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This publication is the report to the Water Resources Council on suitable criteria for water quality classification. The working party's recommended criteria are intended for incorporation into regulations of new water and soil legislation. The report provides recommendations for water quality standards appropriate to each of the water quality classes defined in the endorsed report on water quality management from the Policy and Planning Committee.

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Contents

Foreword

On 12 September 1979 the Water Resources Council established a working party to consider and recommend suitable standards for the various classes proposed in the water quality classification provisions to be included in the reviewed Water and Soil Conservation Act.

After several meetings members have recommended suitable standards to the Water Resources Council.

The recommendations of the working party are published now for the information of the public.

A W Gibson
Director of Water and Soil Conservation

Preface

Letter from Mr Jack Vickerman, Chairman of the Water Quality Criteria Working Party, to Mr Malcolm Conway, Chairman, of the Water Resources Council, on presentation of the Working Party's Report.

Chairman—

In presenting the following report to the Water Resources Council, it is appropriate that I first draw attention to the context in which the respective Water Quality Standards have been arrived at and recommended.

The Working Party has been constituted of people with scientific and engineering expertise and the initial phase of its deliberations involved reaching agreement upon quality criteria appropriate in the present state of technology for absolute protection of the respective water uses designated by the Council.

It then became increasingly evident that as most waters are subject to multiple use, a Water Quality Management Strategy cannot be effective if based upon an idealistic scientific scale that is neither attainable in most situations nor capable of ready verification in the field. Accordingly, the Working Party has devoted much time in the final stages of its task to finding that delicate compromise which will allow widest possible use of classified waters while at the same time maintaining a good order of quality and an adequate level of protection for those important special uses. The intended water management philosophy has not previously been set out in sufficiently full detail to provide a base upon which the recommended standards could be predicted. Accordingly Section 2 of the report sets out the rationale for, and the role of, the intended classification system, and this is the management basis upon which the recommended standards rely. Careful attention should first be given to this section of the report by those who would wish to debate the efficacy of the various standards and criteria proposed for the water classes in Sections 4 and 5.

Agreement on some of the more problematical standards was achieved largely as a result of the presentation of well-researched papers on the state of the art by members of the Working Party. Key papers in this regard were: Microbial criteria for classifications by Mr D G Till; Discussion paper on dissolved oxygen requirements by Dr D Scott; and those on BOD and pH by Dr C D Stevenson. These are included as appendices to the report.

I commend Mrs J A Boshier, Water Resources Consultant Engineer, for her valuable interpretation of the mind of the Working Party and the translation of this into the coherent report which has emerged.

The Working Party has been a unique assembly of people with competent specialist experience and it has been a particular privilege to be assigned the responsibility of Chairman of this team. The debate has been stimulating and has undoubtedly been a simulation of the wider debate on the standards which will take place in the wider community over an extended period of time. I am confident the recommendations, if adopted, will serve the needs of the New Zealand people well in the era ahead notwithstanding the inevitable controversy that attaches to any set of environmental regulatory standards.

Finally my thanks are due to all members of the working party and supporting staff of the Water and Soil Division, Ministry of Works. Although some names have been specifically mentioned, all have made an active and willing contribution toward resolution of a complex assignment.

J L Vickerman
Chairman,
Water Quality Criteria Working Party

[1] Introduction

On 12 September 1979 the Water Resources Council established a working party to consider and recommend suitable standards for the various classes proposed in the water quality classification provisions to be included in the reviewed Water and Soil Conservation Act.

The terms of reference of the working party were:

> "to report to the Water Resources Council on suitable criteria for water quality classification. The party's recommendations shall be suitable for inclusion in proposed regulations to the new water and soil act and shall agree with the endorsed report on water quality management from the Policy and Planning Committee."

Membership of the working party was:

Mr J L Vickerman *Chairman*	Member of the Water Resources Council representing the New Zealand Manufacturers' Federation and Chief Civil Engineer, New Zealand Forest Products.
Mr K J Currie	Water Resources Officer, Manawatu Regional Water Board.
Mr W R Howie	Manager, Technical Services, Water and Soil Division, Ministry of Works and Development.
Mr J J Molloy	Group Technical Manager R and W Hellaby Limited.
Dr C D Stevenson	Scientist, Section Leader for Water Section, Chemistry Division, DSIR.
Dr M E U Taylor	Research Director, Water and Soil Division, Ministry of Works and Development.
Mr D G Till	Chief Bacteriologist, Department of Health.
Dr M Larcombe	Principal, Bioresearches Limited, Auckland.
Dr D Scott	Senior Lecturer, Department of Zoology, Otago University and Chairman, National Pollution Advisory Council for New Zealand Acclimatisation Societies.

The working party met on five occasions and has resolved the standards it considers appropriate for the proposed classes.

In order to arrive at appropriate criteria it was necessary for the working party to fully understand the role of classification in water resources management as is being proposed for legislative amendment. Consequently the second section of this report records the working party's understanding of this aspect.

The working party has agreed with and has taken into account the approach to water resources management proposed by the Water Resources Council on the recommendation of the Water Quality Management Working Party. With this approach the policies of a regional water board for water resources management can be comprehensively stated in the water management statement. This gives regional water boards the necessary flexibility in developing and using appropriate management procedures.

In attempting to formulate water quality standards for the given water use classes the working party found, in certain instances, that the definition of uses was not conducive to the assignment of consistent or defensible water quality standards. Where this situation arose changes in the wording defining the use have been recommended and they, together with the reasons for such changes, are set out in the third section.

The working party agrees with the objectives of water management of protecting uses of water and preventing the undue degradation of water quality. Within this framework the proposed water quality standards for classified waters are intended to define minimum national quality requirements appropriate to the waters and water uses concerned. The recommended standards are contained in the fourth section of this report.

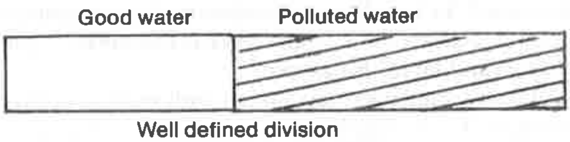
The working party notes and agrees that these water quality standards should become regulations issued pursuant to the main Act. Regulations provide the standards with sufficient formal status to ensure their authority, yet may be changed if the need arises. Some of the standards require additional information concerning their use, measuring technique, or interpretation for different situations. This kind of information should be contained in guidelines issued by the National Authority.

The technical papers in the appendices contain a distillation of the research and studies used as a basis for proposing certain of the standards and are regarded by the working party as an important integral part of this report.

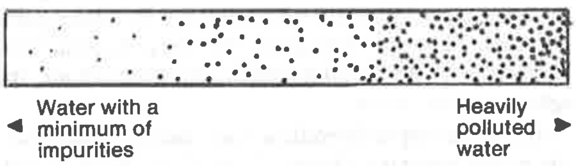
[2] The Role of Water Quality Classification

[2.1] The concept of water quality in rivers, lakes, and seas

A common misconception which must be set aside is:



Whereas the position in reality is:



The concept of characterising water as "polluted" or "not polluted" does not provide a realistic measure of water quality. Perhaps 5% of New Zealand waters could still be described as polluted but we are, at this stage, seeking a management strategy for the remaining 95% as well. The acceptability of the quality of any particular body of water relies upon recognition of the uses to be made of it, and thereby the particular characteristics which water must possess to be satisfactory for those specific uses.

[2.2] Modulating Change in Water Quality

Water in its natural state mostly possesses a wide range of organic and inorganic impurities and its visual appearance may vary widely from clear to highly coloured or turbid. This range of natural quality becomes further modified by the influence of man's actions, individually and in communities. If we desire to improve or maintain the character of a particular body of water this can be achieved only to the extent that it is practicable to constrain the actions of man. Such actions influencing water quality come under the following four headings:

(a) *The discharge of liquid wastes of domestic and industrial origin for assimilation into the water cycle.* Appropriate degrees of pretreatment of wastes are expected. Technological and economic constraints limit the extent to which effluent discharges can be practicably improved. Most waste treatment processes result in suspended solids being substantially removed but with dissolved solids remaining to be assimilated in the receiving waters after first being sufficiently stabilised to avoid undue impact upon the aquatic ecology.

(b) *Abstraction of water for consumptive uses.* This action reduces the residual flow in rivers and their propensity for dilution of waste.

(c) *The damming of river flows.* High retention times and flooding fertile land increases the nutrient quality of the water.

(d) *Change in character of the adjoining land surface in the catchment area.* This alters the nature of rainfall discharge into streams, the animal faecal contribution, the sediment and nutrient contribution.

The foregoing activities are legitimate and accordingly water quality measurement and management is essentially a matter of compromise between uses, e.g., those relating to public recreation and enjoyment on the one hand and those relating to the other essential requirements of public communities on the other hand.

It is also to be observed that there is a wide variation between catchments, both as to the natural condition of water quality and the superimposed demands of man upon the water resource. The responsibility for resolving the conflicting demands should therefore be largely in the hands of the regional body as it is substantially the local people who live in intimate contact with the water resource and with its quality limitations.

We have to view the need of our current situation as maintaining some appropriate measure of compromise over (and between) the demands made by others upon the waters of the country.

Water is *a resource to be used and enjoyed* and the role of the authorities is to ensure wise husbandry of it. The word *management* has been adopted to best fit this concept.

[2.3] Proposed basis of management

Water management control strategy under the proposed legislation will be administered by regional water boards and will be manifested through the mandatory preparation of a *Water Management Statement* promulgated for each water region as a whole, or for each individual catchment as appropriate. This statement will identify all the important uses required to be made of a water resource and it will have the endorsement of the local public. Such a statement will become the framework for management decisions by the board in those things it can control or influence, viz., water allocation plans, water classification, water rights, and land use constraints.

Once promulgated, the statement will provide a moderately firm basis for the board achieving the best practicable water quality in areas where it is sought by the local public. Such management strategy need not involve classification nor involve specific measurement of quality, although some standards can be introduced and be based on current scientific opinion. A regional water board retains flexibility in being able to tailor its Water Management Statement and the administration thereof according to the particular characteristics of each local resource. A board will be constrained by the Act only to the extent that its strategy must observe a few broadly defined objectives.

[2.4] Water classification

Classification is a *subordinate and optional measure which may* be applied by a regional water board in a localised situation where its management position will be strengthened by such application. The National Water and Soil Authority may also require a classification in a local situation where it considers it to be in the national interest to resolve some conflict. The rationale for a system of classification is:

(a) As population density increases, with associated needs for residential, industrial, and recreational developments, *some waters* become subject to more intensive multiple use. The inherent flexibility of the regional water board's water management strategy under its Water Management Statement may provide an insufficiently defined base to resolve conflict in some of the intensive use situations. Boards and the Planning Tribunal become subject to increased pressure from interests representing the two extremes, recreational and developmental. They will then require the protection and guidance of a more firmly based and legally endowed scale of water quality standards to ensure that the character of the waters under contention is not degraded below some absolute national minimum.

(b) Uses of water include not only the taking, damming, or diverting of water, or the discharge of water or waste (for which water rights may be obtained) but they also include swimming, boating, canoeing, aesthetic enjoyment, and the protection and maintenance of aquatic and other wildlife. These latter uses, sometimes referred to as "instream" uses, are able to be pursued by any member of the public and, while they do not require authorisation, they do require that an acceptable water quality is provided and safeguarded. Adequate protection of these uses will sometimes need to rely on firmly established water quality criteria which are legally constraining on the granting of water rights. Classification will provide for the protection of water quality for instream uses *where these qualify for a special measure of protection.*

(c) Central Government, reflecting general public opinion, will desire the quality of all New Zealand waters to be kept at as good a level of quality as practicable. Such a level *cannot simply be defined* in an Act as it will vary from catchment to catchment. On the other hand central Government has an obligation to ensure that a certain minimum and consistent water quality is maintained throughout the country for the respective purposes to which the water is put. It *is* practicable to define such a minimum.

(d) Certain uses of water are of a nature which make it important that the quality characteristic of the water is controlled with a greater level of stringency than for other uses, e.g., shellfish, bathing waters.

The proposed classification policy, which is a change from the present, therefore will rely upon the following understandings:

(a) Classification is an optional second level management aid and is not intended to be applied universally. The aim of a regional water board should be to keep maximum flexibility in its management strategy by applying classifications with discretion.

(b) Classification will provide for the protection of water quality for instream uses.

(c) Classification standards are intended as national minima for the designated uses, beyond which quality will not be allowed to range except for natural causes.

(d) Regional water boards will be expected to ensure water quality characteristics are maintained as much superior to the prescribed standards as can reasonably and practicably be achieved in the local situation bearing in mind known local aspirations. Classification will provide an ultimate legal barrier to withstand extreme pressure for water degradation.

[2.5] Basis for classification standards

Upon the premises of the foregoing philosophy the standards for the various classes of water should be established as follows:

Classes W F R CR CS

This group results from identification of a principal contact use. Standards here should be at a threshold beyond which the use could not be effectively achieved or enjoyed on a continuing basis.

Class S

Will be applied to designate certain waters that should be preserved in a largely natural condition to the exclusion of any action which would cause an adverse change in the character of the water.

Class CD

This will be applied sparingly to designate a very limited extent of open coastal water where a high level of waste discharge concentration, including disintegrated solids, is permissible.

Classes G CE CO

These are waters for no singled-out principal use, but are subject to competing uses both present and likely future ones. Importantly, waste assimilation is one significant use. These classes should not include vast areas of water not subject to conflict of use, as such waters should continue to be managed under the flexibility of a Water

Management Statement and in the absence of any classification.

The standards for these waters should ensure the protection and maintenance of the following basic uses or characteristics:

(a) the maintenance of a substantially unaltered aquatic community;
(b) the general aesthetic amenity;
(c) fishing;
(d) stock watering;
(e) irrigation;
(f) public water supply after extensive treatment;
(g) occasional contact use such as swimming.

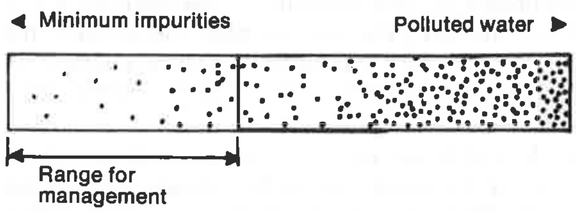
Accordingly, standards may be more relaxed than apply for the principal use classes, but still at a level which provides a satisfactory water condition for common or general uses and the maintenance of a relatively healthy ecological community.

These classes G, CE, and CO may be applied as a residual classification to achieve the reasonable continuity of a classification.

The Working Party has used the concept of an overlay classification system to arrive at the standards recommended. Initially it listed the uses of water to be protected and the specific water quality requirements for those uses, e.g., bathing required limits on bacteriological quality, pH, and appearance. Then, because general uses and aquatic life also needed protection their water quality requirements were added. A composite standard has therefore been recommended for each class.

[2.6] Effects of Classification

Returning to the concept of water quality graded from heavily polluted to water containing a minimum of impurities, a classification in effect specifies the range within which the water quality must be managed.



For Class S the range is very small, while for Class G it is wider. Having specific legal authority the requirements of a classification control the level of degradation of water quality that can be permitted by any discharge of waste. A classification consequently reduces the need for instream users to oppose every application to discharge waste. It provides positive protection for the water quality requirements of instream users and indicates the real constraints that dischargers will face.

[3] Recommended definitions for water use classes

In attempting to formulate water quality criteria for the given water use classes the working party considered that some of the use classes should be redefined. The working party considers that:

3.1 *The definition of Class S water* (i.e., being water for special scenic or scientific purposes or public water supply from a controlled catchment; such water not receiving or likely to receive or be affected by any waste discharge) *should be changed* because the objectives of this class are believed to be to maintain the water in its natural state and to avoid changes in its quality resulting from any discharge of waste. It is not to prevent any discharge at all, but rather to strictly limit them.

If a water supply comes from a controlled catchment, it does not need classifying. What is required, however, is protection of water quality in a catchment where the main water use is to be public water supply but where the full control of a controlled catchment designation is not provided.

In addition to special scenic or scientific purposes, special recreational purposes should also be included.

A recommended redefinition of Class S is – Class S water, being water protected for an outstanding special purpose of a scenic, scientific, or recreational character, such use being specifically designated in the classification, or water used as a source of public water supply where treatment equivalent to only disinfection could be reasonably expected.

3.2 *The definition of Class F water* (i.e., being water for a recognised fish spawning area) *be changed*. The inclusion of the word "recognised" could make it difficult to determine such spawning areas, as spawning may occur along a whole river from the tidal mouth to the headwaters. Inclusion of "recognised" would require the type of fish to be stated as well as the spawning area.

A recommended redefinition of Class F is – Class F water, being water specially protected for fish spawning purposes.

3.3 *The definition of Class W water* (i.e., being water used as a source for public water supply or for use in the preparation and processing of food for sale for human consumption) *be expanded*. It is considered that two water supply classes are necessary to cover the distinctly different water quality requirements for systems applying flocculation, filtration, and disinfection treatments. For Class W, then, protection of water quality in a catchment is required where the main use is public water supply but where the level of control is not as stringent as that for Class S.

A recommended redefinition of Class W is – Class W water, being water for a source for public water supply or for the preparation and processing of food for sale for human consumption where treatment at least equivalent to flocculation, filtration, and disinfection could be reasonably expected.

[4] Recommended water quality standards for each water use class

Class G water (being water for general use purposes)

(a) The natural water temperature shall not be changed by more than 3°C and shall not exceed 25°C.

(b) the pH of the water shall be within the range 6.0-9.0 units.

(c) The water shall not be tainted so as to make it unpalatable nor contain substances which would render it unsuitable for consumption by farm animals, or unsuitable for irrigation.

(d) The water shall not emit an objectionable odour.

(e) There shall be no substantial adverse effect on the aquatic community by reason of toxic substances.

(f) Aquatic organisms shall not be rendered unsuitable for human consumption by accumulation of excessive concentrations of toxic substances.

(g) The natural colour and clarity of the water shall not be changed to a conspicuous extent.

(h) The concentration of dissolved oxygen shall exceed 5 g/m^3.

(i) There shall be no visible oil or grease films or conspicuous floatable or suspended materials.

(j) The daily average five-day biochemical oxygen demand at 20°C shall not exceed 5 g/m^3.

Where the water quality does not comply with these requirements, no action shall be permitted which will cause the water quality to deviate further from compliance with these requirements.

Class R water (being water for regular public bathing)

(a) The natural water temperature shall not be changed by more than 3°C and shall not exceed 25°C.

(b) The pH of the water shall be within the range 6.5-9.0 units.

(c) The water shall not be tainted so as to make it unpalatable nor contain substances which would render it unsuitable for consumption by humans or farm animals or unsuitable for irrigation.

(d) The water shall not emit an objectionable odour.

(e) There shall be no substantial adverse effect on the aquatic community by reason of toxic substances.

(f) Aquatic organisms shall not be rendered unsuitable for human consumption by accumulation of excessive concentrations of toxic substances.

(g) The natural colour and clarity of the water shall not be changed to a conspicuous extent.

(h) The concentration of dissolved oxygen shall exceed 5 g/m^3.

(i) The median faecal coliform bacteria concentration shall not exceed 200 per 100 ml based on a minimum of one water sample taken on each of five separate days over not more than a 30 day period; nor shall more than 10% of samples taken on separate days during any 30 day period exceed 400 faecal coliforms per 100 ml.

(j) There shall be no visible oil or grease films or conspicuous floatable or suspended materials.

(k) The daily average five-day biochemical oxygen demand at 20°C shall not exceed 3 g/m^3.

Where water quality does not comply with these requirements, no action shall be permitted which will cause the water quality to deviate further from compliance with these requirements.

Class S water

(being water protected for an outstanding special purpose of a scenic, scientific, or recreational character, such use being specifically designated in the classification, or water used as a source of public water supply where treatment equivalent to only disinfection could be reasonably expected).

The quality of the natural water shall not be significantly altered in those characteristics which have a direct bearing upon the suitability of the water for the specific use or uses designated.

Class W water

(being water for a source for public water supply or for the preparation and processing of food for sale for human consumption where treatment at least equivalent to flocculation, filtration, and disinfection could be reasonably expected).

(a) The natural water temperature shall not be changed by more than 3°C and shall not exceed 25°C.

(b) The pH of the water shall be within the range 6.0-9.0 units.

(c) The water shall not be tainted so as to make it unpalatable after treatment nor contain substances which would render it unsuitable for consumption by humans or farm animals or unsuitable for irrigation.

(d) The water shall not emit an objectionable odour.

(e) There shall be no substantial adverse effect on the aquatic community by reason of toxic substances.

(f) Aquatic organisms shall not be rendered unsuitable for human consumption by accumulation of excessive concentrations of toxic substances.

(g) The natural colour and clarity shall not be changed to a conspicuous extent.

(h) The concentration of dissolved oxygen shall exceed 5 g/m^3.

(i) The daily average five-day biochemical oxygen demand at 20°C shall not exceed 3 g/m^3.

(j) The median faecal coliform bacteria concentration shall not exceed 2000 per 100 ml based on a minimum of one water sample taken on each of ten separate days over not more than a 30 day period; nor shall more than 10% of samples taken on separate days during any 30 day period exceed 4000 faecal coliforms per 100 ml.

(k) The concentration of ammonia-nitrogen shall not exceed 0.2 g/m^3.

(l) There shall be no visible oil or grease films or conspicuous floatable or suspended materials.

Where the water quality does not comply with these requirements, no action shall be permitted which will cause the water quality to deviate further from compliance with these requirements.

Class F water

(being water specially protected for fish spawning purposes).

(a) The natural water temperature shall not be changed by more than 3°C and shall not exceed 25°C. For salmonid spawning waters during the spawning season the water temperature shall not exceed 13°C.

(b) The pH of the water shall be within the range 6.0-9.0 units, and within that range the maximum change shall not be greater than 1.0 unit.

(c) The water shall not be tainted as to make it unpalatable nor contain substances which would render it unsuitable for consumption by farm animals or unsuitable for irrigation.

(d) The water shall not emit an objectionable odour.

(e) There shall be no adverse effect on the aquatic community by reason of toxic substances.

(f) Aquatic organisms shall not be rendered unsuitable for human consumption by accumulation of excessive concentrations of toxic substances.

(g) The natural colour and clarity of the water shall not be changed to a conspicuous extent.

(h) The concentration of dissolved oxygen shall exceed 80% of the saturation concentration.

(i) The daily average five-day biochemical oxygen demand at 20°C shall not exceed 2 g/m^3.

(j) There shall be no visible oil or grease films or conspicuous floatable or suspended materials.

Where the water quality does not comply with these requirements, no action shall be permitted which will cause the water quality to deviate further from compliance with these requirements.

Class CD water

(being limited open coastal water made available for substantially untreated waste discharge purposes).

(a) There shall be no conspicuous accumulation of oil, grease, or other floatable waste materials.

(b) The aquatic life shall not be substantially adversely affected by reason of toxic substances.

Class CE water

(being enclosed coastal water for general use purposes).

(a) The natural water temperature shall not be changed by more than 3°C.

(b) The pH of the water shall be within the range 6.7-9.0 units and within that range the maximum change shall not be greater than 0.5 units.

(c) The water shall not emit an objectionable odour.

(d) The aquatic community shall not be adversely affected by reason of toxic substances.

(e) Aquatic organisms shall not be rendered unsuitable for human consumption by accumulation of excessive concentrations of toxic substances

(f) The natural colour and clarity of the water shall not be changed to a conspicuous extent.

(g) The concentration of dissolved oxygen shall exceed 80% of saturation concentration.

(h) There shall be no visible oil or grease films or conspicuous floatable or suspended materials.

Where the water quality does not comply with these requirements no action shall be permitted which will cause the water quality to deviate further from compliance with these requirements.

Class CO water

(being open coastal water for general use purposes).

(a) The natural water temperature shall not be changed by more than 3°C.

(b) The pH of the water shall be within the range 6.7-9.0 units and within that range the maximum change shall not be greater than 0.5 units.

(c) The water shall not emit an objectionable odour.

(d) The aquatic community shall not be substantially adversely affected by reason of toxic substances.

(e) Aquatic organisms shall not be rendered unsuitable for human consumption by accumulation of excessive concentrations of toxic substances.

(f) The natural colour and clarity of the water shall not be changed to a conspicuous extent.

(g) The concentration of dissolved oxygen shall exceed 80% of saturation concentration.

(h) There shall be no visible oil or grease films or conspicuous floatable or suspended materials.

(i) There shall be no fouling of fishing grounds.

Where the water quality does not comply with these requirements, no action shall be permitted which will cause the water quality to deviate further from compliance with these requirements.

Class CR water

(being coastal water for regular public bathing purposes).

(a) The natural water temperature shall not be changed by more than 3°C.

(b) The pH of the water shall be within the range 6.7-9.0 units and within that range the maximum change shall not be greater than 0.5 units.

(c) The water shall not emit an objectionable odour.

(d) The aquatic community shall not be adversely affected by reason of toxic substances.

(e) Aquatic organisms shall not be rendered unsuitable for human consumption by accumulation of excessive concentrations of toxic substances.

(f) The natural colour and clarity of the water shall not be changed to a conspicuous extent.

(g) The concentration of dissolved oxygen shall exceed 80% of saturation concentration.

(h) The median faecal coloform bacteria concentration shall not exceed 200 per 100 ml based on a minimum of one water sample taken on each of five separate days over not more than a 30 day period; nor shall more than 10% of samples taken on separate days during any 30 day period exceed 400 faecal coliforms per 100 ml.

(i) There shall be no visible oil or grease films, or conspicuous floatable or suspended materials.

Where the water quality does not comply with these requirements, no action shall be permitted which will cause the water quality to deviate further from compliance with these requirements.

Class CS water

(being water from which edible shellfish are regularly taken for human consumption or waters in which shellfish are cultivated or farmed).

(a) The natural water temperature shall not be changed by more than 3°C.

(b) The pH of the water shall be within the range 7.8-8.4 units.

(c) The water shall not emit an objectionable odour.

(d) The aquatic community shall not be adversely affected by reason of toxic substances.

(e) Aquatic organisms shall not be rendered unsuitable for human consumption by accumulation of excessive concentrations of toxic substances.

(f) The natural colour and clarity of the water shall not be changed to a conspicuous extent.

(g) The concentration of dissolved oxygen shall exceed 80% of the saturation concentration.

(h) The median faecal coliform bacterial concentration shall not exceed 14 MPN per 100 ml based on a minimum of one water sample taken on each of 10 consecutive days when the risk of contamination is greatest, and not more than 10% of the sample shall exceed 43 MPN per 100 ml.

(i) There shall be no visible oil or grease films, or conspicuous floatable or suspended materials.

Where the water quality does not comply with these requirements, no action shall be permitted which will cause the water quality to deviate further from compliance with these requirements.

Symbol X water

(being water which is sensitive to enrichment)

The Working Party spent some time discussing the desirability of setting national minimum standards for this water. The outcome was that national standards could not be set with any confidence yet.

[5] Guidelines

In formulating water quality standards for the water use classes, it was considered that for some of the standards an explanation of sampling technique, measuring technique, or interpretation of the standards should be given in guidelines. The Working Party was particularly concerned that the following aspects should be brought out in guidelines.

(a) The bacteriological standards for the classes have been set in accordance with the recommendations of the Chief Bacteriologist of the Department of Health, with reference to the literature and personal consultation with experts such as Dr Geldreich. These incorporate or are based on the best information available and accord with the generally accepted overseas practice.

However, the criteria recommended are not free from continuing evaluation and debate on the local and the international scene. They must be considered in the light of the still poorly defined relationship between increasing coliform contamination in water and the consequential increase of illness from waterborne disease. The significance of test results must be evaluated not only by reference to the criteria recommended but also by reference to a sanitary survey designed to determine the origin of the contamination. Additionally the variability of coliform contamination in the natural environment and in the 95% confidence limits of testing erode the apparently simply picture conveyed by the numerical limits recommended.

(b) The "colour and clarity" standard is common to most of the use classes. Both colour and clarity can be measured using a variety of tests and in many instances can be related to the concentration of suspended solids in the water. Guidelines could provide explanation of the usefulness of various tests and the relationship of suspended solids concentration to these.

(c) The BOD standard is a useful measure of the general organic pollution levels in waters. However the method of carrying out the BOD test, the number of tests required, and the interpretation of results need to be explained and discussed so that the BOD standard can be applied to best effect.

APPENDIX I

Discussion paper on microbiological criteria for classifications

1. All too frequently discussions such as this are hampered by a semantic problem, the distinction between criteria, guidelines, and standards. These distinctions are of practical importance in terms of the nature of the input data needed and the level of Government with operative responsibility for the development and promulgation of guidelines and standards. They are also important in assuring that the data produced can be considered in the context of risk analysis.

A health-effects, recreational water quality *criterion* is defined as a quantifiable relationship between the density of some indicator of quality of the water on one hand, and the health risks associated with its recreational use on the other. The latter can be measured as illness or symptomology; the diseases are usually infectious in nature and the risk associated activities are primarily those in which there is significant exposure of the head to the water.

A *guideline* derived from such a criterion is a suggested upper limit for the indicator density associated with unacceptable health risks. The concept of acceptability implies that there are social, economic, and even political as well as medical inputs to a guideline's derivation, and that these inputs may vary.

A water quality *standard* obtained from the criterion is a guideline fixed in law.

2. Such criteria as defined can be produced through prospective epidemiological investigations - a very expensive and time-consuming exercise, difficult to implement - and from an accumulation of case and outbreak reports provided that data are available on indicator densities in the water at the time of the exposure; but the very nature of the analysis of such outbreaks predicates against the availability of this information.

3. Pollution of aquatic systems by the excreta of warm-blooded animals creates public health problems for man and animals as enteric microbial pathogens may inhabit the gut of most warm-blooded animals and be shed in the faeces. The argument that the uncontrollable source of agricultural animals as contributors of enteric pathogens is probably not a high risk is fallacious. Present limited knowledge has not shown a high risk of virus infections from agricultural animal sources, but this is not so for bacterial and protozoan infections. The presence of bacterial, viral, protozoan, and possibly fungal species as pathogenic to man and other animals, is indicated by the faecal coliform group of bacteria.

4. Increasing microbiological knowledge has enlarged our understanding of the complex interrelationship of indicator organisms such as faecal coliforms with disease, and thus the number of faecal coliforms present is indicative of the degree of health risk associated with using the water for drinking, swimming, or shellfish harvesting. Obviously the ratio of pathogens to coliforms in contaminated waters is a factor of the prevalence of disease in the community contributing to those waters.

An ideal indicator fulfilling all the criteria as laid down (Scarpino 1974) has yet to be discovered, and as direct demonstration of microbial pathogens is not always feasible, faecal coliforms are the microorganism of choice, by virtue of the ever-increasing information on their value as indicators of potential pathogens faecal in origin.

5. As knowledge has increased so has our understanding of the complex interrelationship between so-called indicators and disease. In fact there is a growing awareness today of the significance of what were previously called indicator organisms (coliforms) as potential contributors to pathogenicity. Viruses causing a number of diseases and non-faecally associated bacteria causing infections of ear, eye, nose, and throat have all been isolated from water (Bonde 1974; Scarpino 1974).

The relationship between numbers of specific disease-causing organisms in water and the potential for transmission of disease is elusive, as the number required to cause disease varies, dependant on the organism, the host, and their interraction. In some instances a single cell of *Salmonella*, or a single virus particle, may be all that is necessary, whereas in other instances the number of bacteria as an infective dose may be as high as 10^6 or 10^7.

6. A growing problem of potential medical significance which no responsible health authority can ignore, but which poses considerable economic burden, is the transfer of characteristics which alter the resistance of pathogenic bacteria, the R-factor (or resistance transfer factor RTF) to antibiotics, heavy metals, and ultraviolet light. The significance of this, while not fully comprehended as yet, suggests that pathogens and non-pathogens alike in a common environment such as water may transfer resistance to common antibiotic therapy. The concern is that such RTF may pass from pathogen, to indicator to pathogen, to man and animals, with consequent grave concern in the field of medical treatment.

7. Disease transmission via the aquatic route including drinking water, recreational water, and seafood from polluted sources, has been and continues to be a problem.

Presently, the indicator system using faecal coliform is the most practical for the indication of potential hazards from bacterial and viral pollution of water. Correlation between human pollution sources, disease, and the numbers and significance of the microbial system in question remain elusive. Berg (1974) has shown that Polio Virus I at a concentration of two plaque forming units (PFU, a method of enumerating virus particles) will cause disease in 67% of the unimmunised population.

However the lack of epidemiological correlation between faecal coliform levels in coastal swimming waters and the incidence of disease may not have validity in fresh waters and it does not take into account non-reported diseases which may develop as an unrecognised result of swimming in polluted waters. Epidemiological evidence is only one consideration in settling microbiological criteria but until viral technology advances in particular, and bacterial technology in general, in many instances this rather inaccurate philosophy is all that is available.

8. The presence of faecal coliform bacteria indicates degradation of water quality and a relative risk of disease transmission.

9. Although it is agreed, that certain investigators express doubt as to the value of rigid microbiological standards for bathing waters, the WHO and the US Environmental Protection Agency stress that there is not sufficient justification for the relaxation of these criteria, and suggest as a general practice the application of a single set of criteria for recreation in fresh, estuarine, and marine waters. I support this concept and personally consider that more rigid concepts such as the EEC Directive of 8 December 1975 is excessively restrictive, or at least so until further substantiating evidence is available from current research.

10. An important point to consider is that guidelines or standards the same or similar to existing levels are easier to support, either from previous acceptance, or in the case of where derived from international agencies such as WHO or US EPA, by the wealth of scientific investigation available. From a legal point of view, data developed from any new methods, and/or from redefined bacterial indicator systems, will be subject to challenge. This is especially true if results from such tests are used in litigation. Scientifically this is inhibiting but is a fact of life.

Another point associated with this which may soon surface involves acceptance and certification of laboratories (their facilities, personnel, methods, etc.). Such laboratories must meet minimum standards of acceptance and requirements relate to the use of specific procedures as laid down in designated standard manuals. Attempts to use other methodologies to such references will be subject to challenge. (TELARC - Testing Laboratory Registration Council).

11. Although there is virtually no scientific evidence available to support the public health concern at waterborne virological disease in New Zealand, it would be illogical to assume that the epidemiological information available, and the strong international epidemiological and scientific evidence of incidence of waterborne virus diseases, is not true for New Zealand as elsewhere. It is a fact however that economics and the logistics of virological investigations, coupled with the fact that there appears to be no obvious major disease incidence at present apart from Hepatitis A, places routine virological surveillance in a low priority. (Discussion of the status quo regarding the New Zealand NWASCO research contracts to Otago University may provide information in this field).

12. Class R

Proposal: As a regulation with accompanying guidelines.

Based on a minimum of five samples taken over a 30 day period, the faecal coliform level should not exceed a log mean of 200 per 100 ml, nor should more than 10 percent of the total samples taken during any 30 day period exceed 400 per 100 ml.

Comment: Existing guidelines and standards on a worldwide basis have been reviewed in several World Health Organisation documents (WHO 1977, 1978). The guidelines most commonly used in the USA are as quoted above for direct contact recreation waters (US EPA 1976) and the same or similar are applied in many countries. They were derived by the National Technical Advisory Committee to the US Federal Water Quality Administration (1968) from the findings of studies on bathing waters and health (Stevenson 1953).

The figure of 200 faecal coliform/100 ml appears in widespread literature on the subject and can be justified but I am not as confident with a log mean when coupled with a percentage; however, sampling guidelines as to frequency may answer this. I would prefer a median with an upper percent limit where there is likely to be limited samples; distribution in an area is not homogeneous, and an input distribution with marked peaks could convey a false impression.

The figure of 200 is well supported epidemiologically and microbiologically by Cabelli *et al* 1979.

13. Class CS

Proposal: As a regulation with accompanying guidelines.

The median faecal coliform bacterial concentration should not exceed 14 MPN per 100 ml with not more than 10 percent of samples exceeding 43 MPN per 100 ml for the taking of shellfish.

Comment: This standard is as applied by the Department of Health for commercial shellfish-growing waters; is as laid down by the US National Shellfish Sanitation Programme; has wide international recognition based on scientific and epidemiological evidence; and is incorporated in a Memorandum of Understanding between the New Zealand Ministry of Agriculture and Fisheries, Department of Health, and the US Food and Drug Administration of the Department of Health, Education, and Welfare.

14. Class W

Proposal: As a regulation with accompanying guidelines.

Based on a minimum of five samples taken over a 30 day period, the faecal coliform level should not exceed a median of 2000 per 100 ml, nor should more than 10 percent of the total samples taken during any 30 day period exceed 4000 per 100 ml.

Comment: Obviously such a criterion is open to question as WHO no longer proposes any standard for raw water suitable for treatment as a potable supply, on the assumption that the most polluted water if treated sufficiently can be brought to the WHO standard for drinking waters. Economics have of course not been considered and I consider that in a country such as New Zealand some protection of suitable waters for treatment at minimal cost is warranted.

Desmond G. Till
9.4.1980

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

CINCINNATI, OHIO 45268

September 5, 1980

Mr. Desmond G. Till
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Dear Desmond:

I must apologize for the delay in reply to our inquiry (August 7, 1980) concerning criteria and standard concepts for fecal coliform. My excuse was a much needed vacation. The penalty is facing a mountain of paper work.

In regards to the bathing water standard, the log mean of 200 fecal coliforms per 100 mL is a value intended for use in monitoring long term water quality conditions in a given recreational area. However, the decision to open and close a beach was intended to relate to "nor should more than 10 percent of the total samples taken during any 30 day period exceed 400 per 100 mL."

The question of why 10 percent was chosen has never been fully explained in any publication to my knowledge. Lee McCabe, who was on the committee that developed the bathing water standard, told me the 10 percent value relates to a practical concern for sample frequency. In his analysis of the bathing beach data and epidemiological reports of increased illness among bathers, he concluded the risk was significant when more than 5% of the samples exceeded the 400 fecal coliform per 100 mL value. To base the decision to open and close a bathing beach on this percent of samples would require a minimum of 20 samples analyzed per month. The committee argued that this number of samples per month would be considered excessive by some health agencies, so the decision was made to use a 10% value. Under this modification, a minimum of only 10 samples per month would be required and the decision to close a beach could relate to an occurrence of more than one sample with over 400 fecal coliforms in that period.

While the recommended standards stated a minimum of 5 samples per month were needed to develop a log mean value or 10 samples per month to establish an unacceptable frequency of more than 400 fecal coliforms per 100 mL, the fact remains that more frequent sampling of bathing waters should be done. Frequency of sampling needed to establish or monitor bathing water quality for continued acceptability should be related to the peak bathing periods. Usually this restriction requires sample collections to be made in the afternoons. The optimum frequency would be daily sampling during the recognized bathing season; the minimum sampling frequency should include Friday, Saturday, Sunday and holidays to serve periods of greatest recreational use. When sampling is limited to the days of peak recreational use, a morning and afternoon sampling and use of a rapid fecal coliform testing procedure (7 hr-FC test, 24 hr M-FC procedure or A-1 medium in a 24 hr MPN test) are desirable, particularly if bathing beach closure periods, based on the bacteriological quality of water are to be enforced.

We hope these comments help your committee resolve the issue on standard setting and the realistic application to an effective monitoring program. Enclosed are three recent papers that may be of further interest to you.

Sincerely,

Ed Geldreich

Edwin E. Geldreich
Chief, Microbiological Treatment Branch
Drinking Water Research Division
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APPENDIX II

Discussion paper on dissolved oxygen requirements

Introduction

Aquatic environments in New Zealand, as elsewhere, are normally characterised by dissolved oxygen well distributed through the water column, and to a lesser extent the substratum below the column. As a first level requirement it can therefore be said that dissolved oxygen is necessary as a vital part of the metabolism of what we regard as normal or typical aquatic environments.

The significance of oxygen is most readily seen in relation to the biological communities. Without oxygen in the water, very large sections of these communities are absent, and the communities that function in the absence of oxygen (anaerobic) produce metabolites (e.g., sulphides, amines, mercaptans) that are generally considered objectionable.

The level of oxygen required to provide acceptable conditions cannot be separated from the intended uses and as a general statement it can be said that the requirements for oxygen *per se* in relation to recreation, aesthetics, water supply, agriculture, and industry are neither high nor specific. If these uses do appear to have a requirement, it is typically because of a correlation between oxygen and the distribution of organisms.

Oxygen requirements thus tend to resolve into the level necessary to exclude undesirable communities (anaerobic) or to permit the existence of desired species.

Exclusion of undesirable communities

It could be argued that provided some free oxygen is present, then anaerobic communities will not develop. However, it is possible to have substantial anaerobic deposits and at the same time free oxygen at appreciable levels in the water column. Such a condition is likely with a high organic load in a small stream with a moderate to low velocity, and in practice oxygen levels well above zero appear to be necessary.

Criteria concerned only with exclusion do not appear to have been developed, and the preferred approach has been to provide guidelines aimed at giving some degree of protection to important species. Since this is usually well above zero, the exclusion of undesirable communities is assured. This thinking is implicit in the previous classes, and is certainly a convenient way of arriving at a standard.

Maintenance of desired species

Fish are of economic and recreational significance, and their oxygen requirements have been studied in some detail. At the same time dissolved oxygen standards have often been fixed with fish in mind. This concentration on one group of organisms has tended to obscure the fact that fish are part of a community, certain elements of which may be at least as sensitive as fish if not more so. An example is provided by Nebeker (1972) who showed that in a laboratory situation, reduction of the oxygen concentration to 6 mg/l prevented completion of the life cycle in terms of hatching by a factor of 70–85% in three species of mayflies. This example is particularly significant in New Zealand where mayflies form a major component in the food supply of stream fish.

However the tendency has been to assume that if the fish are protected the other communities are too. This viewpoint is accepted here for convenience, but particularly sensitive invertebrates should be borne in mind (Davis 1975).

1 Species differences

The sporting and economic significance of salmonids has resulted in a concentration of research on this group. By a fortunate coincidence, however, their oxygen requirements are relatively high (Doudoroff and Shumway 1970; Warren, Doudoroff, Shumway 1973; Davis 1975), so that standards set to protect this group tend to protect all fish. Of the groups in New Zealand other than salmonids, the non-salmonid exotics tend to have lower oxygen requirements, while the New Zealand natives are virtually unknown in this respect. Some such as the eels and swamp dwellers may have lower requirements, but the species inhabiting colder, fast streams may be similar to salmonids (Benzie 1968).

2 Development of criteria

Useful recent summaries of the effects of reduction in the level of dissolved oxygen are provided by Doudoroff and Shumway (1973) and Davis (1975). The first major point to emerge is that various responses are apparent in different species at different levels of reduction, and the degree of risk or adversity increases with the degree of hypoxia. It is therefore incorrect to consider particular levels as providing a clear division between a normal healthy population and one adversely affected. The one exception is the 'no effect' level and this can be considered first.

Doudoroff and Shumway (1970, p.265) consider this level to be represented by the existing natural regime, i.e., no depression on a seasonal basis below the estimated, natural, minimum level for the same season. This is of doubtful value from a general point of view since the natural regime could involve a greater or lesser degree of pollution. However the context suggests minimal pollution, so that the criterion suggests no significant adverse effect with no reduction of high natural levels. This view is based on, but not directly related to, a large amount of experimental data. Warren, Doudoroff, Shumway (1973) working with largemouth bass and coho salmon come to substantially similar conclusions. Davis (1975) surveys the literature for the level at which sublethal responses first become apparent (i.e., the incipient sublethal threshold). The responses involved were behavioural and physiological, and the groups considered are freshwater species, marine non-anadromous, anadromous, and eggs and larvae. He considers criteria in terms of both content (concentration) and availability (pressure) and proposes a no effect level 1 S.D. above the mean incipient response level for the group. His results are summarised in Table 1.

Table 1 No effect level of dissolved oxygen

Group	PO_2	mg O_2/1	% sat. at15°C
Freshwater mixed (no salmonids)	95	5.50	60
Freshwater salmonid	120	7.75	76
Marine	140	8.75	100
Salmonid larvae and eggs	155	9.75	98

The criteria developed by Davis have impressed the writer as being the most soundly based available, and due weight will be given to his opinion.

When levels at which adverse responses are apparent are considered a wide range for both species and response curve is evident, and the situation can best be illustrated by examples. Only some of the types of response studied are given here.

Growth

Doudoroff and Shumway (1970, p 136) describe experiments in which young coho salmon were fed abundantly at 18°C and O_2 concentration of 9 mg/1. Reductions of O_2 concentration to levels of 5, 4, and 3 mg/1 showed corresponding reductions of growth based on net weight of 8%, 17%, and 42%. Graphical presentation for the relation between growth and oxygen levels for largemouth bass and coho salmon are given by Warren, Doudoroff, Shumway (1973) in their Figures 20 and 21, included here.

Swimming ability

Fish swim in several modes but two readily recognisable are maximum speed and maximum sustained speed. Both are important in different contexts, but information on the relation of oxygen levels to performance is available only for the latter. Experiemental evidence on this is given in Table 2.

Embryonic development

The results of studies in this are well summarised by Doudoroff and Shumway (1970).

(a) No clear evidence exists showing a general increase in egg mortality (or failure to hatch) over a range of oxygen concentrations down to 2-3 mg/1 in various species of salmonids in laboratory experiements.

(b) Reduction in oxygen concentration during incubation resulted in a reduction in weight of the newly hatched larvae. For three salmonid species, mean weights at hatching at O_2 levels of 2.5–3.0 mg/1 were ¼ to ½ of the controls of air saturation.

(c) Increases of the velocity of water movement around the embryos tend to reduce the effects of hypoxia because of an increased rate of delivery of oxygen to the egg surface.

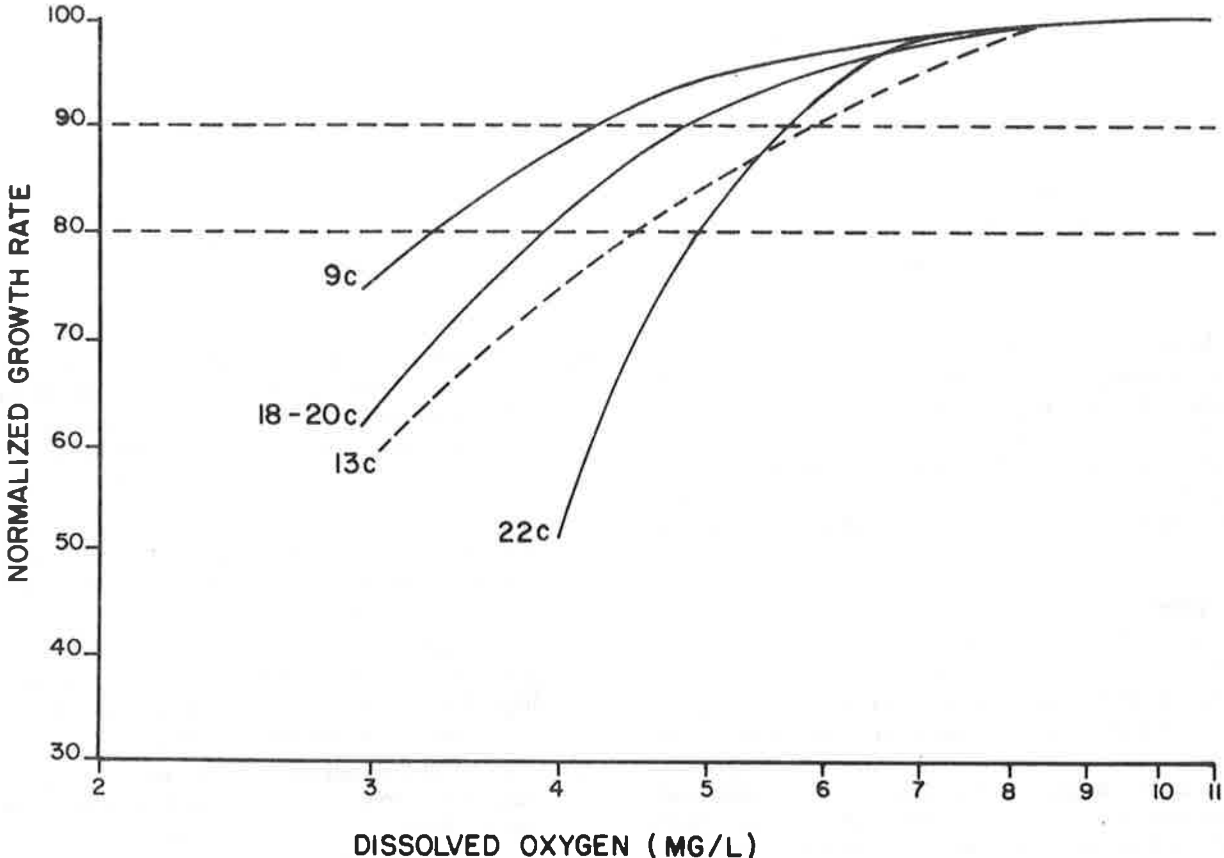
(d) High mortality of salmonid embryos in stream gravel when the intra-gravel oxygen was relatively high (4–8 mg/1) does not indicate that these oxygen levels were associated with the mortality.

(e) Embryos of non-salmonid species show a range of minimum oxygen concentration required for normal development from 2-5 mg/1.

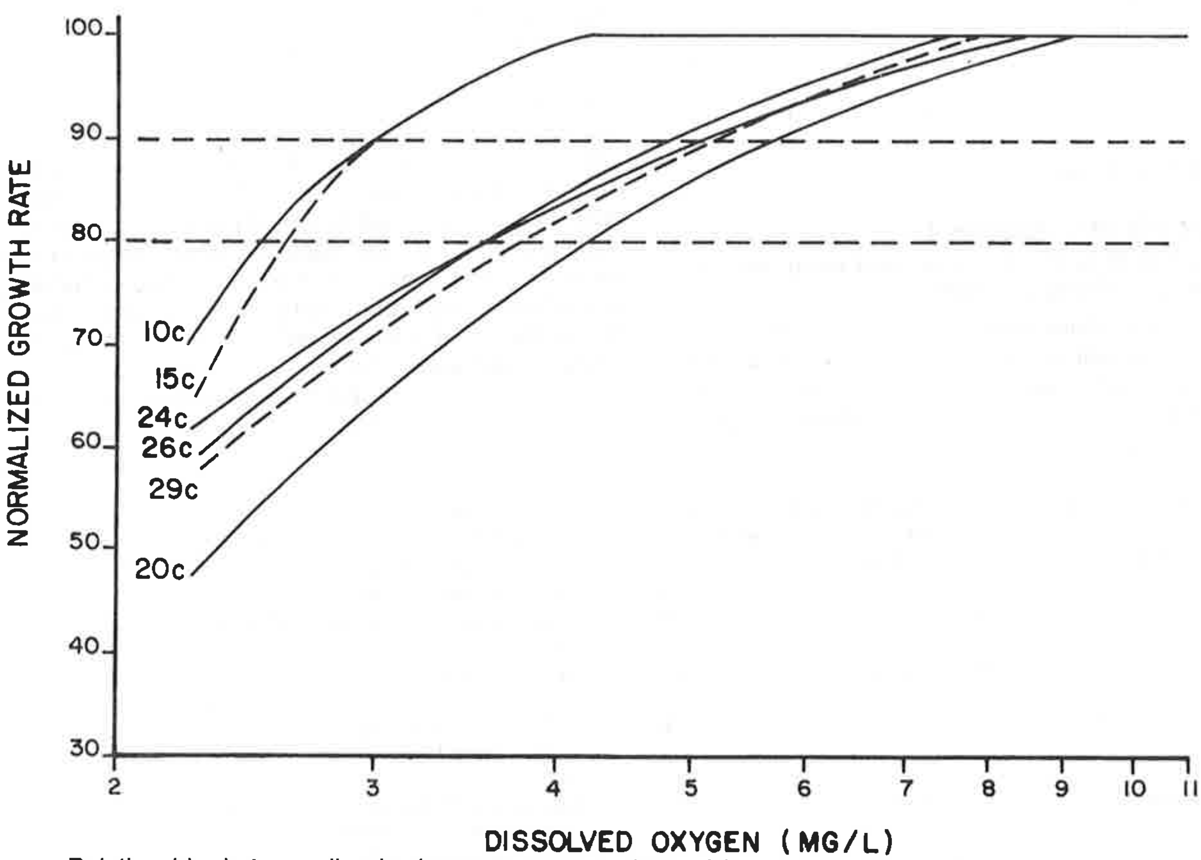
Still lower levels of dissolved oxygen raise the possibility of defining lethal levels. A major problem here is the time period over which the test is made, and while tests over 24 hours or seven days give useful information in developing guidelines they do not necessarily indicate a true tolerance threshold (incipient lethal level). The last index can be defined as the level at which 50% of the test animals appear capable of surviving indefinitely. A variety of factors can influence the estimates obtained and the practical significance of most of the tests reported is dubious. Doudoroff and Shumway (1970) tabulate tests on 95 species, but discard many of these as being of little value. The most useful type of test was when a constant level of O_2 was maintained, and for 29 species of this type of test, the lethal levels are well below 3 mg/1. For 8 species of salmonids lethal levels ranged above 2.2 mg/1, and the authors concede that the salmonids are among the fish most sensitive to O_2 deficiency.

Table 2 Hypoxia and swimming performance (MSS: maximum sustained speed)

Species	T °C	Size	O_2 mg/1	O_2% Sat.	Swimming	Author
Rainbow trout	14.1	12.5 cm		50	Reduction in MSS by 43%.	Jones 1971
	22.4	11.8 cm		50	Reduction in MSS by 30%.	
Atlantic salmon	15	87-135 g	4.5	44	MSS of 55 cm/sec not maintained below this level.	Kutty and Saunders 1973
Largemouth bass	25	Juvenile	5-6	60-71	MSS reduced below this level.	Dahlberg, Shumway and Doudoroff 1968
			3	36	10% reduction of MSS as compared with 100% saturation value.	
Coho salmon	20	Juvenile	5-6	55-66	Reduction of MSS of 10% compared with 100% saturation.	Dahlberg, Shumway and Doudoroff 1968
			3	33	Reduction of MS of 30% compared with 100% saturation.	
			2.5	27.5	Reduction of MSS of 40% comparedwith 100% saturation.	



Relationships between dissolved oxygen concentration and the normalised growth rate of juvenile largemouth bass reared in aquaria and fed to repletion on live food at temperatures ranging from 10° to 20°C. Growth rates were normalised on the basis that maximum growth occurred at air saturation levels of oxygen. (Figure 20 in Warren, Doudoroff and Shumway 1973)



Relationships between dissolved oxygen concentration and the normalised growth rate of juvenile coho salmon reared in aquaria and fed unrestricted rations of live food at temperatures ranging from 9° to 22°C. Growth rates were normalised on the basis of determined or estimated growth rates at air saturation levels of oxygen. The 18–20°C curve is based on many more experiments than the other curves and is considered to be more reliable. (Figure 21 in Warren, Doudoroff and Shumway 1973)

There is considerable variation in resistance with various factors including exposure time, size, age, temperature, season, and these factors need to be considered in applying research to management.

A further phenomenon discussed by Doudoroff and Shumway (1970) is that of acclimation to low oxygen concentrations.

3. Development of guidelines

This requires the basic criteria derived experimentally and also the environmental variables and likely interactions. Socio-economic criteria are then applied to reach a level that is acceptable.

Temperature

Temperature variation is particularly significant here since an increase in temperature reduces the solubility of oxygen and the partial pressure of oxygen, and at the same time normally increases the metabolic demand of the fish. Thus when the fish requires a greater rate of supply of dissolved oxygen, the amount in the water decreases markedly. One practical conclusion from this is that it is more useful to set levels in terms of saturation since this helps to compensate for temperature variation. This point is emphasised by Davis (1975) and illustrated in recommendations below.

Activity level

Setting of minimal oxygen levels too low may result in reduced possibilities for vital activities. Brett (1970) determined the oxygen requirements for young sockeye salmon at 20°C for important activities.

Activity	O_2 cost of energy expenditure as mg O_2/kg wt of fish/hour	% active metabolic rate
Aggression	180	22.9
Feeding - Maintenance ration	300	37.3
Feeding - Maximum ration	450	55.4
Migrating up river	625	75.0

Since the active metabolic rate is already limited by oxygen levels at temperatures above 15°C (Brett 1964), significant reduction in saturation level would severely limit energy expenditure for important activities.

Interaction with pollutants

Reduced oxygen levels are typically associated with products of organic pollution, and in a complex situation a variety of toxic substances may be present. In general toxins and low oxygen show positive interaction on mortality, e.g., increased toxicity of Kraft pulp with effluent (Alderdice and Brett 1957), increased toxicity of high pH (Townshend and Cheyne 1944), increased toxicity of ammonia, salts of zinc, lead, and copper, and a mixture of monohydric phenols (Lloyd 1961). The possible mechanism is an increased rate of uptake of the toxin at the gills due to accelerated gill ventilation due to hypoxia.

The practical conclusion is that if organic toxins are regularly associated with reduced oxygen, then any movement of minimum levels should be upward.

Recommendations

Three sets of recommendations are discussed here as representing the most recent level of informed opinion.

(a) Doudoroff and Shumway (1970)

These authors recognise the need for differing levels of protection in different situations. What is distinctive about their approach is that they relate their levels to the existing seasonal minima. The choices they suggest are summarised as follows:

Level	Protection
A	Maximum protection, unimpaired productivity.
B_1	High level of protection for major spawning grounds of salmonids.
B	High level of protection but some risk of damage.
C	Moderate protection, some reduction in production expected.
D	Low level of protection for unimportant fisheries. Permits persistance of tolerant species. Elimination of salmonids likely.

These levels are reproduced graphically in the authors' Figure 1, included here. As an illustration of the application, the writer has estimated a summer minimum in Otago and Southland as follows: typical undersaturation during darkness is 90%, a maximum night temperature of 18°C, giving a minimum of 8.5 mg/l. In small shallow streams the degree of undersaturation could be 80% and this would give a minimum of 7.6 mg/l. Interpolation on the graph gives figures as follows:

	Curve B	*Curve C*
90% saturation	7.4	6.0
80% saturation	6.8	5.6

Thus even at 80% saturation and the lowest level that could reasonably be expected for salmonids the minimum is nearer 6 than 5 mg/l.

(b) Warren, Doudoroff and Shumway (1973)

These authors lay much stress on production of coho salmon and largemouth bass.

Recommended levels of oxygen on mg/l

	Level	*Coho salmon*	*Largemouth bass*
A	No reduction of production from maximum	No reduction from near saturation at any temperature.	15°C. No reduction from saturation
			15°C. Minimum of 4.2 mg/l.

B	10% reduction in production	At 22°C or over, 5.5-6 mg/l.	15°C, 3 mg/l.
		22°C, 5 mg/l	20°C, 5 mg/l.
C	20% reduction in production	At 22°C or over, 5 mg/l.	15°C, 2.5 mg/l.
		22°C, 4 mg/l.	20°C, 4 mg/l.

A *It is worth noting that these authors recommend the use of the guidelines given by Doudoroff and Shumway (1970) where general production on freshwater fisheries or a nationwide basis is required.*

(c) Davis (1975)

This author emphasises the importance of the oxygen pressure required to drive the gas across fish gills as well as the amount available. He therefore expresses his levels as % saturation and takes into account the effect of temperature on metabolic rate and gas solubility. He allows three levels of production as follows:

Level	Specifications
A	1 standard deviation above the mean incipient oxygen response level for the group. There is little depression of oxygen from saturation, and a high degree of protection is assured for important fish stocks.
B	Based onthe group mean, this level is where the average member of the community starts to exhibit distress. Some degree of risk to part of the community if the oxygen minimum is prolonged beyond a few hours.
C	1 standard deviation below the group mean. A large proportion of the community affected by low oxygen. Deleterious effects may be severe if the minima are prolonged beyond a very few hours. To be applied only if fish populations are dispensable.

His Table 10, included here, summarises the above recommendations.

Davis further adds that application of his criteria on a nationwide basis is questionable. A more satisfactory approach is to take regional variation into account.

4 Standards

The fixing of standards of New Zealand has been accompanied by much comment. The application of the previous classification was not accepted as satisfactory by fisheries authorities, and at the hearing in Invercargill before the Town and Country Planning Appeal Board in 1974, the Southland Acclimatisation Society and the Ministry of Agriculture and Fisheries presented evidence on oxygen levels. The finding at that hearing was that 6 mg/l rather than 5 mg/l was a more appropriate level for salmonid fisheries. Since then, the useful paper of Davis (1975) has come to hand suggesting further upward revision of levels for fisheries, and Church, Davis and Taylor (1979) have briefly reviewed requirements for fish in New Zealand rivers.

If the guidelines are considered in relation to a minimum level of dissolved oxygen of 5 mg/l, it can be said that while this level would certainly prevent visual or olfactory offence, it could not be regarded as much protection to freshwater fisheries. In the warmer parts of New Zealand, the night temperature could rise above 18°C, and the saturation in very weedy rivers could reach 80% or a little less depending on conditions. This would tend to give a lower seasonal minimum. The fact remains that from Doudoroff and Shumway's guidelines a level nearer 6 mg/l is indicated for moderate protection of freshwater fisheries.

The criteria of Davis would also prevent offence, but his ecological groupings are more specific. Freshwater salmonids would be receiving dubious protection at 5 mg/l (49% saturation at 15°C). Marine fish at 5 mg/l (63% saturation at 15°C) would also not be well looked after.

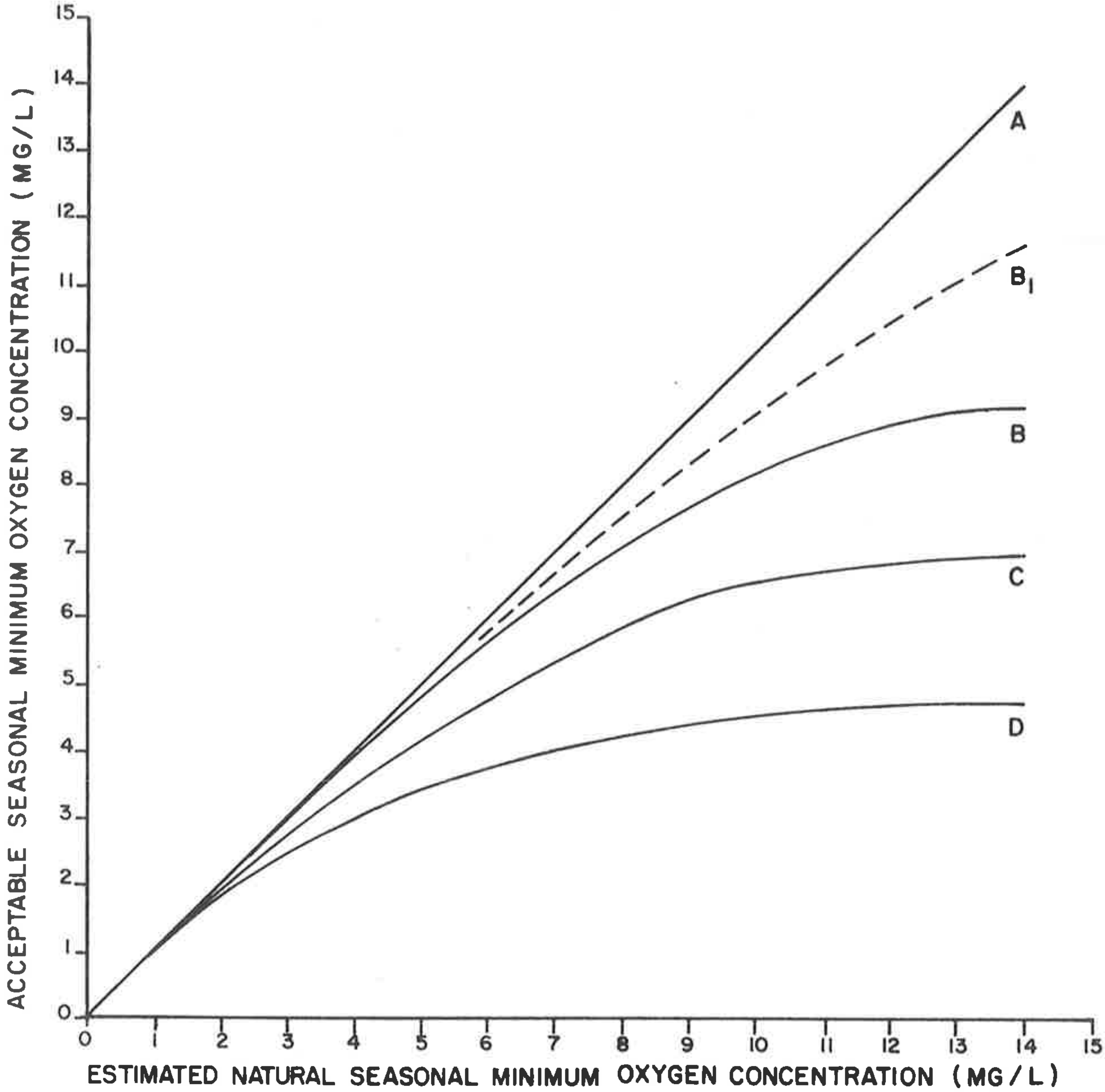
On the other hand the suggested oxygen minimum of 80% saturation for fish spawning areas fits fairly well into the B level of protection in Table 10. This high level of saturation is needed to allow full activity by the valuable parent fish and also to ensure a sufficiently high oxygen level in the water column to allow adequate but much lower levels in the intra gravel water.

An example of NZ standards developed by a regional water board is provided by Otago in their proposals for a water management plan (ORWB 1980). Briefly, a concept of zoning is related to water quality types as follows:

Water type	O_2 level
1	Substantially greater than 85% saturation.
2	Greater than 85% saturation.
3	Substantially greater than 70% saturation.
4	Greater than 70%.

These levels are higher than those in the 1967 Act and higher than those presently proposed by this committee. If distributed in accordance with the proposed land zoning they would imply a high level of protection for uses where oxygen is involved, and also a substantial protection of present quality.

Donald Scott
29.5.1980



Proposed dissolved oxygen criteria for protection of freshwater fisheries: Curves relating "acceptable" seasonal dissolved oxygen minima, or minimum levels that are deemed appropriate to different, specified levels of protection of fisheries, to estimated natural seasonal minima. Curves or lines designated A, B_1, B, C, and D correspond to levels of protection described in the text.
(Figure 1 in Doudoroff and Shumway 1970)

Group	Protection level	PO_2	ml O_2/l	mg O_2	% sat. at C for criteria 0	5	10	15	20	25
Freshwater mixed fish population including salmonids	A	110	5.08	7.25	69	70	70	71	79	87
	B	85	3.68	5.25	54	54	54	54	57	63
	C	60	2.28	3.25	38	38	38	38	39	39
Freshwater mixed fish population with no salmonids	A	95	3.85	5.50	60	60	60	60	60	66
	B	75	2.80	4.00	47	47	47	47	47	48
	C	55	1.75	2.50	35	35	35	35	35	36
Freshwater salmonid population (including steelhead)	A	120	5.43	7.75	76	76	76	76	85	93
	B	90	4.20	6.00	57	57	57	59	65	72
	C	60	2.98	4.25	38	38	38	42	46	51
Salmonid larvae and mature eggs of salmonids	A	155	6.83	9.75	98	98	98	98	100	100
	B	120	5.60	8.00	76	76	76	79	87	95
	C	85	4.55	6.50	54	54	57	64	71	78
Marine nonanadromous species*	A	140	6.13	8.75	88	88	95	100	100	100
	B	110	4.73	6.75	69	69	74	82	90	98
	C	80	3.15	4.50	50	51	51	55	60	65
Anadromous marine species, including salmonids*	A	160	6.30	9.00	100	100	100	100	100	100
	B	125	4.55	6.50	79	79	79	79	87	94
	C	90	2.80	4.00	57	57	57	57	57	58

*Percentage saturation calculations based on salinity of 28°/oo.

(Table 10 in Davis 1975)

Oxygen criteria based on percentage saturation values derived with three levels of protection as outlined in the text. PO_2s and values of mg O_2/litre were extracted from Table 9 (Davis 1975) and rounded off for use here. The values shown for millilitres O_2/litre were calculated from the values of milligrams O_2/litre in this table.

The criteria essential for protection of aquatic fish populations are expressed as percentage saturation values at various temperatures. They were derived from both PO_2 and mg O_2/litre values as both oxygen tension and oxygen content are critical factors. At the lower temperatures, the percentage saturation value was determined using the PO_2 values essential for maintaining the necessary oxygen tension gradient between water and blood for proper gas exchange. Higher percentage saturation values are necessary at the higher temperatures to provide sufficient oxygen content to meet the requirements of respiration as defined by the mg O_2/litre values.

Percentage saturation values are defined as "oxygen minima" at each level of protection. Graphical presentation of the results is found in Figure 19 (Davis 1975). The temperatures corresponding to the percentage saturation criteria are defined as "seasonal temperature maxima".

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APPENDIX III

Discussion paper on the temperature standard for Class F

Temperature, Class F - the most critical period is the autumn when the eggs are maturing inside the female. This requires temperatures below a certain level (probably 13-14°C), but there is little hard information here. When it comes to spawning and incubation there is more. An early worker (Embody 1934) gave an upper level of 12.8°C for brown trout and 15.6°C for rainbow trout. A more recent summary (Train 1979) gives the following:

Species	*Spawning optimum or mean*	*egg survival limit*
Atlantic salmon	5	11
Brook trout	9	13
Coho salmon	10	13
Rainbow trout	8	15
Sockeye salmon	10	13

Thus an upper figure of 13°C would not be over-protective to eggs and it would be a bit above the preferred range for adults spawning. This figure could be easily justified and actually 12°C would be more sensible. This figure would apply from April to October (although some rainbows spawn as late as November). Outside this period the young fish would still be in the general area and until more work has been done there seems little alternative to using 25°C as an upper limit. I would like to improve on this but it will have to wait.

Donald Scott
11.6.1980

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APPENDIX IV

Discussion paper on the rationale for classification standards for BOD

The British Royal Commission on Sewage Disposal (1912, 1913) has set out a river water classification based on observation of numerous river sections and the average BOD in water samples taken from those sections, as follows:

River condition	*Average* BOD_5 (g/m³)
Very clean	1
Clean	2
Fairly clean	3
Doubtful	5
Bad	10

An indication of the actual observations used to decide on the condition of rivers is set out in Table 1.

It may be noted that relatively few of the characteristics noted would be greatly affected by increased flow velocity in rivers.

Further, the Eighth Report of the Commission states:

Our officers have submitted to (the BOD_5) test a large number of samples drawn from various streams:
(a) at points where signs of sewage pollution were observed; and
(b) where there were no signs of pollution.
By comparing the results of analysis of the two sets of samples it was hoped to arrive at a figure for dissolved oxygen absorption in five days, which should represent a limit not to be exceeded without signs of pollution being likely to manifest themselves.

In view of the variations, both seasonal and local, in the conditions common to streams receiving sewage liquids, it is obvious that such a figure can only be an approximate one. But the data thus obtained, supplemented by the results of channel experiments, justify us in concluding that if 100,000 cubic centimetres of river water do not normally take up more than 0.4 gram of dissolved oxygen in five days, the river will ordinarily be free from signs of pollution, and that if a river water normally gives a higher figure than this it will almost certainly show signs of pollution, except perhaps in very cold weather.

This figure (0.4) we term the "limiting figure", and in our opinion it should be the foundation on which any scheme of standards should be constructed.

Temperature, however, is an important factor, and if the five days test be carried out at different temperatures which prevail at different seasons in our streams, the results will be found to vary to a marked extent. Our experiments have been carried out at a temperature of 65°F. Assuming 0.4 to be the true "limiting figure" at this temperature, during the colder months of the year, a river could withstand, without nuisance, much worse pollution. To preserve a wide margin of safety we have adopted the temperature of 65°F and, for the same reason, the dry-weather flow of the river."

Table 1 Classification of rivers in accordance with their visible degree of cleanness, based on riverside observations under normal summer conditions.

Observed condition of river water	**Very clean**	**Clean**	**Fairly clean**	**Doubtful**	**Bad**
Suspended matter	Clear	Clear	Fairly clear	Slightly turbid	Turbid
Opalescence	Bright	Bright	Slightly opalescent	Opalescent	Opalescent
Smell on being shaken in bottle	Odourless	Faint earthy smell	Pronounced earthy smell	Strong earthy or wormy smell	Soapy, faecal or putrid smell
Appearance in bulk	Limpid	–	Slightly brown and opalescent	Black looking	Brown or black and soapy looking
Delicate fish	May be plentiful	Scarce	Probably absent	Absent	Absent
Coarse fish	–	Plentiful	Plentiful	Scarce	Absent
Stones in shallows	Clean and bare	Clean	Lightly coated with brown fluffy deposit	Coated with brown fluffy deposit	Coated with grey growth and deposit
Stones in pools	Clean and bare	Covered with fine light brown deposit	Lightly coated with brown fluffy deposit	Coated with brown fluffy deposit	Coated with brown or black mud
Water weeds	Scarce	Plentiful. Fronds clean except in late autumn	Plentiful. Fronds brown coloured in places	Plentiful and covered with fluffy deposit	Scarce
Green algae	Scarce	Moderate quantities in shallows	Plentiful in shallows	Abundant	Abundant in protected pools
Grey algae	–	–	–	Present	Plentiful
Insects, larvae, etc.	–	–	–	Plentiful in green algae	Abundant in green algae

More recent studies (Sladecek 1979) of the relationship between BOD_5 and saprobric zones suggests similar BOD_5 standards to those recommended by the Royal Commission. Saprobric classifications, upper limits of average BOD_5, and the associated water characteristics are listed below for the zones of interest in water management:

oligosaprobic: BOD_5 – 2.5 g/m³; brooks and rivulets, clean lakes and very poor fish ponds, excellent for recreation.

β-mesosaprobic: BOD_5 – 5 g/m³; rivers, lakes and fish ponds with medium water quality, with water-blooms and difficulties in water treatment, admissible for recreation.

α-mesosaprobic: BOD_5 – 10 g/m³; distinctly polluted waters not suitable for recreation.

Sladecek (1979) reports that higher flow velocities give a more desirable aquatic community for the same water quality. The data reported suggests that at velocities of about 0.8 m/sec the aquatic community in a stream having an average BOD_5 of 5 g/m³ would be comparable with that expected for a stream having a low velocity of about 0.05 m/sec and a BOD_5 concentration of 2.5 g/m³. On the other hand, European and British observations are likely to be made on streams. The effects of increased flow and increased temperature are, intuitively, likely to counteract one another, and it is considered that the likely higher velocities in many New Zealand streams should therefore not justify an increased permissable BOD_5. This is particularly so because salmonids are the predominant sporting fish in our fresh waters and they generally require waters of high saprobic quality.

The Swiss Ordinance for Waste Water Discharge (L'Assemblée federale de la Confederation Suisse 1975) requires that the concentration of dissolved organic carbon shall not exceed 2 mg C/l and that BOD_5 shall not exceed 4 mg/l in receiving waters. These values apply for water flows exceeding the 95% low flow. The standards are evidently based on research undertaken at the Swiss Federal Institute for Water Resources and Water Pollution Control (1979). These studies suggest that *Ephemerella* (mayflies) are likely to be present in streams receiving a little over 1% of raw waste water (probably corresponding to about 2.5-3.5 g/m³ BOD_5), but that *Hydropsyche* (caddis) will predominate if the raw waste water percentage approaches 2% (probably corresponding to a BOD_5 of 4-6 g/m³).

The UK National Water Council has recently published a classification system for British river water quality (Lester 1979), part of which is set out in Table 2.

The average BOD levels suggested relate to three-year rolling averages. Accordingly, BOD values for shorter periods are likely to be very close to the class limiting 95 percentile values (e.g., during low summer flows).

It is likely that the general public would find waters of substantially poorer quality than the "fairly clean" class of the Royal Commission or classes 1B (Table 2) unacceptable. The elimination of mayflies from a stretch of river is likely to be an unacceptable change in the aquatic community, at least to the angling fraternity.

For Class R and Class W waters rather more stringent standards for BOD are desirable on general aesthetic grounds and, particularly for Class W waters, to decrease the likelihood of taste and odour problems.

Means of expressing the standard

Any expression of the standard must:

(a) give adequate control of water quality at all times;

(b) not impose an undue burden on authorities responsible for monitoring compliance;

(c) not impose unreasonable restrictions on discharges.

Expression in terms of daily average BOD values is considered to best meet these three requirements. Aquatic comunities and aesthetic appearance of the river bed will generally respond to "typical" or average BOD values over at least several days, rather than instantaneous values, provided dissolved oxygen levels are always satisfactory (as specified in a separate requirement). Specification of a maximum daily average value will therefore cover these aspects. Because samples can usually be stored on ice for 24 hours without unacceptable changes in BOD, a daily average value can reasonably be obtained by analysing a single composite sample, preferably collected using an automatic sampler. Specification of the daily average is consistent with common water right conditions controlling BOD discharges and will often avoid the necessity for a discharger to construct effluent storage facilities to smooth out diurnal variations in discharge rates.

Specification of longer-term and particularly annual average values is unsatisfactory because this would permit high BOD values continuously over periods of weeks or months. Estimation of longer-term average BOD values with acceptable accuracy would also increase the monitoring effort required.

Specification of a maximum instantaneous BOD value low enough to ensure protection of the aquatic community and amenity values would either needlessly decrease the BOD loadings on a receiving water, or necessitate construction of effluent storage facilities to achieve uniform discharge rates. Either effect would impose unreasonable restrictions on dischargers.

Proposed standards

For Class G: The daily average five-day biochemical oxygen demand at 20°C shall not exceed 5 g/m³.

For Classes R and W: The daily average five-day biochemical oxygen demand at 20°C shall not exceed 3 g/m³.

C.D. Stevenson
17.7.1980

Table 2 U.K. National Water Council River Classification System

River Class	Quality criteria	Remarks	Current potential uses
	Class limiting criteria (95%ile)		
1A	(i) Dissolved oxygen saturation greater than 80%. (ii) Biochemical oxygen demand not greater than 3 mg/l. (iii) Ammonia not greater than 0.4 mg/l. (iv) Where the water is abstracted for drinking water, it complies with requirements for A2* water. (v) Non-toxic to fish in EIFAC terms (or best estimates if EIFAC figures not available).	(i) Average BOD probably not greater than 1.5 mg/l. (ii) Visible evidence of pollution should be absent.	(i) Water of high quality for potable supply abstractions and for all other abstractions. (ii) Game or other high class fisheries. (iii) High amenity value.
1B	(i) DO greater than 60% saturation. (ii) BOD not greater than 5 mg/l. (iii) Ammonia not greater than 0.9 mg/l. (iv) Where water is abstracted for drinking water, it complies with the requirements for A2* water. (v) Non-toxic to fish in EIFAC terms (or best estimates if EIFAC figures not available).	(i) Average BOD probably not greater than 2 mg/l. (ii) Average ammonia probably not greater than 0.5 mg/l. (iii) Visible evidence of pollution should be absent. (iv) Waters of high quality which cannot be placed in Class 1A because of high proportion of high quality effluent present or because of the effect of physical factors such as canalisation, low gradient, or eutrophication. (v) Class 1A and Class 1B together are essentially the Class 1 of the River Pollution Survey.	Water of less high quality than Class 1A but usuable for substantially the same purposes.
2	(i) DO greater than 40% saturation. (ii) BOD not greater than 9 mg/l. (iii) Where water is abstracted for drinking water, it complies with the requirements for A3* water. (iv) Non-toxic to fish in EIFAC terms (or best estimates if EIFAC figures not available).	(i) Average BOD probably not greater than 5 mg/l. (ii) Similar to Class 2 of RPS. (iii) Water not showing physical signs of pollution other than humic colouration and a little foaming below weirs.	(i) Waters suitable for potable supply after advanced treatment. (ii) Supporting reasonably good coarse fisheries. (iii) Moderate amenity value.

*A2, A3 are EEC categories for surface water intended for the abstraction of drinking water as follows:

A2 Normal physical, chemical treatment and disinfection, e.g., pre-chlorination, coagulation, flocculation, decantation, filtration, disinfection (final chlorination).

A3 Intensive physical and chemical treatment, extended treatment and disinfection.

Under extreme weather conditions (e.g., flood, drought, freeze-up), or when dominated by plant growth, or by aquatic plant decay, rivers usually in Classes 1, 2 and 3 may have BODs and dissolved oxygen levels, or ammonia content outside the stated levels for those Classes. When this occurs the cause should be stated along with analytical results.

The BOD determinations refer to 5 day carbonaceous BOD (ATU). Ammonia figures are expressed as NH_4.

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APPENDIX V

Discussion paper on the rationale for classification standards for pH in fresh waters

A review by the European Inland Fisheries Advisory Commission (EIFAC) of the FAO (EIFAC 1968) concluded that the pH range which is not directly lethal to fish is 5-9. Within the pH range 5-6, acid discharges may liberate sufficient carbon dioxide from bicarbonate in the water to be directly toxic. Since most natural waters would not attain pH values below 6 unless they were subject to an acid discharge, a lower pH limit of 6.0 is reasonable. Also, by pH 6.0 slightly more than two-thirds of the alkalinity of a natural water has been removed, and any further additions of acid are likely to cause very large pH changes which are likely to be difficult to control.

The Ohio River Sanitation Commission (ORSANCO) state (ORSANCO 1975) that, although fish have been found at pH values between 4 and 10, the safe range is 5-9 and for maximum productivity the pH value should lie between 6.5 and 8.5. Where an acid discharge decreases pH to 6.0, there will be a quite rapid increase in pH associated with the loss of excess free carbon dioxide produced by the acid. Accordingly, if pH 6 is accepted as the lower limit for classified waters, the receiving water pH will be outside the "most productive" range for only a relatively short distance downstream of a maximum permissible acid discharge. This is considered quite an acceptable situation.

During summer many natural waters develop pH values in excess of 9, associated with photosynthesis. Aquatic communities seem well able to tolerate these conditions.

It has been suggested that fish cannot tolerate sudden pH changes. However, EIFAC (1968) notes specifically that:

"although in early literature, it was stated that fish could not withstand sudden changes in pH value, both Brown and Jewel (1926) and Wiebe (1931) found that various North American coarse fish species could withstand rapid transfer between waters of widely different pH values within the normal range. Lloyd and Jordan (1964) found no difference between the susceptibility of batches of rainbow trout acclimated to pH values of 8.40, 7.5, and 6.55 when they were exposed to lethal acid (or alkali) solutions."

Class W waters are considered suitable as a source of supply which will receive flocculation, filtration, and chlorination (or equivalent treatments) before distribution to consumers. A pH in the vicinity of 6.0 is commonly required during flocculation treatment, and accordingly such a pH is quite acceptable in a raw water. In most waters, increasing the pH from the 7-8 range to 9.0 would require only a relatively small increase in the quantity of acid or alum necessary to achieve the optimum pH for the flocculation treatment step. Accordingly, the adoption of the pH limits appropriate to Class G (6.0-6.9) is appropriate for Class W.

The most important consideration in determining acceptable pH values in waters used for bathing is the possible occurrence of eye irritation, but there appears to be little information about this. Mood, Clarke and Gelperin (1951) present data suggesting some increase in eye irritation in swimming pools with a low concentration of chlorine (0.05 g/m^3 total chlorine) at a pH of 7.0, compared with a pH of 8.0. However, it is not known to what extent the presence of chlorine would have affected the results, and all other available information seems to relate to higher chlorine concentrations. Normal opthalmic solutions at pHs of 7-8 cause no irritation to the eye, but a slight feeling of irritation is experienced at pH 9 and solutions with a pH of 6.3-6.6 cause a feeling of dryness (Gifford and Vail 1947). These observations suggest an appropriate pH range for Class R waters would be either 6.5-9.0 or 7.0-9.0. It must be emphasised that there is very little information on which to base the recommendations and there may well be natural waters outside the recommended pH range which do not cause any noticable bather discomfort.

C.D. Stevenson
17.7.1980

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APPENDIX VI

Discussion paper on combined effect of dissolved oxygen and BOD standards

Freshwaters

In freshwaters, dissolved oxygen and BOD standards are complementary controls on water quality; the dissolved oxygen relates directly to the survival of aquatic organisms, whereas the BOD relates to aesthetic effects and the type of aquatic community which will be present.

Dissolved oxygen levels are affected by the loading of degradable organic materials, photosynthesis/respiration activity of algae and water weeds, and reaeration characteristics of the water. Low dissolved oxygen levels can occur in the absence of high loadings of degradable organic materials, if there are extensive algal growths and low reaeration rates. Conversely, high dissolved oxygen levels may be maintained in spite of high BOD loadings where reaeration rates are very high; although, under these conditions, unsightly bacterial slimes are likely to develop and desirable aquatic organisms will disappear. In the fresh water classes, limits are given for both dissolved oxygen and BOD, to provide adequate control for the wide variety of receiving water conditions.

For Class F, a very high standard of water quality is required, since the standards must ensure that not only is the water in the stream itself adequately oxygenated, but that the dissolved oxygen levels do not drop excessively in water percolating through gravel salmonid spawning redds. A high percentage saturation control for dissolved oxygen (80%) is chosen to reflect the requirement for maintenance of a very high standard of water quality. Use of a high fixed minimum dissolved oxygen concentration (e.g., 9 or 10 g/m^3) would either be unattainable in warmer waters, or not ensure reasonably attainable high quality in colder waters.

For other freshwater classes (G, W, R), a minimum dissolved oxygen concentration is chosen to protect aquatic organisms, while providing for reasonable waste assimilation in the receiving water. High temperature and low dissolved oxygen together have a greater adverse affect on aquatic organisms than either condition separately. Use of a percent saturation standard would actually permit decreasing dissolved oxygen concentrations at higher temperatures, so that the lowest dissolved oxygen concentrations would be permissible only when they are likely to be most damaging. The minimum dissolved oxygen concentration chosen ($5 g/m^3$) is considered to provide reasonable protection under elevated temperature conditions, while allowing reasonable dissolved oxygen depressions for waste assimilation, particularly at lower temperatures.

Control of aesthetic characteristics related to organic loading is achieved principally through BOD standards, and the different concentrations chosen for the classes G, R, and W, and F reflect the requirement for increasingly clean waters under these classifications.

Coastal waters

BOD standards for freshwater are based on information about the effects of degradable organic materials on the character of flowing streams and their aquatic community. Since dilutions of effluents in seawater are commonly higher and more variable than in freshwaters, and flows and flow patterns are highly variable, the BOD criteria established for freshwaters are not reasonably applicable in coastal water classes. Accordingly, only dissolved oxygen standards are specified.

As for freshwaters, where maintenance of high water quality is the principal concern (Classes CR, CS) a high percentage saturation limit (80%) is chosen. In the case of Class CR, this higher dissolved oxygen requirement than in Class R is desirable because of the lack of information about reasonable BOD standards to maintain pleasing aesthetic characteristics.

For the other coastal classes, where reasonable provision for waste assimilation is required, a fixed minimum oxygen concentration provides protection of aquatic organisms. In the seawater classes 5 g/m^3 dissolved oxygen corresponds to a higher percentage saturation than in freshwaters, as is reasonable in view of the increased dilutions available in coastal situations.

C D Stevenson
27.8.1980

APPENDIX VII

Discussion paper on pH standards for seawater

Seawater is fairly well buffered against pH change compared to most natural waters, largely because of the buffering effect of borate and because the equilibrium between carbon dioxide in solution and carbon dioxide in the air is maintained constant due to the partial pressure of CO_2 in the air being constant on a global scale.

The pH of seawater in open waters is almost always found to be within the range 8.2-8.3. In estuaries, however, due to dilution and changes in chemical composition, pH may range from about 7.5-8.3.

Marine creatures (as distinct from estuarine organisms) have accustomed themselves to the pH range 8.2–8.3 and show signs of distress if the pH deviates far from this. Thus the arctic codfish (*Gadus gadus*) was found to die rapidly at pH 6.7, a pH which would be entirely tolerable to most freshwater fish.

In view of the relatively high buffer capacity of seawater it would require significant concentrations of acid or alkali in a discharge to cause the pH of seawater to deviate from the range 8.0–8.3.

M E U Taylor
2.10.1980

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