporadic, as many aquatic plants die in winter and consequently return the phosphates and other materials back to the water. In intensive fish-culturing systems the concentration of phosphate can be controlled by controlling the diets of fish. Most commercial fish diets contain 10 - 20 g phosphate/kg of feed, although the ionic demands of fish are fully met with 6 - 8 g/kg feed. Therefore, reduction in the phosphate concentration of feed will reduce the direct excretion of phosphate by the fish.

The Effects of Phosphorus

Norms

The effect of phosphate on the following norms are considered:

Fitness of the fish species in terms of health and growth.

Effects

As phosphorus is a major component of nucleic acids and molecules involved in the storage and use of energy in cells, it is an essential dietary requirement of all organisms. Symptoms of phosphorus deficiency include poor appetite accompanied by depression of growth. Decreased bone calcification and cranial and skeletal deformities have been noted in some species. Fish require phosphate concentrations of between 0.42 and 1.09 % in the diet, intake exceeding this concentration being excreted directly. The source of dietary phosphorus is important as phosphorus of plant origin is not as available as that from animal sources.

Natural dissolved phosphates are considered to be largely non-toxic, although certain man-made organophosphates do have toxic effects (see Pesticides Guideline). It is, however, likely that high concentrations of dissolved phosphate may lead to osmotic stress, as is the case with high nitrate concentrations.

Criteria

Table of Criteria and Effects of Phosphate on the Health of Fish

Phosphate concentration (mg/L orthophosphate)	**Effect**
0.077	Increase in stream diatom biomass
Target water quality range 0.1	***Ensures the protection of all aquatic organisms; no changes in trophic status likely***
< 0.6	Optimum for growth of carp and gold fish at or below upper limits of this range

Mitigation

High phosphate concentrations in closed recirculating fish culture systems may be reduced by partial water exchange.

Modifications The presence of high phosphate concentrations in natural waters are indicative of organic waste effluent, and therefore contamination of fish flesh by heavy metals and bacteria, such as *E.coli*, should be considered.

Sources of information

DALLAS H.F. and J.A. Day 1993. *Effect of Water Quality Variables on Riverine Ecosystems: A Review*. Prepared for the Water Research Commission, University of Cape Town.

GOLTERMAN H.L. 1966. *Methods for Chemical Analysis of Fresh Waters*. IBP Handbook 8. Blackwell Scientific Publications, Oxford.

HEPHER B. And S. Sandbank 1984. *The Effects of Phosphorus Supplementation to Common Carp Diets on Fish Growth.* Aquaculture 36: 323-332.

SHEPHERD J. and N. Bromage 1988. *Intensive Fish Farming*. BSP Professional Books, London.

VIOLA S., G. Zohar & S. Arieli 1986. *Phosphorus Requirements and its Availability from Different Sources for Intensive Pond Culture Species in Israel*. Bamidgeh 38: 3-12.

Selenium

Background Information

Introduction

Selenium is a semi-metallic element of pronounced photoconductivity and combines readily with several metals with similar characteristics to itself. Selenium occurs in three oxidation states, namely, VI, IV and II, with the tetravalent state being the most common. The chemistry of selenium is similar to that of sulphur and selenium often replaces sulphur in mineral ores. The ability of selenium to mimic sulphur makes it toxic in fairly small quantities as it replaces sulphur in important amino acids.

At low concentrations selenium is an essential nutritional micro-element 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. Selenium forms insoluble metal selenides, which tend to be incorporated into sediments, particularly under anaerobic conditions. There are approximately 50 selenium minerals, examples of which are clausthalite, crookestie and eucairite as well as minerals containing oxidized selenium such as nickel, copper and lead complexes. Selenium also occurs in association with sulphide minerals of copper, iron, mercury, nickel, lead and zinc, where it replaces sulphur.

The speciation of selenium is influenced by pH and the redox potential of the aquatic environment. In aquatic environments of low pH or high reducing capacity, elemental selenium (Se) is reduced to selenides (Se^{2-}). At high pH and/or under oxidizing conditions, elemental selenium is oxidized to selenite (SeO_3^{2-}) and then selenate (SeO_4^{2-}), which represent Se(IV) and Se(VI), respectively. Selenides and selenium have low solubilities and selenite forms insoluble complexes with iron.

Typically, the concentration of selenium in surface water is less than 10 µg/L. Elevated concentrations can occur in ground water in seleniferous areas or as a result of inflows from industrially polluted sources. Selenium is used in the manufacture of glass and ceramics, ink and paint pigments, plastics, rubber, photoelectric cells and various alloys.

Selenium tends to be incorporated into sediments, particularly under anaerobic conditions. Selenium is also bio-accumulated by certain plants and benthic invertebrates. These may be used as indicator organisms in the bio-assays of selenium.

Interactions

The chemistry of selenium is similar to that of **sulphur**. Metabolically, selenium interacts with **sulphur**, **iron** and **arsenic**, and with metals such as **copper**, **cadmium** and **mercury**.

Selenium has a moderating influence on the toxicity of other heavy metals. For example, the toxicity of methyl-mercury, thallium, cadmium and tellurium is decreased by dietary selenium. Waterborne selenium may also reduce the toxic effects of some heavy metals, for instance mercury.

Measurement

The criteria are given in terms of the total selenium concentration in units of μg/L. The reference method for the determination of selenium is atomic absorption spectrophotometry. 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 necessary. 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.

Treatment Options

Selenium in water supplies is most effectively removed by one of the following processes:

Coagulation and precipitation by treatment with lime or ferric chloride at pH greater than 8.5. Careful monitoring is needed to ensure effective removal;
Adsorption onto activated alumina at low pH.

The processes involved require skilled operation and process control. Both processes produce a waste stream that may be rich in selenium and may therefore present disposal difficulties.

The Effects of Selenium

Norms

The norms used in the guideline for selenium are based on the effects of:

- The fitness of the fish species in terms of health, growth, reproduction and behaviour.
- The fitness of fish flesh for human consumption.

Effects

Selenium is usually considered a limiting nutrient and is associated with diseases resulting from a dietary deficiency of selenium. Lethal concentrations of selenium are approximately 37 times higher than those in natural diets of fish. On the other hand, toxic concentrations of waterborne selenium are approximately 600 times higher than background concentrations (100 mg/L). Acute toxicity occurs at a concentration of 35 mg/L and chronic toxicity at about 0.5 mg/L.

Although fish may seldom be exposed to toxic levels of waterborne selenium, they may consume plants or benthic invertebrates that have accumulated sufficient amounts of selenium to be toxic. This may result in large fish-kills or impaired reproduction of fish. When fish accumulate selenium, high proportions accumulate in the ovaries so that the developing eggs contain toxic levels. The resulting young are weak and usually do not survive.

Selenium also has a protective effect on the survival of fish exposed to other heavy metals. For example fish exposed to waterborne mixtures of mercury and selenium show increased survival and increased growth compared to those fish exposed to mercury alone. The optimal molar proportion of mercury:selenium is approximately 1.5:1.

Concentrations of selenium in fish are not high enough to constitute a risk, unless the fish feed on plant or benthic invertebrates, or reared near an industrial site which releases effluents containing high levels of selenium.

Mitigation

There are no known measures that mitigate the effects of selenium toxicity in fish.

Criteria

Table of Criteria and Effects of Selenium on the Health of Fish

Selenium Concentration (mg Se(VI)/L)	**Effects**
Target Water Quality Range ***< 0.3***	***No known adverse effects on fish***
0.46	21 day LC_{50} for rainbow trout
12.5	96 hr LC_{50} for rainbow trout
26.1 - 28.5	96 hr LC_{50} for goldfish, *Carassius auratus*, and *Lepomis macrochirus*
35.0	96 hr LC_{50} for carp, *Cyprinus carpio*.

Sources of Information

APHA 1989. *Standard Methods for the Examination of Water and Waste Water*, 17th Edition. L.S. Clesceri, A.E. Greenberg and R.R. Trussel (eds). American Public Health Association, American Water Works Association and Water Pollution Control Federation, Washington DC, USA.

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

CUVIN M.L.A. and R.W. Furness 1988. Uptake and Elimination of Inorganic Mercury and Selenium by Minnows *Phoxinus phoxinus*. Aquatic Toxicology, 13: 205-216.

DALLAS H.F. and J.A. Day 1993. *The Effect of Water Quality Variables on Riverine Ecosystems: A Review*. Freshwater Research Unit, University of Cape Town, Rondebosch.

FERGUSON J.E. *The Heavy Elements: Chemistry, Environmental Impact and Health Effects.* Pergamon Press, Tokyo.

FRIBERG L. 1988. *The GESAMP Evaluation of Potentially Harmful Substances in Fish and other Seafood with Special Reference to Carcinogenic Substances*. Aquatic Toxicology, 11: 379-393.

HODSON P.V. 1988. *The Effect of Metal Metabolism on Uptake, Disposition and Toxicity in Fish*. Aquatic Toxicology, 11(2): 3-18.

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

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.

WHO 1984. *Guidelines for Drinking-water Quality*, 2nd Edition, Volume 1: Recommendations. World Health Organization, Geneva.

Sulphide

Background Information

Introduction

Sulphide is the -II oxidation state of sulphur. Sulphides can exist in solution as un-ionized hydrogen sulphide (H_2S) or as soluble sulphides (S^{2-}). Sodium and potassium sulphides are soluble in water, while the transition metal sulphides are insoluble at neutral pH. Hydrogen sulphide is a highly toxic gas with a strong characteristic rotten- egg odour, although at high concentrations this may not be evident.

Occurrence

A wide variety of sulphide minerals occurs in nature, iron pyrites (FeS_2) and galena (PbS) being most common. As sulphide in solution is oxidised by atmospheric oxygen, dissolved sulphide concentrations are almost undetectable in aerobic waters. Elevated sulphide concentrations are found only under anaerobic or reducing conditions. Sulphate may be reduced to sulphide under anaerobic conditions by sulphur reducing bacteria, of the genus *Desulfovibrio*. Other sources of hydrogen sulphide include bacterial decomposition of organic matter in the absence of dissolved oxygen, nitrate and iron and/or manganese oxides. The formation of hydrogen sulphide in ponds and natural waters is often associated with anaerobic conditions following excessive eutrophication. Similarly, the presence of hydrogen sulphide in intensive fish culture systems is the first indication of filter-system collapse due to excessive accumulation of waste. Production of hydrogen sulphide also occurs during decomposition of sewage and is common in effluents from tanneries and paper mills. Ground water and hot springs may also contain high concentrations of hydrogen sulphide.

Interactions

In the presence of oxygen, hydrogen sulphide and soluble sulphides are oxidised to sulphur. Further oxidation to sulphate may take place in the presence of sulphur- oxidising bacteria of the *Thiobacillus* group. The presence of hydrogen sulphide or other soluble sulphides in water is thus usually associated with the absence of **dissolved oxygen** and with large amounts of decomposing organic matter. The toxic effects of a combination of low dissolved oxygen and an excess hydrogen sulphide act in concert and are therefore not easy to distinguish from each other.

In natural water bodies and earthen ponds, hydrogen sulphide in submerged anaerobic sediment combines with iron hydroxides to form black non-toxic iron monosulphides. Disturbance of these foetid sediments during floods or harvesting of fish can result in the release of high concentrations of hydrogen sulphide. pH affects the ionization state of sulphides in water.

Measurement

Three forms of sulphide can be characterised analytically:

> *Total sulphide*, which includes dissolved sulphides, hydrogen sulphide and suspended, acid-soluble metal sulphides.
>
> *Dissolved sulphide*, which consists of total sulphide minus the contribution from the suspended particulate sulphides.
>
> *Un-ionized hydrogen sulphide*, which is calculation from the concentration of dissolved sulphide, the pH and the ionization constant of H_2S.

The methylene blue method is the reference method used for determining sulphide. The type of sulphide measured, depends on the pre-treatment of the sample. The concentration of hydrogen sulphide is dependent on dissociation of sulphide according to the equilibria:

$H_2S = HS^- + H^+$ and
$HS^- = S^{-2} + H^+$

The position of equilibria for the different sulphide species is governed by pH. At pH 9, approximately 99 % of the sulphide is present as HS^-; at pH 7, the sulphide is equally divided between HS^- and H_2S; and at pH 5, approximately 99 % of the sulphide is present as H_2S.

Data Interpretation

Mean sample values should be used in the interpretation of criteria, in conjunction with pH values.

Treatment Options

Short-term treatment by aeration of anaerobic water facilitates rapid oxidation of toxic hydrogen sulphide to non-toxic sulphates. Long-term treatment includes the removal of decaying organic matter, reduction in biological load and the removal of dissolved nutrients. Strategies to control levels of nutrient input should also be implemented. Under fish-culture conditions this includes more efficient feeding practices and effective water quality management.

Sulphide and hydrogen sulphide exist in equilibrium in water, the ratio depending mainly on the pH. At pH levels above 10 the sulphide form will predominate, whereas below pH 5, undissociated hydrogen sulphide predominates.

Many metals form insoluble compounds with the sulphide ion and can be removed by settlement and filtration. However, since most of these metals are toxic in their own right, the risks associated with their use in treating domestic or industrial water are too great.

Hydrogen sulphide can be stripped from water by agitation or aeration or treatment through a stripping tower. High removal efficiency is achieved at pH levels less than 5, when most of the sulphide present will be in the form of hydrogen sulphide.

The Effects of Sulphides

Norms

The norms used in the guideline for sulphides are based on the toxicity of sulphides in terms of:

- The fitness of fish species in terms of tolerance levels during various life stages, physiological changes, behavioural changes and effects on reproductive success.

Effects

In common with the effects of other dissolved gases, the effects of hydrogen sulphide are dependent on the concentration, duration of exposure, temperature and pH. The effects of long-term exposure to sublethal hydrogen sulphide levels vary considerably with the life stage. In adults the effects are most evident as reduced reproductive success of the organisms concerned, including reduced fecundity because of reduced egg deposition and a high incidence of infertile eggs resulting from a reduction in or absence of male spawning activity. In fish that are sediment-spawners this effect is compounded by a significantly reduced hatching success, as eggs are likely to be exposed to hydrogen sulphide because of their proximity to the sediments. However, eggs of fish generally show greater tolerance to hydrogen sulphide than do larvae which are considered the most susceptible life history stage. Larval fish exposed to hydrogen sulphide show reduced survival, are smaller and show a high incidence of deformity. Juvenile fish are at least twice as resistant to hydrogen sulphide as are larval fish. The effect of exposure on juveniles is dependent on the extent of acute damage but includes reduced growth and survival.

The acute toxic effects of hydrogen sulphide are manifested as gill damage, causing interference in respiration as well as asphyxiation and death. Early histological symptoms include thickening of the gill epithelium, which leads to reduced permeability to oxygen. This response is typical of that for any gill irritant and includes increased ventilation and secretion of mucus. Fish may also be observed gasping for air at the surface of the water. Exposure to critical levels of hydrogen sulphide causes gill lesions, necrosis and sloughing off of gill tissue. This ultimately results in blood hypoxia, homeostatic failure and mortality.

Mitigation

Recovery from hydrogen sulphide poisoning relies on restoring dissolved oxygen to acceptable levels. Aeration of the water has the dual effect of oxidising toxic hydrogen sulphide to non-toxic forms and relieving the stress caused by impaired respiration. Addition of salt up to 5 g/L is beneficial in cases of osmotic stress. Continued maintenance of high water quality allows for restoration of damaged gill tissue. Under intensive culture conditions chemotherapeutic treatment of secondary gill infection may also be considered.

Criteria

Table of Criteria and Effects of Un-ionised Hydrogen Sulphide on the Health of Fish

Sulphide Concentration ($mg\ H_2S/L$)	Effect
Target Water Quality Range < 0.001	***Concentrations should be less than or equal to this concentration for optimal growth***
0.002	Long-term health hazard for fish
0.002 - 0.006	Egg survival and fry development decreases Egg deposition of trout, goldfish and bluegill reduced Growth after hatching reduced (bluegill)
0.006 - 0.012	Decrease in growth rate; toxic level for fry of salmonids and bluegill
0.012 - 0.06	Lethal range for juveniles and adults of most species

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.

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

KROM M.D., A. Neori and J. van Rijn 1989. *Importance of Water Flow Rate in Controlling Water Quality Processes in Marine and Freshwater Fish Ponds*. Bamidgeh 41: 23-33.

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

SMITH L.L. and D.M. Oseid 1973. *Effect of Hydrogen Sulphide on Development and Survival of Eight Freshwater Fish Species.* International Symposium on the Early Life History of Fish. In the Early Life History of Fish (p. 417-430), (Ed.) J.H.S. Blaxter, Springer-Verlag.

TRAIN 1979. *Quality Criteria for Water*. U.S. Environmental Protection Agency, Washington DC, USA.

TUCKER C.S. 1993. *Water Analysis* (p. 166-197). In Fish Medicine, (Ed.) M.K. Stoskopf. W.B. Saunders Company, Philadelphia.

Temperature

Background Information

Introduction

Temperature is the most important physical variable affecting the metabolic rate of fish and is therefore one of the most important water quality attributes in aquaculture. Natural aquatic temperature regimes serve as an immediate indicator of the species that can be farmed in a particular area.

Temperature responses of fish can be divided into resistance, tolerance and preference. The temperature resistance of a fish is its critical thermal range, which is a measure of thermal resistance determined by increasing or decreasing the water temperature at a rate of 1 °C/min until the loss of equilibrium. Survival of fish above or below this range is virtually zero. The tolerance range of fish is the range of temperatures at which 50 % of the population survives. Both the resistance and tolerance range are dependent on acclimation. The preferred temperature is the range of temperatures at which, if given a choice, fish will spend most of their time. The preferred temperature is species-specific and is closely correlated with the temperature for optimum growth.

Occurrence

All water bodies are subject to daily and seasonal variations in temperature. Natural variation in temperature is directly and indirectly dependent on prevailing weather conditions. Direct changes in water temperature result from changes in ambient air temperatures, while indirect changes may result from the inflow of water of a different temperature. For example, the temperature regime may be altered by increased rainwater inflow or inflow of water released from melting snow or after a hailstorm. The rate at which a water body resists thermal change is dependent on the volume and the surface-area-to-volume ratio. These factors also affect the homogeneity of temperature within the water body. A high resistance to external perturbations, such as wind and wind reach, can result in thermal stratification within the water body.

Artificial changes in water temperature can be caused by structural changes to catchment areas, such as the construction of impoundments and canals, which result in altered water flow. More noticeable changes result from discharges of heated effluent from power-generating and industrial operations.

Interactions

The effect of temperature on organisms is predominantly manifested through its control of the rate of biochemical reactions. As fish are poikilotherms, their metabolism is temperature dependent, with ambient water temperature controlling molecular activation of metabolites. The optimal temperature of species is therefore the temperature at which most biochemical reactions are at their most efficient.

The effect of temperature on biochemical reactions is not limited to fish but also affects the metabolism of other aquatic organisms, many of which are integrally important for successful aquaculture. Temperature controls the rate of nutrient cycling and therefore affects the availability of food and thus the rate of productivity.

The interactions of temperature with other physical and chemical properties of water are also critical for aquaculture. For example, the oxygen-carrying capacity of water decreases with increasing temperature and the equilibrium between non-toxic ionised ammonia and toxic un-ionised ammonia are temperature- and pH- dependent. The toxicity of several metals is temperature dependent.

Measurement The standard unit for the measurement of water temperature is degrees Celsius (°C), usually measured with a mercury, alcohol or electronic thermometer. To be of value for aquaculture, the description of water temperatures should include both spatial and temporal records and should include seasonal maxima and minima and a measure of thermal homogeneity by measuring temperature at various stations and depths.

Data Interpretation

The degree of temporal variation in water temperature is critical to the survival of fish. It is essential that water temperatures do not exceed tolerance limits. The sensitivity of different fish to sudden change in temperature (thermal shock) varies from species to species. Rapid changes in temperature should therefore be avoided.

Treatment Options

Chronic effects are irreversible. Under controlled hatchery conditions temperature can be rapidly increased by way of heaters or cooled by the application of ice. Every effort should however be made for adequate temperature control measures under hatchery conditions.

The Effects of Temperature

Norms

The norms used in the guideline based on the effects of temperature on:

- The fitness of cold, intermediate and warm water species in terms of tolerance levels during various life-history stages, physiological changes and behavioural changes.
- Reproductive success.

Effects

Temperature affects all aspects of the biology of fishes. Optimal water temperatures (see Target Guidelines in the table below) lead to maximal growth rate, efficient food conversion and best condition of fish. Resistance to disease and tolerance of toxins (metabolites and pollutants) is enhanced by an appropriate temperature regime. The response of fish to unfavourable temperatures is dependent on the extremity and duration of the change in temperature outside of normal limits. The response is manifested as a decrease in productivity ranging from increased levels of stress to complete metabolic dysfunction and mortality. Fish are capable, to a limited extent, of increasing their thermal tolerance ranges through acclimation. High mortalities in embryos and larval fish may occur as a consequence of temperature fluctuations. The acute response of fish to exposure to critical upper or lower temperatures includes a loss of equilibrium and metabolic dysfunction. An increased rate of respiration is also observed when fish are exposed to upper critical thermal limits. Short-term responses to sub-lethal temperatures are behavioural changes, including a lower level of activity and loss of appetite. A decrease in oxygen saturation concomitant with elevated water temperature results in increased respiration, with fish often gulping air from the water surface. Short-term elevation in temperature also increases the incidence of deformity in larval fish. Typical long-term responses to unfavourable temperatures include slow growth, poor feed-conversion efficiency, depressed production, poor condition and increased susceptibility to disease, particularly bacterial and fungal infections. There is also a very low survival rate of larval fish, if reproduction occurs at all.

Thermal shock symptoms from a high to a low temperature causes degeneration of erythrocytes, resulting in haemolytic serum.

Fish that have died as a consequence of thermal shock can be eaten, on condition that they are fresh.

Mitigation Under hatchery and intensive indoor-culture conditions there is greater scope for mitigation, than is the case with pond-culture systems. Temperatures in hatcheries are controlled by heaters or heat exchangers (passive or in concert with heat pumps). Maintenance of temperature is vital to ensure high rates of hatching, larval survival and growth.

The stress effects of adverse, particularly of high temperatures, can be reduced by management intervention. Options include maintenance of good water quality by reduced feeding and increased water flow, adequate aeration and reduced stocking densities.

Criteria **Table of Criteria and Effects of Temperature (°C) on some Fish Species**

Species	**Lower lethal temperature tolerance range**	***Target water quality range* for growth**	***Target water quality range* for egg incubation & larval development**	**Upper lethal temperature range**
Cold-water species				
Oncorhynchus mykiss	2	17 - 18	4 - 10	27
Salmo trutta	2	12 - 13	2 - 11	26 - 28
Intermediate species				
Cyprinus carpio	2 - 4	30 - 32	18 - 23	32 - 41
Micropterus salmoides	6	25 - 27	16 - 24	36
Warm-water species				
Clarias gariepinus	8 - 10	28 - 30	27 - 30	40 - 43
Oreochromis mossambicus	9 - 11	28 - 30	24 - 28	40 - 45

Modifications The costs involved in controlling temperature under pond-culture conditions are prohibitive and not feasible. When stocking natural waters, it is essential to ensure that the species under consideration can perform optimally in the thermal range of the water body. When transferring fish into new water it is vital to ensure ample acclimation to any change of water temperature. The normal acclimation rate is a change of 2 °C every 10 minutes.

Sources of Information

CRAWSHAW L.I. 1979. *Responses to Rapid Temperature Change in Vertebrate Ectotherms*. Am. Zool. 19: 225-237.

FRY F.E.J. 1971. *The Effect of Environmental Factors on the Physiology of Fish*. In W.S. Hoar and D.J. Randall (eds). Fish Physiology, Volume 6: 1-98. Academic Press, New York.

JOBLING M. 1981. *Temperature Tolerance and the Final Thermal Preferendum- rapid Methods for Assessment of Optimum Growth Temperature*. J. Fish Biol. 19: 439-455.

Total Dissolved Gases

Background Information

Introduction

Air is composed mainly of nitrogen, oxygen, argon, carbon dioxide and water vapour. The pressure of an individual gas, if it occupies an entire volume by itself, is called its partial pressure. The partial pressure of a gas in a liquid is called gas tension. The pressure represented by a unit mass of dissolved gas increases with temperature and varies under different conditions. At equilibrium, the partial pressure of a gas is equal to its gas tension. If the partial pressure is above the gas tension, the individual gas is supersaturated. The total gas pressure of dissolved gasses is calculated by adding together the gas tensions of each of the constituent gases, while the barometric pressure of dissolved gas is calculated by adding together each of the partial pressures. The dissolution or bubble-forming potential of a supersaturated solution depends on the difference, called the differential pressure (ΔP), between total gas pressure and barometric pressure. When total gas pressure is equal to barometric pressure, the solution is in equilibrium. If ΔP is less than 0, then gas bubbles cannot form regardless of the degree of supersaturation of a single gas.

All atmospherical gases are dissolved to some extent in water. While certain concentrations are necessary for life in water, the degree of saturation of a particular gas determines its effects and availability. Supersaturation of gas is an unstable condition and as gases come out of solution, they form bubbles which may impact on fish health. The biological risk of a given ΔP to fish depends on the ratio of nitrogen + argon:oxygen.

Occurrence

Gas supersaturation in natural waters depends on the type of water body and local geo-physical conditions, for example, the presence of waterfalls. The degree of saturation is highly variable in ground waters, with some showing supersaturation. The degree of gas supersaturation in streams and rivers is influenced by upstream conditions, but primarily occurs as a result of air entrapment in fast-flowing regions. The operations of dams and hydroelectric facilities can also have a major effect on dissolved gas supersaturation, both above and below impoundments through their effect on water flow.

Unconfined fish can move to deeper waters, where hydrostatic pressure can reduce the effect of a high ΔP. The effect of supersaturated water flowing into fish culture systems is compounded by the shallow depth of culture tanks, as there is no mitigating effect of the hydrostatic pressure of overlying water. Fish-culture systems drawing from dams are prone to gas supersaturation, as dams may collect supersaturated water during periods of high inflow and only release the water over a period of months. In recirculating fish-culture systems, gas supersaturation may occur if air is sucked into a pressurized water system due to leaks on the suction side of the pump, if intake structures that are not adequately covered, or if submerged aeration devices are used. Heating of water under pressure can also result in gas supersaturation. In ponds and lakes with dense plant growth, oxygen supersaturation can occur as a result of photosynthetic activity. High concentrations of dissolved oxygen may accumulate during periods of intense solar radiation and low wind velocity.

Interactions

Gas saturation is dependent on water **temperature**, **salinity**, biological oxygen demand, photosynthetic activity, atmospheric pressure, water movement and biological gas production.

Measurement

Gas saturation is measured with a gas saturometer, which measures ΔP by membrane diffusion. Gas supersaturation may also be calculated as a percentage of ambient barometric pressure (BP) and may be computed by the equation:

$$\text{Total Gas Pressure (\%)} = (\text{BP} + \Delta P / \text{BP}) \times 100$$

Data Interpretation

Mean sample values should be used to compare with the criteria given. The proportions of individual gases should also be known. Gas supersaturation may vary both daily and seasonally, and therefore a single gas determination may result in an incorrect assumption about the risk at a given site. Gas supersaturation should be interpreted in terms of temperature and ΔP.

Treatment Options

Supersaturation is quickly rectified by vigorous agitation of the water. Prevention of supersaturation in hatcheries and fish-culture systems may require design modifications such as degassing columns and alteration in the method of water supply to prevent entrapment of air. Certain operating procedures can also reduce gas supersaturation. For example, excessive flows should not be used when filling tanks.

The Effects of Total Dissolved Gases

Norms

The guideline for total dissolved gases is based on the effect of gas supersaturation on the fitness of cold- and warm-water fish species, in terms of health, growth and behaviour.

Effects

Exposure of fish to gas supersaturation may result in gas bubble trauma (GBT) and clinical symptoms vary according to the magnitude of ΔP, species and life-history stage.

Acute effects

Acute GBT is the result of bubble formation in the vascular system and tissues, leading to a large array of clinical symptoms associated with tissue damage and vascular occlusions. Eggs and newly hatched fry are the most resistant to high ΔP values, although bubbles forming on exterior surfaces may cause them to float. In trout, larvae are resistant for about 16 days after hatching after which bubbles form in the mouth, gill cavity and yolk sac. Accumulation of bubbles in larvae prevents normal feeding and swimming. In extreme cases, hyper inflation of the swimbladder, cranial swelling, oedematous and swollen gill lamellae, gas bubbles within the yolk- sac, and rupture of the yolk-sac membrane, have been reported.

In adult and juvenile fish the major clinical signs of acute GBT include the formation of bubbles in the blood (emboli) and in the tissues and organs (emphysema). Emphysema is commonly exhibited in the mouth and fin rays, and by protrusion of the eyes (popeye or exophthalmia). The formation of bubbles in the capillary system of organs and tissues may result in haemorrhaging, restricted blood flow and necrosis and increased mortality due to secondary bacterial infections. Acute gas supersaturation seems to have an "all or nothing" response on the growth of fish.

Chronic effects

Chronic GBT is associated with extravascular symptoms such as bubble formation in the gut and buccal cavity, hyper inflation or rupture of the swim bladder and low-level mortality over extended periods of time. In larvae the formation of gas bubbles on the roof of the mouth and/or improper development of the opercular cavity may lead to heavy mortality at the onset of feeding.

Mitigation The extent of physical damage incurred from GBT often renders this condition untreatable.

Criteria

Table of Criteria and Effects of Gas Supersaturation on the Health ofFish

Saturation Level (% TGP)	**Effects**
Cold-water fish	
Target Water Quality Range < 100	***No known adverse effects; for nitrogen saturation (N_2) add 5% to the upper limit of this range***
106 - 108	Some signs of GBT, 2 % mortality in salmonid alevins
108 - 120	Gas accumulation in yolk-sac; up to 20 % mortality in salmonid alevins Petechial haemorrhages, necrotic areas on fins, exophthalmia, in salmonid fry 6 - 80 % mortality over 3 days in juvenile salmonids 5 - 100 % mortality over 7 days in rainbow trout juveniles (165 - 195 mm)
120 - 125	Lethal to alevins and fry of salmonids 32 - 100 % mortality within 3 days in salmonid juveniles
> 125	100 % mortality in 8 - 24 hrs in salmonids
112 - 130 (% N_2)*	High mortality, bubbles in fins, under skin, in vascular system and organs in rainbow trout fry 0 - 70 % mortality over two weeks in juvenile rainbow trout
> 130 (% N_2)*	100 % mortality in 18 hrs - 3 days in rainbow trout
Intermediate / Warm-water fish	
Target Water Quality Range < 105	***No known adverse effects of fish***
115 - 120	50 % mortality in adult carp, adult goldfish and adult bluegill exposed for 20 days
120 - 125	10 % mortality in largemouth bass exposed for 20 days 50 % mortality in young goldfish, young carp and eel

* The partial gas pressure levels for N_2 cannot not be converted to %TGP with the available data.

Sources of Information

COLT J. 1986. *Gas Supersaturation - Impact on the Design and Operation of Aquatic Systems*. Aquacultural Engineering, 5: 49-85.

TUCKER C.S. 1993. *Water Analysis* (p.166-197). In Fish Medicine, (Ed.) M.K. Stoskopf. W.B. Saunders Company, Philadelphia.

WEITKAMP D.E. and M. Katz 1980. *A Review of Dissolved Gas Supersaturation Literature*. Trans. Am. Fish. Soc. 109: 659-702.

Total Dissolved Solids

Background Information

Introduction

Total dissolved solids is a composite measure of the total amount of material dissolved in it. This parameter is represented in three ways: as total dissolved solids (TDS), as salinity, or as conductivity. **TDS** and **salinity** are both measures of the mass of solutes in water, however, they differ in the components they measure. TDS is the mass of the dissolved inorganic and organic compounds in water, whereas salinity measures only the dissolved inorganic content. **Conductivity**, on the other hand, refers to the number of charged particles (in this case, ions) and is a measure of the ability of the water to conduct electricity. In most instances the terms are interchangeable as the dissolved solids that commonly make a substantial contribution (>1 mg/kg) to the total dissolved solid content are inorganic ions. In fresh-water, the major ions include carbonate, bicarbonate, chloride, sulphate, nitrate, sodium, potassium, calcium and magnesium. However, in water that contains a high dissolved organic carbon content, TDS values will be much higher than those of conductivity and salinity.

The tolerance of fish species to variations in TDS concentrations dependent on physiological adaptation. Species capable of tolerating wide salinity ranges are defined as **euryhaline** while those tolerating only limited ranges are referred to as **stenohaline**.

Occurrence

The ionic content of water depends on the physical and chemical properties of the geological formations, such as soils and rocks, through which it flows. The sources of major ions are described in the respective guidelines. Dissolved organic carbon, in the form of humic acids, derived from decaying vegetable matter may also contribute to TDS.

Naturally saline waters are associated with underground water supplies. Effluent water from tanneries and food industries may also contribute to increased salinity concentrations in water bodies.

Interactions

The ionic component of TDS is often pH related. TDS can affect **dissolved gas saturation**, but is not affected by temperature.

Measurement

TDS is measured by weighing the dry residue from a known volume of water filtered through a 0.45 µm pore size filter. A relatively low temperature (<70 °C) must be used to dry samples to prevent loss of volatile organic compounds.

Salinity is a mass ratio (g/kg) and is usually expressed in parts/thousand (ppt). Salinity is commonly determined by refractometry or specific gravity. Refractometers measure the refractive index, which is the ratio of the speed of light in a vacuum to its speed through the sample. Specific gravity (SG) is the ratio of the densities of the sample at the reference temperature to distilled water at the standard temperature, measured with a hydrometer. Salinity is directly correlated to specific gravity and may be obtained from conversion tables or converted from SG by the empirical formula:

$$S = 1.1 + 1\,300(SG - 0.999)$$

Indirect measurements of salinity using hydrometer readings are subject to error as density is affected by temperature. Therefore, it is often necessary to correct to reference temperature, which is the calibration temperature of the hydrometer. It is usual to state reference, standard and reference temperatures when expressing a hydrometer reading (H). For example, H(15.6/15.6 °C) = 10.25 at 10 °C. This means that the sample has a density of 1.025 at 10 °C when measured with a hydrometer calibrated at reference and standard temperatures of 15.6 °C.

Reference and standard temperatures are normally inscribed on the hydrometer. Correction terms to convert hydrometer readings (H) to SG should be included with the hydrometer.

Electrical conductivity is measured using a portable conductivity meters. Conductivity is expressed in terms of milli Siemens per meter (mS m^{-1}). Conductivity is a useful surrogate measure of TDS used by the Department of Water Affairs and Forestry (DWAF).

Data Interpretation

Mean values should be used to compare with the criteria given. Salinity and conductivity measurements should also be interpreted in conjunction with **alkalinity** and **total hardness** in order to establish the nature of contributing ions.

Treatment Options

The removal of sodium- and chloride-ion derived salinity is only possible by distillation, membrane filtration or electrodialysis. A recently developed technique, incorporating filtration through a semi-permeable Teflon membrane with distillation, is currently undergoing pilot-scale testing in the leather industry. Use of the above methods are not suitable under aquaculture conditions.

The Effects of TDS

Norms

The norms used in the guideline for TDS are based on:

- Tolerance levels of fish to the effects of salinity during various life stages, physiological changes, behavioural changes and reproduction.

Effects

Almost all bony fishes are osmoregulators, as they maintain their body fluids at a constant osmotic concentration of approximately 10 g/L in spite of changes in external concentration. The body fluids of fish in fresh water have a higher ionic concentration than that of the surrounding water. There is a constant osmotic flow of water into the body and a loss of ions to the environment. Fresh-water fish compensate for this effect by producing large volumes of dilute urine and by actively absorbing ions from the surrounding water. However, if the salinity of the surrounding water exceeds the osmotic concentration of the body fluids, the situation is reversed, as water is lost from the body and ions accumulate. Marine fish counteract this effect by drinking water to restore the water content. They also possess cells in the gill epithelium that eliminate excess salts.

Stenohaline freshwater fish are normally tolerant of salinities up to the iso-osmotic equivalent of the ionic concentration of the body fluids (see criteria). Survival rates at these salinities are decreased however, and depend on acclimation and water temperature. Increases in salinity beyond 5 g/L may result in decreased productivity resulting from increased stress levels. The tolerance of eggs and larvae to salinity is less than that of juvenile or adult fish. Increased salinity at early life stages may result in higher mortalities and lower growth rates at values below the iso-osmotic concentration.

Exposure of freshwater *stenohaline* fish to salinities hyperosmotic to body fluids (i.e., > 10 g/L) invariably causes disruption of homeostatic balance, which leads to metabolic disfunction and mortality.

Obvious symptoms of osmotic shock include loss of equilibrium and increased respiratory rates.

In contrast to *stenohaline* species, *euryhaline* fish are capable of tolerating salinities above and below the osmotic concentration of the body fluids. Tolerance limits of these fish are species specific and are greatly influenced by acclimation, life history stage and water temperature. The effect of salinity on the growth of euryhaline fish has been most intensively studied in *Oreochromis* species, the results of which indicate that growth of adult and juvenile fish is improved with increasing salinity.

Mitigation

The removal of dissolved salt from water is not feasible at any level, therefore the salinity tolerances of species to be stocked should be taken into account. Gradual acclimation, of even highly *euryhaline* species, is necessary for any change in the salinity. Very little information exists on the time required for acclimation to changes in salinity.

Addition of rock salt to water up to a concentration of 2 g/L has a beneficial effect on the health of fish during recovery from the toxic effects of certain water quality constituents, such as metabolites (ammonia and nitrite), low dissolved oxygen and hydrogen sulphide. In addition, rock salt is used chemotherapeutically as a treatment for fungal infection by *Saprolegnia*.

Modifications **Salinity Tolerance Limited of *Stenohaline* and *Euryhaline* Fish**

Upper Tolerance limits (g/L)	**Species**
Stenohaline species	
Target Water Quality Range ***< 2***	
17	*Cyprinus carpio*
12	*Ictalurus punctatus, Perca fluviatus*
10	*Ctenopharyngodon idella*
11.6 (Adults) 10 (Larvae) > 0.5 (Best growth in larvae)	*Clarias gariepinus*
10	*Labeo umbratus*
Euryhaline species	
120	*Oreochromis mossambicus*
35	*Salmo trutta*
35	*Oncorhynchus mykiss*

Sources of Information

ALABASTER J.S. and R. Lloyd 1980. *Salinity in Water Quality Criteria for Freshwater Fish*. London: Butterworths.

BRITZ P.J. 1988. Environmental Requirements for the Hatchery Rearing of African Catfish *Clarias gariepinus* (Pisces: Clariidae) Larvae and Juveniles, MSc Thesis. Rhodes University, Grahamstown, 123 pp.

DALLAS H.F. and J.A. Day 1993. *Effect of Water Quality Variables on Riverine Ecosystems: A Review.* Prepared for the Water Research Commission, University of Cape Town.

Total Hardness

Background Information

Introduction

Water hardness was originally described as the soap-destroying power of a water, caused by the presence of calcium and magnesium salts and measured by titration against a standard soap solution. The current definition of total hardness, is the sum of the calcium and magnesium concentrations, expressed as mg/L of calcium carbonate. Other metals such as strontium, iron, aluminium, zinc and manganese may occasionally contribute to the hardness of water, but calcium- and magnesium-hardness usually predominate. *Temporary hardness* is due to the presence of carbonates and bicarbonates of calcium and magnesium which can be removed by boiling, whereas *permanent hardness* is attributable to other ions, such as sulphate and chloride, which cannot be removed by boiling.

Total hardness is a general term that indicates the total quantity of divalent ions present in the water and does not specifically identify calcium, magnesium or other divalent salts that contribute to water hardness. It is possible to have hard water that contains only magnesium and no calcium, or calcium and no magnesium.

Occurrence

The natural hardness of water is influenced by the geology of the catchment, in particular presence of soluble calcium and magnesium minerals. Total hardness of inland water ranges between 0 and 1 000 mg $CaCO_3$/L. Hardness in surface waters rarely exceeds 100 mg $CaCO_3$/L. Seawater has a hardness of about 6 500 mg $CaCO_3$ /L, which is made up approximately of a calcium hardness of 1 000 mg/L and a magnesium hardness of 5 500 mg/L.

Interactions

Hard waters usually exhibit fairly high alkalinities, although during acidification, alkalinity can be rapidly reduced while the concentrations of calcium and magnesium (i.e. hardness) remains the same. Calcium and magnesium interact with metals, decreasing the toxicity of metals such as zinc and copper. Similarly, increased calcium concentrations decrease the toxicity of ammonia.

Measurement

Total hardness is expressed as mg $CaCO_3$/L. Total hardness is calculated from the calcium and magnesium concentrations as follows:

$$\text{Total hardness (mg } CaCO_3\text{/L)} = 2.497 \times [\text{mg Ca/L}] + 4.118 \times [\text{mg Mg/L}]$$

This is the preferred method as it reflects the relative proportions of calcium and magnesium making up total hardness.

Total hardness is also reported in many other ways, including degrees of total hardness (dH). One degree of total hardness is equal to 10 mg/L of calcium or magnesium oxide.

The reference method for the determination of total hardness is by the EDTA titrimetric method. No special precautions are required during sampling for total hardness. Samples can be stored at room temperature for several days before analysis or cooled to 4 °C and held for at least 2 weeks.

Data Interpretation

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

The degree of water hardness is determined by the concentration of calcium carbonate according to the table below:

Hardness Range (mg $CaCO_3$/L)	**Description of Hardness**
0 - 50	Soft
50 - 100	Moderately soft
100 - 150	Slightly hard
150 - 200	Moderately hard
200 - 300	Hard
> 300	Very hard

Treatment Options

Water is commonly softened either by the addition of lime followed by recarbonation, or by using ion exchange, sometimes preceded by a precipitation if the feed water is particularly hard. A number of processes are employed in the treatment of hard water. Few, however are suitable for aquacultural purposes, except for demineralisation in recirculating systems using mixed-bed ion exchange columns, which can be used to remove all hardness-forming ions, together with other ions in solution.

The Effects of Total Hardness

Norms

The norms used in the guideline for total hardness are based on:

- The general requirements of calcium and magnesium by fish.
- The effects of water hardness on the health, growth and reproduction of fish.
- The effects of water hardness on other water quality criteria that affect fish health.

Effects

Adequate concentrations of calcium and magnesium are necessary to ensure growth and survival of fish. Calcium is necessary for bone formation, blood clotting and other biological processes. Calcium in culture water reduces the loss of other salts from fish. A loss of salts causes a reduction in growth, as the fish must use energy supplied through the diet to re-absorb lost salts. Low levels of calcium also results in reduced disease resistance in fry. Magnesium and calcium play a role in muscle contraction and the transmission of nervous impulses in animals.

The optimal water hardness necessary for fish to thrive is dependent on the species of fish. Most fish grow well over a wide range of hardness values (30 - 100 mg $CaCO_3$/L). There are however exceptions to the rule. For example, discus fish (*Symphysodon discus*) require soft water, while African cichlids thrive in water with a total hardness greater than 100 mg $CaCO_3$/L.

Fish exposed to $CaCO_3$ concentrations that do not meet their species- specific requirements generally show reduced growth, disruption of osmotic balance, decreased hatchability and survival of fry, and reduced resistance to disease.

Fish exposed to soft water are more susceptible to other adverse water quality conditions. For example, the toxicity of heavy metals is increased in soft waters in which there are insufficient calcium and magnesium ions to compete with toxic metal ions for adsorption sites on the gills. Similarly, ammonia toxicity is increased in waters low in calcium.

Mitigation

Identifying the specific requirements of the fish to be farmed, and utilizing a suitable water source, are advisable.

Intensive farming (e.g. tank culture)

Water that is excessively hard can be softened by adding distilled or deionized water. Water may also be filtered through peat. Similarly, water that is too soft can be modified by adding hard water or by adding calcium chloride or magnesium sulfate to the water. Filtration of the water through marble chips or coral sand can be used to increase hardness.

Extensive farming (e.g. pond culture)

Agricultural limestone or gypsum, or food-grade calcium chloride, can be used to raise calcium levels in soft, alkaline waters. Water hardness can be reduced by increasing the pH to 8.3, which causes the calcium to precipitate out of solution as insoluble calcium carbonate.

Criteria **Table of Criteria and Effects of Water Hardness on the Health of Fish**

Concentration (mg/L $CaCO_3$)	Effects
5	Impairs growth and survival of catfish fry
10	Minimum recommended concentration for catfish
Target Water Quality Range 20 - 100	***No known adverse effects; recommended range for most fresh-water fish***
> 175	Production generally less than optimal; osmoregulation of most fish species may be impaired
> 300	Survival and growth of freshwater prawns affected; much lower concentrations are preferred
300 - 500	Recommended concentration for the successful hatching of silver carp eggs. Recommended for high survival, good growth and feed conversion of red drum, *Sciaenops ocellatus*, juveniles

Modifications Water hardness is predominantly dependent on the concentrations of magnesium and calcium salts. The water hardness suitable for fish will depend on species-specific requirements.

Sources of Information

APHA 1975. *Standard Methods for the Examination of Water and Waste Water*, 14th Edition. American Public Health Association, American Water Works Association, Water Pollution Control Federation. Published by the American Public Health Association, Washington DC, USA.

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.

APHA 1992. *Standard Methods for the Examination of Water and Waste Water*, 18th 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 4: Agricultural Use.

GONZAL A.C., E.V. Aralar and J.M.F. Pavico 1987. The Effects of Water Hardness on the Hatching and Viability of Silver Carp (*Hypophthalmichthys molitrix*) Eggs, Aquaculture, 64(2): 111-118.

KUNIN R. 1972. *Water Softening by Ion Exchange*, Proc., Fourteenth Water Quality Conference, University of Illinois, Urbana, Il.

PURSLEY M.G. and W.R. Walters 1994. *Effect of Total Water Hardness and Chloride on Survival, Growth and Feed Conversion of Juvenile Red Drum* ***Sciaenops acellatus***. Journal of the World Aquaculture Society, 24(3): 448 - 453.

STOSKOPF D.V.M. 1993. *Fish Medicine*. W.B. Saunders Company, Mexico.

TAYLOR E.W. 1958. *The Examination of Water and Water Supplies*, 7th Edition, Churchill Ltd., London.

WURTS W.A. 1994. *Understanding Water Hardness*. World Aquaculture, 24(1).

Total Suspended Matter

Background Information

Introduction

Total suspended matter, as its name suggests, is the amount of inorganic and organic material suspended in the water. The impact of total suspended matter on the suitability of water for aquaculture depends on two factors; the physical presence of particles in the water and the degree to which it attenuates light. Total suspended matter is, therefore, measured in terms of concentration of suspended matter per liter (mg/l). Turbidity measures the light scattering ability of water and is indicative of the concentration of suspended matter in water. Other measures, such as **Clarity**, the transparency of water and **settleable material**, the suspended matter which settles after a defined time period, commonly used to assess potability of water are not relevant criteria in terms of aquaculture usage.

Microorganisms are often associated with suspended matter, hence low total suspended matter minimises the potential for transmission of infectious diseases.

Occurrence

Suspended matter in water usually consists of a mixture of inorganic matter, such as clay and soil particles, and organic matter. The latter can be both living matter such as microorganisms, and non-living matter such as dead algal cells. The turbidity as a measure of TSM in water can range from less than one nephelometric turbidity unit (NTU) in very clear water, to more than 1 000 NTU in turbid, muddy water.

Considerable quantities of suspended material are derived from natural processes of weathering and erosion, although anthropogenic activities, such as deforestation, poor agricultural practices, general construction and mining operations, often exacerbate the rate of these processes. Soil particles constitute the major part of the suspended matter contributing to the turbidity in most natural waters. Discharge of sewage and other wastes can contribute significantly to turbidity. Some fish species, such as carp, may cause re-suspension of sediments in ponds and dams through their feeding habits.

Interactions

Turbidity has a considerable effect on the ecology of water bodies. Reduced light penetration caused by even intermediate levels of suspensoids (suspended material) reduces photosynthetic activity and primary production by micro and macrophytes. Reduction in phytoplankton production and inhibition of macrophyte development results in reduced food availability and poor habitat diversity. In addition, macrophytes often play an important role in nutrient cycling in fresh water, as they provide surfaces for attachment of periphyton and bacteria.

Waters with high loads of suspended matter often support high microbiological growth, with most activity concentrated on the surface of the suspensoids. Growth of microfauna is encouraged by nutrients absorbed on the surfaces of particulates. The presence of high microbiological growth as well as the absorptive capacities of silt particles often increase the risk of water deoxygenation. Under normal conditions there is an equilibrium between oxygen entering the air water interface and the oxygen demand of suspensoids. However, perturbations, such as during flood episodes, may disturb this balance causing extreme hypoxic conditions.

The absorptive properties of some suspended particles may also lead to the entrapment of undesirable inorganic and organic compounds in water, including metal-humate complexes, potentially toxic inorganic ions such as iron (II) and aluminium and herbicides. Further the presence of suspended particles may also interfere with the detection of these compounds.

Measurement

Total suspended matter is measured by weighing the residue collected on a 0.2 - 0.5 µm filter from a known volume of water evaporated to dryness at a temperature below 70 °C. Total suspended matter is expressed as mg/L. Turbidity is generally measured in Nephelometric Turbidity Units (NTU) with a turbidity meter. The total suspended and turbidity of a sample should be determined on the day of collection. If necessary, samples may be stored in the dark for 24 hours, after which irreversible changes in turbidity occur. Samples must be shaken vigorously before analysis. In highly turbid waters NTU measurements cannot be made, therefore, dry mass is the only available measure.

Secchi disk transparency (Sdt) is also frequently used as a measure of turbidity, but is considered to be inaccurate, as the relationship between turbidity and Sdt is curvilinear.

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. **Suspended matter** concentration and content should also be interpreted in conjunction with turbidity.

Treatment Options

The control of suspended matter in natural water systems relies on the introduction of sound catchment management practices. Removal of benthic feeding fish species, in particular carp, may also reduce levels of suspended sediments. Aquatic macrophytes and reed beds often act as sediment traps. Under controlled aquaculture conditions suspensoids may be removed by mechanical filtration. Non-toxic flocculating agents, such as hay, may be added to ponds to accelerate settling out of fine particulate matter. Flocculating agents containing aluminium can be used, provided that the pH is not too low and the resultant aluminium complexes and hydroxides can be removed (see Aluminium Guideline).

The Effects of Total Suspended Matter

Norms

The norms used in the guideline are based on the effects of suspended matter and turbidity on:

- The tolerance limits of fish to suspended matter and turbidity. These differ according to morphological, physiological and behavioural adaptation to conditions of low light intensity, low dissolved oxygen and suspended particles.

Effects

Fish species tolerant of turbid environments or to high suspensoid loads may be recognised by a number of morphological characters, including circum-oral barbels, abundant sense organs on the body, smaller eyes, air-breathing organs and an absence of bright pigmentation. Physiological adaptations include a tolerance to low dissolved oxygen concentrations, gill cleansing and protecting mechanisms. The feeding behaviour of such fish is suited to foraging under conditions of low light intensity and seldom relies on vision. Fish adapted to turbid environments are often photophobic and may show decreased growth performance and survival if kept under high light intensities. Other behavioural responses include avoidance and migratory behaviour.

Fish that routinely reproduce in waters with high suspensoid loads also show considerable adaptation in their breeding biology. Many have evolved mechanisms to prevent smothering of eggs by sediments. These include the production of adhesive eggs which are stuck to submerged vegetation and behavioural mechanisms, such as mouth brooding. Larvae of these fish also have behavioural adaptations for the prevention of smothering.

The effects of suspended sediment on fish are dependent on the characteristics (composition, shape and size) of the suspended material. Suspended matter of high mineral content has a more serious effect on fish than do natural sediments. The organic component of natural sediments has a mitigating effect in that it dilutes the abrasiveness of mineral particles. Increased abrasion of gill surfaces may also result from erosion by angular particles. Particle size also determines the effect of turbidity on fish health, with smaller particles having a greater potential to clog gills than larger ones.

Eggs and larvae are also more adversely affected by suspended matter due to their higher oxygen demands and smothering. Sub-lethal concentrations of turbidity result in reduced growth rates amongst species which rely primarily on vision to obtain food. Visual predators display a reduction in feeding efficiency due to decreased reactive distances and may cease feeding if turbidity levels are too high. Breeding behaviour may also be altered by the presence of turbid water, this is especially true for salmonids and species which require gravel beds or a clean substratum for spawning. Low levels of turbidity have been found to be advantageous to some species, through a reduction in predation by piscivorous birds.

Acute effects

The acute effects of suspended matter vary from interference in respiration to asphyxiation and death. The toxicity of suspended particles depends on the level of coating and clogging of gills and the extent of abrasion of the brachial epithelium. Exposure to high concentrations of suspended particles may cause clogging of the primary and secondary lamellae of gills resulting in poor circulation of water through the gills. Packing of the gills with suspensoids is a common symptom found in dead fish. Damage due to abrasion of the gill epithelial tissue may vary from erosion of microvillae to necrosis of the epithelium and destruction of the lamellae. Early histological symptoms associated with gill abrasion include lesions and thickening of the gill epithelium. This results in reduced permeability to oxygen and may even lead to homeostatic failure. Extreme gill erosion ultimately results in blood hypoxia and death.

The elevated levels of stress combined with the presence of gill damage in fish exposed to high suspensoid levels often results in increased susceptibility to disease. Pathological damage of gill tissue also initiates physiological responses, including an increase in breathing rate and secretion of mucus which is thought to reduce secondary infection by pathogens.

Mitigation

Recovery by fish from the effects of high suspensoid loads often relies on the restoration and cleansing of gill tissue and any step taken to reduce the concentrations of suspended matter will have a mitigatory effect. The addition of uncontaminated water, mechanical filtration and aeration of the water will counteract the effects of low dissolved oxygen concentrations and impaired respiration. Under intensive culture conditions chemotherapeutic treatment of secondary gill infections may also be required.

Criteria

Table of Criteria and Effects of Suspended Matter and Turbidity on the Health of Fish

Species groups	Suspensoid load at first adverse reaction (mg/L)	Lethal suspensoid load (mg/L)
Turbid water species		**Target Water Quality Range < 20 000 mg/L**
Cyprinus carpio	20 000	175 000 - 250 000
Clarias gariepinus	No effect at 350 (NTU)	
Micropterus salmoides	20 000	101 000
Tilapia rendalli (adult)	5 000	42 000 - 48 000
Tilapia rendalli (juvenile)	5 000	21 000 - 24 000
Clear water species		**Target Water Quality Range < 25 NTU**
Oncorhynchus mykiss	< 25 (NTU)	
Salmo trutta	86 mg/L	

Sources of Information

ALABASTER J.S. 1972. *Suspended Solids and Fisheries*. Proc. R. Soc. Lond. B180: 395-406.

ALABASTER J.S. and R. Lloyd 1980. *Water Quality Criteria for Freshwater Fish*. FAO, United Nations, Butterworths, London, 297pp.

BRUTON M.N. 1985. *The Effects of Suspensoids on Fish*. Hydrobiol., 125: 221-241.

Viruses

Background Information

Introduction

Viruses range in size from 25 nm to approximately 300 nm. Viruses are unique in that they do not have an independent metabolism, as do protozoans or bacteria, but are completely dependent on the metabolic machinery of a living cell of a host organisms for their multiplication.

Many viruses may be present in water at any one time. Their small size makes it difficult to detect them. When the resistance of fish is reduced by stress or by poor water quality, the risk of their succumbing to viral infections increases, although symptoms can be masked by bacterial or parasitic infections. It is therefore difficult to identify viral diseases. Maintaining optimal water quality appears to be the best defence against viral infections. Aquaculturists are advised to follow standard hatchery protocols such as maintaining hygienic conditions, good water quality and avoiding over-crowding of fish.

Occurrence

Viruses are always present in water. If fish are stressed as a consequence of poor water quality, improper nutrition, or in any way kept under sub-optimal conditions, their resistance to diseases (including viral diseases) decreases. Once a viral disease is manifest, it will rapidly affect healthy fish in the same system.

Interactions

A number of physical, chemical and biological factors determine the rate of decline of virus levels in water. The most significant factors are temperature, biological activity and sunlight. Viruses may be found in association with sediments and particulate matter.

Measurement

Due to the nature of viruses, identification and quantification methods are complex. Generally, tissue samples are macerated, clarified and treated with anti-microbial agents that retard contamination. Samples are inoculated into cell cultures and incubated for 14 days. Viruses are usually identified by serum neutralization.

Treatment Options

It is only recently that vaccines have come to play a part in the control of fish viral diseases. Many of these vaccines are still in experimental stages of development.

Vaccines for preventing some viral infections in salmonids are available. "Avoidance" of viral infections can be implemented by careful husbandry practices in hatcheries and by obtaining seed from certified disease-free hatcheries.

As a precautionary measure it is advisable to separate units of ponds or tanks so that these can be isolated if necessary.

The Effects of Viruses

Norms

The norms used in the guideline for viruses are based on:

- The effects of viral diseases on the health, growth, survival of fish.

Effects

The effect of viruses on fish may be acute, resulting in extensive tissue damage and rapid death. Viral infections of fish are frequently accompanied by secondary bacterial invasions, a fact which frequently complicates accurate diagnosis.

In any viral infection, a certain percentage of the infected fish may not demonstrate any diagnostic signs yet may be infected and act as carriers of the virus. Fish that are affected by viral diseases exhibit "poor" feeding behaviour and growth retardation.

Fish with viral infections must not be marketed and must be isolated, even though no human infections from fish viruses have been reported. For some viral diseases such as lymphocystis, it is recommended that the fish be killed.

Mitigation

When fish are stressed or are subjected to poor water quality conditions their resistance to viruses is reduced. The water supply for fish in aquacultural conditions should be free of parasites, pathogens and of general good quality.

Criteria **Table of Criteria and Effects of Treatments for some Viral Fish Diseases**

Virus	Species affected	Symptoms & Pathology	Prevention & Treatment
Lymphocystis	Tilapia	External lesions, warts	No cure; fish should be destroyed
Infectious Pancreatic Necrosis (IPN)	Trout	Abdominal swelling & gut full of mucus	- Obtain fry from disease-free hatcheries - Rear fry separately - Immunization
Infectious Haematopoietic Necrosis Virus	Trout	Abdominal distention and haemorrhages	- Rear fish > 15°C - Disinfect hatchery equipment
Spring Viraemia	Carp	Haemorrhages on skin	- Immunization with SVC virus
Channel catfish virus disease	Channel catfish	Distended abdomen and exophthalmia	Hatchery hygiene
Carp pox	Carp	Fish disfigured	Segregate diseased fish
Viral Haemorrhagic Septicemia (VHS)	Most fresh-water fish	Haemorrhages on skin	Disinfect hatchery

Sources of Information

BROWN E.E. and J.B. Gratzek 1980. *Fish Farming Handbook*. Van Nostrand Reinhold, New York, pp.390.

PAPERNA I. 1980. *Parasites, Infections and Diseases of Fish in Africa*. Food and Agriculture Organisation of the United Nations. CIFA Technical Paper No. 7.

STOSKOPF M.K. 1993. *Fish Medicine*. W.B. Saunders Company, Philladelphia, pp.873.

TUCKER C.S. and E.H. Robinson 1990. *Channel Catfish Farming Handbook*. Van Nostrand Reinhold, New York, pp.454.

VESTERGAARD JORGENSEN P.E., N.J. Olsen and N. Lorenzen 1991. *Infectious Haematopoietic Necrosis (IHN) and Viral Haemorrhagic Septicemia (VHS): Detection of Trout Antibodies to the Causative Viruses by means of Plaque Neutralization, Immuno Fluorescence and Enzyme-linked Immunosobent Assay*. Journal of Aquatic Animal Health, 3: 100-108.

Zinc

Background Information

Introduction

Zinc is a metallic element. The stable oxidation states of zinc are 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.

Zinc is an essential nutritional trace element for plants and animals, widely used in nucleic acid synthesis and occurring in many enzymes. It forms active sites for various metalloenzymes including DNA and RNA polymerases. Fish are highly susceptible to poisoning by elevated zinc concentrations, whereas humans have a high tolerance to zinc.

Occurrence

The most common mineral form of zinc is the sulphide (sphalerite). Zinc is also found as a carbonate, oxide and silicate and may occur in association with 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 hydrolyse to form relatively insoluble hydroxides, which tend to be associated with sediments. On acidification of water, the insoluble hydroxides are released into solution. If the water is acidic, leaching of zinc 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 inland waters is usually low, typically about 0.015 mg/L. Elevated zinc concentrations arise at neutral and alkaline pH, when 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 very low, typically about 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.

Interactions

Toxicity to solutions containing zinc is mainly attributable to the zinc ion (Zn^{2+}) and to a lesser extent to particulate zinc present as the basic carbonate or the hydroxide suspended in solution.

Zinc interacts strongly with cadmium, which is chemically very similar. Zinc, however, is an essential element and of relatively low toxicity to living organisms, whereas cadmium is not essential and is highly toxic to all higher organisms. Metabolically, zinc interacts with copper. As is the case with all metals, the pH of the water determines the concentration of soluble zinc.

There is a curvilinear relationship between the logarithm of survival of fish and the logarithm of the zinc concentration. Environmental changes alter the shape and/or position of this curve. The following factors affect the concentration at which zinc is lethal:

Temperature; increases in temperature decrease survival rates;

Dissolved oxygen levels: reduced dissolved oxygen concentrations reduce the LC_{50} concentrations for rainbow trout;

Water hardness: concentrations of zinc which are acutely lethal to fish are higher in hard than in soft water. The addition of sodium ions reduces zinc toxicity;

Additive effects with other metals: zinc and copper sulphates in hard water are additive in their toxicities. In soft water they are synergistic.

Measurement

The criteria are given in terms of soluble zinc concentrations, in units of mg/L. The reference method for the determination of zinc is atomic absorption spectrophotometry. If other methods are used, their characteristics relative to the reference type 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 concentration of the **suspended solids** and related metals, such as **cadmium** and **copper**.

Treatment Options

Zinc in water supplies is most conveniently removed by using lime to raise the pH to 9.5 - 10, thereby precipitating the insoluble zinc hydroxide. 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, zinc-rich sludge is generated in the process which may present disposal difficulties.

The Effects of Zinc

Norms

The norms used in the guideline for zinc are based on:

- The effects of zinc on the fitness of the fish species in terms of health, growth, reproduction and behaviour.

Effects

In all cases of zinc poisoning, fish die from suffocation due to the deposition of precipitated zinc salts directly onto the gills. Histological examination of gill tissue exposed to zinc reveals secondary lamellae with swollen epithelial cells that separate from the pillar cells and slough off. Zinc also plays a role in disrupting ion exchange. Symptoms of zinc toxicity include darkening in colour and increased swimming activity.

At high zinc concentrations, feeding and growth may be impaired and fish may exhibit avoidance behaviour. Reduced resistance to *Aeromonas* and infectious pancreatic necrosis are also observed. Fewer viral antibodies are found in fish exposed to sublethal zinc concentrations.

Juvenile fish are more susceptible to zinc than are adults. Eggs are most resistant, although uptake may occur by adsorption on the chorion, which results in some diffusion into the egg.

Mitigation

The addition of chelating agents such as nitrilotriacetic acid (NTA) or ethylenediaminetetra-acetic acid (EDTA) at neutral pH values reduces the effects of acute lethal toxicity of zinc on salmonids. Humic substances, amino acids, polypeptides and other soluble organic matter may complex zinc and may also non- specifically adsorb onto zinc receptor sites, thereby blocking absorption of zinc.

Criteria

Table of Target Water Quality Ranges for Salmonids and Cyprinids

Water hardness (mg/L $CaCO_3$)	***Target Water Quality Range* soluble zinc (mg/L)**	
	Salmonids	**Cyprinids**
10	0.03	0.3
50	0.2	0.7
100	0.3	1.0
500	0.5	2.0

Sources of Information

ALABASTER J.S and R. LLOYD 1982. *Water Quality Criteria for Freshwater Fish*, 2nd Edition. Butterworth Scientific, London, 361pp.

BIRGE W.J., R.D. Hoyt, J.A. Black, M.D. Kercher and W.A. Robinson 1993. *Effects of Chemical Stresses on Behaviour of Larval and Juvenile Fishes and Amphibians*. American Fisheries Society Symposium, 14: 55-65.

BURTON D.J., E.L. Morgan and J. Cairns Jnr. 1972. Mortality Curves of Bluegills (*Lepomis macrochirus* Rafinesque). Simultaneously Exposed to Temperature and Zinc Stress. Transactions of the American Fishery Society, 101: 435-441.

EVERALL N.C., N.A.A. MacFarlane and R.W. Sedgewick 1989. The Interaction of Water Hardness and pH with the Acute Toxicity of Zinc to the Brown Trout, *Salmo trutta*. Journal of Fish Biology, 35: 26-27.

Chapter 6

Glossaries

Glossary of terminology

aerobic	of organisms requiring oxygen for respiration *or* conditions where oxygen is available
acclimation	short-term adaptation of individual organisms to specific environmental conditions
acute effect value	the concentration at and above which statistically significant acute adverse effects are expected to occur
adsorption/elution	the attachment of molecules or ions to, and their removal from, a substrate by manipulation of electrical charge or pH
agglomeration	the coalescing of particles in water to form flocs; it can be promoted by gentle stirring or by adding chemicals
algogenic	substances produced by algae
amphoteric	is the capability of a substance to react as an acid or a base, hence of dissolving under basic or acidic conditions
anaerobic	conditions where oxygen is lacking, or of organisms not requiring oxygen for respiration
anionic	characteristic behaviour or property of an ion that has a negative charge. Anions move to the anode in electrolysis
anions	negatively charged ions
assimilative capacity	is the capacity of a water body to accommodate, through processes such as dilution, dispersion and chemical and biological degradation, a quantity of substances without causing any known impairment of use
benthic	inhabiting the bottom of a water body
biochemical oxygen demand (BOD)	the amount of dissolved oxygen consumed by organisms in water rich in organic 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
chronic effect value	the concentration limit which is safe for all or most populations

	even during continuous exposure
chemical oxygen demand (COD)	the amount of oxygen required to oxidise all the organic matter that is susceptible to oxidation by a strong chemical oxidant
chlorophyll	the green pigment in plants and algae that during photosynthesis captures sunlight energy and converts into chemical energy in the form of carbohydrates. Chlorophyll *a*, *b and c*, are forms of chlorophyll, found in different proportions in different plants. Chlorophyll is used as a measure of the quantity of algae in water
clarity	refers to the depth to which light can penetrate in a water body and is measured by the depth to which a Secchi disk (a 20 cm diameter disk printed with black and white quadrants) is visible
coagulation	the agglutination of dispersed particles
cyanosis	the discolouration of the skin due to the presence of oxygen-deficient blood
cytopathogenic or *cytopathic*	refers to damage caused to cells
diffuse pollutant source	see *non-point pollutant source*
dissolution	the process of dissolving
electron acceptor	is an atom or part of a molecule that receives electrons from other substances in a chemical reaction binding the substances together with a covalent bond
eutrophic	a condition characterised by excess nutrients that stimulate excessive plant and algal growth
fecundity	the number of eggs produced by an individual or a species
flocculation	the coalescence of small dispersed particles in flocs through the processes of *coagulation*, aggregation or biochemical reaction of fine suspended particles or by addition of chemical reagents (flocculants)
geosmin	a tertiary alcohol and metabolite produced in trace concentrations by certain Cyanobacteria (blue-green algae), algae and bacteria. It is released into water and soil, where it imparts a typical earthy/muddy odour and taste. The odour and taste threshold for humans is extremely low (of the order of ng/L)
haematology	the study of blood
haemoglobin	the protein occurring in the red blood cells of vertebrates 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
halophyte	a salt-tolerant plant
hard water	water that contains high concentrations of calcium, magnesium, and to a lesser extent other alkaline earth metal ions. Under highly alkaline conditions, the calcium and magnesium of hard waters may precipitate out as scale or as some other insoluble salt of these two metal ions
hardness	defined as the sum of the calcium and magnesium concentrations, both expressed as calcium carbonate, in milligrams per litre
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
hygroscopic	a substance that absorbs water
hypoxia	lack of sufficient oxygen
igneous rock	rock, formed from the cooling of magma that has not changed appreciably since its formation
intensive systems	farming systems where production is based on formulated artificial feeds
ion exchange	the interchange of ions of like charge, usually on a solid medium; used in water treatment, such as water softening
lowest observed effect concentration	the lowest concentration tested that leads to an adverse response statistically different to that of the control, where the statistical significance is measured at the 95 % confidence level
macrophyte	any macroscopic form of aquatic vegetation; encompasses certain species of algae, mosses and ferns as well as aquatic vascular plants
mesotrophic	refers to freshwater bodies that contain moderate quantities of plant nutrients and are moderately productive
metamorphic rock	rock that has been greatly altered from its previous condition through the combined action of heat and pressure
microbes	microscopic organisms such as bacteria or viruses
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, e.g. chemicals, radiation
necrosis	the death of cells or tissues
no observed effect concentration	the highest concentration that gives no adverse effects statistically different to that of the controls, where the statistical significance is measured at the 95% confidence level
non-point pollutant sources	diffuse discharges of pollutants from surface run off, infiltration or atmospheric sources
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
pelagic	refers to animals able to swim 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. temperature, electrical conductivity) and chemical (e.g. concentrations of nitrate, mercury) characteristics of water
point pollutant sources	are discharges of pollutants from known discrete sources e.g. an effluent discharge from an industry. The volume and quality of the discharge can normally be measured
polyvalent metallic ions	ions of metals having more than one oxidation state e.g. Cr(III) and Cr(VI)
poikilothermic	animals whose temperatures vary with that of the surrounding medium
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
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
site-specific	refers to conditions that are unique or specific to a certain site or locality
sub-lethal	the concentration or dose of a toxic substance below the threshold
supersaturation	refers to a solution containing more solute than equilibrium conditions will allow
surficial deposits	unconsolidated alluvial, residual or glacial deposits overlying bedrock or occurring on or near the surface of the earth
teratogenic	of agent or factor causing deformed embryos or offspring
titratable bases	bases that are capable of being analysed quantitatively through the addition of known amounts of a standardised acid solution until a given reaction is produced (colour change, precipitation)
toxic substance	natural or synthetic chemical substance that may cause adverse effects on living organisms, even when present at low concentrations
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)
zeolites	minerals, consisting mainly of hydrous silicates of calcium, sodium and aluminium, which are able to act as cation exchangers and are utilised in the treatment of water to fulfil this function

Glossary of abbreviations / acronyms

APHA	American Public Health Association
BOD	biological oxygen demand
COD	chemical oxygen demand
CSIR	Council for Scientific and Industrial Research
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 change from EEC to EC, formally in 1992
EDTA	ethylene diamine tetra-acetic acid
GAC	granular activated carbon
HOCl	hypochlorous acid
HPLC	high performance liquid chromatography
IAWPRC	International Association for Water Pollution Research and Control
IC	inorganic carbon
NOAEL	no observed adverse effect level. Refers to that test concentration of a toxicant in a toxicological experiment at which no adverse effect on the test organism is observed or measured
NTU	nephelometric turbidity units
$TCID_{50}$	dose of virus required to cause 50 % infection in tissue culture
TDS	total dissolved solids
TOC	total organic carbon
US EPA	United States Environmental Protection Agency

Glossary of units of measure

kg/h	kilograms per hectare
µg/L	micrograms per litre
µS/cm	micro-Siemens per centimetre
meq/L	milli-equivalents per litre
mg/L	milligrams per litre
mM/L	millimoles per litre
mS/m	milli-Siemens per metre
ng/L	nanograms per litre
nm	nanometre
NTU	nephelometric turbidity units
°C	degrees centigrade

Statement regarding this version of the document on 2019-10-14

The South African Water Quality Guidelines are available from http://www.dwa.gov.za/iwqs/wq_guide/index.asp as individual volumes in PDF format. This is not the official source for these documents, which is at http://www.dwa.gov.za/Dir_WQM/docsFrame.htm (Enter the following in the search box: water quality guidelines, which will return the link to South African Water Quality Guidelines, with all the guideline PDF files in a single 10Mb ZIP file.)

The original documents were written in WordPerfect 6.0, using non-standard WordPerfect symbol fonts. These are now rarely installed on users' computers, and even when they are present some PDF readers (e.g. Adobe) do not detect them. A "font not found" warning occurs, and even installing the non-copyright version of the WP font set WPFONTS.EXE does not work in all circumstances. Using an alternative PDF reader is sometimes successful.

For these reasons, Mike Silberbauer has produced this document by converting the PDF file to MS Word, then replacing the special characters with standard characters, where possible. For example, the curly litre sign is replaced with a capital L. The new document had certain formatting differences from the original, for example some bullet points were missing, and the typeface was not exactly the same.

The document was then converted back to PDF for distribution.

The printed copies remain the definitive version of these documents.