Marine Resource Conservation Working Group
Asia Pacific Economic Cooperation

Water Quality Criteria / Standards Adopted in the Asia Pacific Region

Phase 3 Report
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Environmental Protection Department
The Government of Hong Kong Special Administrative Region
of The People's Republic of China

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CONTENTS

Page

CONTENTS

Page

LIST OF FIGURES

Page

LIST OF FIGURES

LIST OF TABLES

Page

LIST OF TABLES

LIST OF TABLES

Page

LIST OF ANNEXES

LIST OF ANNEXES

LIST OF ANNEXES

Page

LIST OF APPENDICES

1 Introduction

1.1 BACKGROUND

Hong Kong, China submitted a project proposal (in Appendix A1) to the Marine Resource Conservation Working Group (MRCWG) of the APEC forum during its 15th meeting with a view to carrying out a literature review on :

- the Water Quality Criteria /Water Quality Standards (WQC/WQS) adopted by the member economies for the protection of the aquatic resources and uses;

- the approach/methodology and the scientific rationales for deriving the WQC/WQS by the member economies.

This project is carried out in phases, with the first phase having started in September 2002. In the first phase, two questionnaires were sent out to the various economies to collect initial information relating to four key issues : (i) the classification of beneficial uses, (ii) the values of the WQC/WQS, (iii) the approach and scientific rationales for deriving these values, and (iv) their application. The report of the first phase was presented at the 16th MRCWG meeting in Hanoi, Vietnam (11–13 October 2003). The report presents the initial findings of the questionnaire-based survey involving 15 economies, with a focus on the general framework of the individual WQC/WQS systems, the classification of beneficial uses and the values of the WQC/WQS.

The second phase, which started in early 2004, put the focus on close examination of the four identified key issues. At the outset, a third questionnaire was sent to the relevant economies to ask for information on the derivation method and the rationale in developing WQC/WQS for oxygen and nutrients. A report was presented at the 18th MRCWG meeting in Phuket, Thailand (17 - 20 May 2005), which describes in greater details the framework, philosophy and methodologies of the water quality criteria management systems of four selected economies : Australia, Canada, New Zealand and the USA.

The project entered into its final phase when approval was sought from the MRCWG in mid 2005. A copy of the project proposal for conducting the final phase and meeting new APEC project requirements is attached in Appendix A2. The work in the third phase comprises literature review of different approaches and steps used for the derivation for the WQC/WQS for dissolved oxygen and nutrients by the same four economies mentioned above. Upon completion of the entire project, a final report containing an account of all findings from various phases and a WQC/WQS database will be prepared for distribution to all APEC economies.

1.2 OBJECTIVES

Further to the review of the broad structure of the WQC/WQS systems, the focus of the third phase is on the detailed derivation of WQC/WQS for dissolved oxygen (DO) and nutrients. These two parameters are chosen because of their wide application in environmental management relating to harmful algal blooms, and thus are suggested for in-depth review to have a good illustration of the designation rationale and derivation process.

Harmful algal blooms (HAB), a phenomenon associated with eutrophication, have attracted much attention in the Asia-Pacific region because of their impact on aquaculture development and the risk to human health. Eutrophication is the process by which waters (lakes, rivers, seas) become excessively enriched with nutrients, typically nitrogen and phosphorus. It normally takes a long time to progress under natural conditions, however, human activities accelerate the process bringing about negative consequences due to the presence of excessive amounts of algae.

The most serious problems of eutrophication result from the massive growth of single-celled algae. The breakdown of these cells when they die can cause a decrease in the concentration of dissolved oxygen as a result of decomposition of organic materials. Aquatic plants which proliferate under the influence of enriched nutrients affect the oxygen and pH of the waters by respiration and decomposition of the dead cells. The greater the growth of algae, the greater the fluctuations in the levels of dissolved oxygen and pH. This can upset the metabolic processes in organisms, resulting in disease or death. Some blue-green algae can produce algal toxics, killing animals and poisoning freshwater reservoirs. An increased amount of algae in lakes, rivers or coastal waters, where recreation is important, is undesirable since it decreases water clarity and the aesthetic values of the area.

Water quality criteria are proposed to protect water resources from degradation by excessive amounts of algae. It is the intention of this report to closely look at the rationale for designation of water quality criteria / standards for protection of aquatic life, and the derivation process for two key parameters in eutrophication, namely dissolved oxygen and nutrients. Information on the development process of three groups of economies : Australia & New Zealand, Canada and the USA is readily available for download from their websites. This report presents an overview of their processes. The grouping is based on the fact that Australia and New Zealand water management systems have been built on the same foundation and they adopt the same water quality criteria and other related policies.

1.3 STRUCTURE

This report contains the following sections and appendices :

Section 1	contains the introduction.
Section 2	summarizes the methodology and the reporting method in the third phase.
Section 3	compiles the information collected from the literature review.
Section 4	summarizes the findings on WQC/WQS for dissolved oxygen.
Section 5	summarizes the findings on WQC/WQS for nutrients.
Section 6	concludes the findings and sets out the steps for completion of the project.
Annex 1-22	contains annexes of literature values and references cited in the derivation of WQC/WQS for oxygen and nutrients.
Annex 23	contains the principal steps for the development of nutrient criteria suggested by USEPA.
Annex 24	contains the list of references cited in the WQC/WQS derivation documents reviewed in this report.
Appendix A	contains the project proposals submitted in 2002 and 2005.
Appendix B	contains the list of contacts of the responsible departments/ agencies for acquiring information in this project.
Appendix C	contains the links for on-line access to WQC/WQS in different economies.
Appendix D	contains the list of WQC/WQS derivation documents reviewed in this project.

2 Methodology and Reporting

Internet search and literature review were the main methods used in this phase to collate information pertaining to the objectives of the project.

Among the three groups of economies studied, the approaches used by these economies to derive WQC/WQS for dissolved oxygen and nutrient related parameters generally reflect several commonly adopted methodologies. Australia and New Zealand adopts the reference condition approach whereas Canada and the USA adopt a mixture of different approaches and methodologies, e.g. toxicity risk assessment, biologically based dose-response model simulation, application of absorption principles, statistical collation of historical observations are used in the national derivation protocol and local derivation process. Each approach used by the respective economy will be discussed in sequence and under separate sections for freshwater and marine water. Given the extensive amount of toxicity data and information quoted in the criteria development, it is not possible to trace the data squarely from the original documents. This project report instead compiles the data and information cited in the derivation documents and provides summary tables and internet linkages as a quick guide (in Annexes 1 to 24, Appendix C and D). The values presented in various tables and the figures in this report are the best reproductions of the information given in the original references.

3 Findings in Phase 3

WQG of Australia and New Zealand

The derivation of water quality guidelines (WQG) for dissolved oxygen and nutrient parameters follow the protocol for physical and chemical stressor. Default trigger values are derived from statistical calculation of a wealth of ecosystem data collected from unmodified or slightly modified ecosystems within five geographical regions across the two nations, i.e. southeast, tropical, southwest and south central Australia, and New Zealand. Ecosystem types include upland river, lowland river, lakes and reservoirs, wetlands, estuaries and marine waters. Collection of data from identified reference sites spanned from 1 to 10 years. The 20^{th}, 50^{th} or 80^{th} percentile values of the reference site data are taken to be the default trigger values for slightly to moderately disturbed ecosystem. A less conservative percentile value (i.e. 10^{th} or 90^{th} percentile) is taken if it is aimed to maintain the water quality of highly disturbed ecosystems. No trigger values are applied for pristine water bodies.

WQC of the USA

Dissolved Oxygen Criteria

Separate sets of WQC/WQS have been developed for freshwater and marine water. Derivation of the freshwater water quality criteria followed a risk-based approach which mainly involved desktop analysis of toxicity information with respect to acute and chronic effects on growth, development rate and survival in embryo and larval in salmonids, non-salmonids and invertebrates. The risk assessment was based on a collection of scientific evidences since the 1970s, including effect data on physiology, growth, reproduction in early life stages, behaviour and swimming pattern. Curve fitting technique was used to convert various toxicity test data to growth rate data for fish exposed to low DO concentrations to derive optimum concentrations that could offer protection to the target species. Criteria were then assigned with reference to a table of fish production impairment risk level taking into account of other factors, e.g. temperature and diurnal fluctuations of DO.

The approach to deriving DO criteria (marine water) combined features of the traditional water quality criteria with a new biological framework. A mathematical model was used to integrate time (replacing the concept of an averaging period) and establish protection limits for different life stages (i.e. larvae versus juveniles and adults). The criteria are intended for protection of aspects relating to aquatic life : (1) juvenile and adult survival, (2) growth effects, and (3) larval recruitment effects. Because of the diurnal swing and seasonal pattern of DO concentrations in the marine environment, a single value (i.e. daily minimum, 7-day mean minimum, 7-day mean, a 30-day mean) is considered not adequate for its intended purpose. The new marine water criteria are applicable to both continuous and cyclic low DO conditions. The acute criterion for the juvenile/adult survival and the chronic criterion for growth are derived primarily following the USEPA traditional approach for toxic chemicals outlined in the Guidelines (USA 1985). These two criteria outline the boundaries beyond which the protection objectives can be met. Where the ambient DO concentration lies between these two values, further evaluation is required using the larval recruitment model that integrates duration and intensity of hypoxia to determine suitability of habitat for the larval recruitment objectives. The criterion in this case will be expressed in terms of "the number of days a continuous exposure can occur" or "the number of days an intensity and hourly duration pattern of exposure can occur".

Nutrient criteria

Because every ecosystem has unique species, climatological, hydrological and soil conditions, Australia, New Zealand and the USA have determined that the development of nutrient criteria could most efficiently be achieved using a reference condition approach as main feature. Both two groups of economies have adopted the regional and water-body type approach to derive "regional" nutrient criteria for application at regional level. The development procedures generally follow five principle steps :

- consideration of historical data;
- characterization of the reference conditions;
- use of predictive models;
- expert judgment and evaluation of interfering factors;
- validation of proposed WQC/WQS.

USEPA derived nutrient criteria based on historical data, reference site data, and evaluation from a panel of specialists with due consideration on the properties of five important variables, namely, nitrogen, phosphorus, silica, chlorophyll-*a*, water clarity and dissolved oxygen. USEPA recommends using the 75th percentile of a distribution of reference condition values as the target condition of a minimally impacted site. Reference condition waters that exceed criteria based on the 75th percentile are good candidates for site-specific criteria. If information about "minimally impacted sites" is unavailable, the 25th percentile of a distribution of samples form the entire population of water bodies within a given physical classification (e.g. an ecoregion) will be used.

The Chesapeake Bay Program is a good example demonstrating the use of different water quality criteria as goals to restore the estuarine-coastal water from eutrophication. The target water quality condition after restoration is defined through the development of criteria for dissolved oxygen, water clarity and chlorophyll-*a*, which are considered as the best and most direct measures of the impacts of too much nutrients and sediment pollution on the bay's aquatic living resources. The development of these criteria followed a variety of approaches: a hybrid of the toxicological- and biological-based criteria derivation methodologies for dissolved oxygen; literature review coupled with field studies, model simulation and data evaluation for water clarity; collation of chlorophyll-*a* concentrations from several independent lines of evidence, i.e. historical observed concentrations, literature values related to trophic status, direct contributions to light attention and contribution to dissolved oxygen conditions.

Attributed to the complex dynamics of the nutrient cycle, and the cause and effect relationship of the HAB, other factors play an influential role in the criteria derivation. Other factors include cyanobacteria, bioavailability of N and P, N:P ratio, flux, chlorophyll-*a*. The development process is complicated and relies heavily on high quality monitoring data, scientific evidence of historical conditions which often based on decade of observations, and expert judgment, particularly in deciding reference sites.

WQG of Canada

The derivation of water quality guidelines for dissolved oxygen (freshwater and marine water) does not follow the standard CCME protocol (CCME 1991) which involves series of chronic studies on required different taxonomy groups. It is based on literature review on toxicity data with endpoints most relevant to setting water quality guidelines, including survival/mortality over relatively short period for acute guidelines; growth and reproduction over longer period for chronic guidelines. Numerical values for freshwater DO water quality guidelines are set with reference to the "slight impairment" level in the USEPA's fish production risk estimates with an additional safety margin of 0.5 mg/L to estimate threshold DO concentrations. Whereas for marine water (interim only), the guideline is the DO concentration corresponding to the risk level of no impairment for salmonids (other life stage) in the USEPA's fish production impairment risk estimates.

Canada has not yet developed new water quality guidelines for nutrients for the protection of aquatic life. Currently, there is a water quality guideline for nitrate but it is only for protection from direct toxic effect and does not consider indirect effect from eutrophication. At provincial level, Saskatchewan and British Columbia have designated narrative and numerical WQGs for nutrients respectively for freshwater system. Total phosphorus and chlorophyll-*a* WQGs have been derived to protect water resources in British Columbia from degradation caused by excessive algae growth. No guidelines have been developed for protection of estuarine and marine waters from eutrophication due to the lack of information available on levels of nutrients or algal biomass.

In the following two sections, the approaches and methodologies used for deriving WQC/WQS for DO and nutrients in freshwater and marine water by each of the target groups of economies are discussed in detail.

4 WQC/WQS for Dissolved Oxygen

4.1 INTRODUCTION

Dissolved oxygen (DO) exhibits different effects on aquatic ecosystems when compared to toxicants. It occurs naturally and has great influence on aquatic organisms which depend upon oxygen for their efficient functioning. The DO concentration measured in a water body reflects the equilibrium between oxygen-consuming process (e.g. respiration) and oxygen-releasing process (e.g. photosynthesis and the physical transfer of oxygen from the atmosphere to the water body). WQC/WQS set for DO, in general, defines the condition offering adequate protection for aerobic organisms.

There are many mechanisms controlling the DO level in the aquatic media. Organic matter, such as sewage effluent or dead plant materials, that is readily available to microorganisms has the greatest impact on DO concentrations. These micro-organisms utilize water column dissolved oxygen as they decompose the organic matter. Whereas in large and deep freshwater system, oxygenation of water depends on circulation by winds, currents and inflows to move aerated water away from the surface. In deep marine waters, especially where light is scarce, oxygen is consumed by bacteria during decomposition of organic matter. In these cases, oxygen concentrations can be reduced to negligible levels and conditions can become anoxic. In shallow area close to shoreline, aquatic plants will raise oxygen level during photosynthesis and consume oxygen during respiration at night, giving rise to a diel cycle.

Overall, DO concentration in a water body is highly dependent on temperature, salinity, biological activity (microbial, primary production) and rate of transfer from the atmosphere. These factors should be taken in consideration when deriving WQC/WQS for DO. Within the scope of this review, it is observed that two approaches have been used by the three groups of economies: (i) Australia and New Zealand, (ii) Canada and (iii) the USA. Australia and New Zealand have adopted a reference data approach while the later two economies have based the derivation on toxicological data. Different sets of WQC/WQS are derived for freshwater and marine water. Section 4.2 to Section 4.6 summarize the key information on the derivation of the WQC/WQS by the economies.

4.2 WQG FOR DISSOLVED OXYGEN (FRESHWATER AND MARINE WATER) OF AUSTRALIA AND NEW ZEALAND

The current default guideline values for dissolved oxygen given in ANZECC (2000) are summarized in Table 4.2.1. They are for local jurisdictions to use when the recommended water quality guidelines derivation protocol cannot be used. The guidelines relate to substantially natural and slightly disturbed ecosystems. Local jurisdictions can make reference to these guidelines to derive their own guidelines that are used as trigger values to assess whether a risk to the health of the ecosystem has occurred.

Table 4.2.1 ANZECC Guideline values of dissolved oxygen applicable to five geographic regions across Australia and New Zealand

Region	Guideline values for Dissolved Oxygen (% saturation, lower and upper limits)					
	Upland River	Lowland River	Lakes & Reservoirs	Wetlands	Estuaries	Marine
Southeast Australia (1)	90 110	85 110	90 110	no data	80 110	90 110
Tropical Australia (1)	90 120	85 120	90 120	90 (2) 120	80 120	90 no data
Southwest Australia (1)	90 na	80 120	90 no data	90 120	90 110	90 na
South central Australia (low rainfall area)	no data	90 no data	90 no data	no data	90 no data	no data
New Zealand (3)	99 103	98 105	--	--	--	--

(1) Dissolved oxygen values were derived from daytime measurements. Dissolved oxygen concentrations may very diurnally and with depth. Monitoring programs should assess this potential variability.
(2) Northern Territory values are <80 (lower limit) and >110% (upper limit) for DO.
(3) DO percentiles may not be very useful as trigger values because of diurnal and seasonal variation – values listed are for daytime sampling.

Information regarding the rationale and derivation of the water quality guidelines is given in the publication titled "Australian and New Zealand Guidelines for Fresh and Marine Water Quality", ANZECC, 2000. It can be downloaded from http://www.deh.gov.au/water/quality/nwqms/index.html.

4.2.1 Overview of the approach

The application of the water quality guidelines works on a trigger-based approach to ensure no detectable change in the level of the stressor, e.g. DO, for high ecological value waters and the ecosystems are adequately protected for slight disturbed and highly disturbed ecosystems. The ANZECC recommended degrees of change from reference conditions (i.e. effect size) according to the level of ecosystem protection are shown in Table 4.2.2.

Table 4.2.2 ANZECC (2000) default effect sizes for different level of protection for physico-chemical stressor

Ecosystem	Effect size or departure from reference by level of ecosystem protection
Condition 1 – high ecological value system	No change to natural values
Condition 2 – slightly to moderately disturbed systems	Median lies within 20^{th} / 80^{th} percentile of reference range
Condition 3 – highly disturbed systems	Locally determined, e.g. 10^{th} / 90^{th} percentile of reference range

The ANZECC (2000) recommends that guidelines be developed on the basis of biological effects data. However, such data are not commonly available. The alternative approach is to base guidelines on the 80^{th} or 20^{th} percentiles of data from reference sites. The approach to deriving the ANZECC default guideline values has used the statistical distribution of reference data collected within five geographical regions across Australia and New Zealand. The reference values for guideline derivation were provided by state agencies and derived from the 20^{th} percentile of the ecosystem data, or other statistical criteria deemed appropriate by the authorities (e.g. 50^{th} percentile), for undisturbed or slightly disturbed reference ecosystems. The reference data were then collated, discussed and agreed for the five regions. Section 4.2.2 summarizes the key information taken into consideration by ANZECC in the guidelines derivation and Section 4.2.3 outlines the ANZECC recommendation procedures for deriving trigger value for dissolved oxygen from reference data by local jurisdictions themselves.

4.2.2 Derivation of the ANZECC guideline values

In deriving the default guideline values for application across Australia and New Zealand, the two nations are delineated into five regions according to the likeliness in ecology, geographical and climate conditions. The five regions are:

(i) Southeast Australia – Victoria, New South Wales, Tasmania, Australian Capital Territory, southern Queensland;

(ii) Southwest Australia – Western Australia;

(iii) Tropical Australia – northern Queensland, Northern Territory, northern Western Australia;

(iv) South central Australia – low rainfall area

(v) New Zealand

State agencies or research organizations in each region first identified appropriate reference sites and collected the data on regular basis for periods spanning from 1 to 10 years depending on the sampling protocol and project-specific conditions. 20th and 50th percentiles were computed according to the water quality conditions of the reference sites. The default guideline values were derived from these reference data agreed upon discussions among the state agencies, research organizations and the ANZECC. Table 4.2.3 shows the reference data supplied by the participating agencies and organizations for the guidelines derivation.

Table 4.2.3 Reference data supplied by Australian state and territory, and New Zealand research and regulatory organizations for deriving default guideline values for dissolved oxygen

Region	States	Guideline values for Dissolved Oxygen (% saturation, lower and upper limits)					
		Upland River	Lowland River	Lakes & Reservoirs	Wetlands	Estuaries	Marine
Southeast Australia	Victoria	95 110	85 110	90 110	--	94	--
	New South Wales (1)	60 120	60 120	--	--	60 120	90 110
	Tasmania	90	90	--	--	--	--
	Queensland (SE) (2)	90	85	--	--	80	90
Tropical Australia	Queensland (Tropical) (3)	90	85	--	--	80	90
	Northern Territory	--	80 (4)	80	80	80	--
	Western Australia (Tropical)	--	--	--	90	--	--
Southwest Australia	Western Australia (SW)	90	80	--	90	96 110	90
South central Australia	South Australia	--	90	90	--	90	--
New Zealand	New Zealand	99 103	98 105	--	--	--	--

(1) The minimum range for DO should be assessed around dawn and the max in late afternoon, in open waters. Greater variation around saturation can be expected in areas with submerged macrophytes.
(2) Trigger values for DO were based on the 20th percentiles but were varied from these slightly according to professional judgment. The DO triggers values for upland and lowland rivers are daytime values and apply only to streams that are flowing.
(3) Problems recognized with assigning DO values due to temperature fluctuations and diurnal periodicity, etc., DO levels in upland streams are very site/time/condition specific hence no default value is proposed. Lowland sites exhibit varying degrees of del cycling – daytime spot measurements commonly fall between 80 & 150% sat. in situ data-logging (limited) has shown that no site has maintained levels greater than 90% over a full 24 hour period and minimum daily values <50% appear to be common.
(4) Values for base flow.

4.2.3 Guidance for deriving trigger value for dissolved oxygen from reference data at local jurisdiction level

Guidance is provided for local jurisdictions to derive reference data, which include guidance to identify reference sites, to devise sampling protocol and to apply the trigger-based approach. Guideline packages detailing the derivation procedures, fact sheets showing more scientific information of the stressors and ecosystem-specific modifying factors and more guidelines on the steps involved in comparing ecosystem data with guideline trigger values are in stock. They could be found in sections 3.1, 3.3.3 and 7.4.4.1 in Vol. 1 of the ANZCEE (2000) Guidelines.

The very first step in the trigger value derivation from reference data is to identify reference sites. Reference sites are to be carefully chosen such that they represent suitable target conditions. Very often the reference conditions for sites that may or may not be disturbed at the time of data collection can be identified based on three sources of information: historical data collected from the site being assessed; spatial data collected from sites or areas nearby that are uninfluenced by the disturbance being assessed; or data derived from other sources, such as published literature, from models, from expert opinions, from detailed consultants and stakeholders. General guidance in assessing reference conditions has been provided, however, guidelines for choosing these reference systems are not based on any objective biological reference, and the final choice of trigger values is dependent on the professional assessment of available data by the jurisdictions. Important factors that should be considered in selecting reference sites are as follows :

- data collected prior to the disturbance should be collected from appropriate time span to provide valid comparisons with post-disturbance data;
- where possible, pre-disturbance data should be collected from appropriate control or reference sites as well as from the site(s) subjected to the disturbance;

- the conditions of the reference site must be consistent with the level of protection proposed for the ecosystem in question – unimpacted, slightly modified or degraded;
- sites should be from the same biogeographic and climatic region;
- reference site catchments should have similar geology, soil types and topography;
- reference sites should contain a range of habitats similar to those at the test sites;
- reference and test sites should not be so close to each other that changes in the test site due to the disturbance also result in changes in the reference sites, nor, conversely, should changes in the reference sites masks changes that might be occurring in the test site.

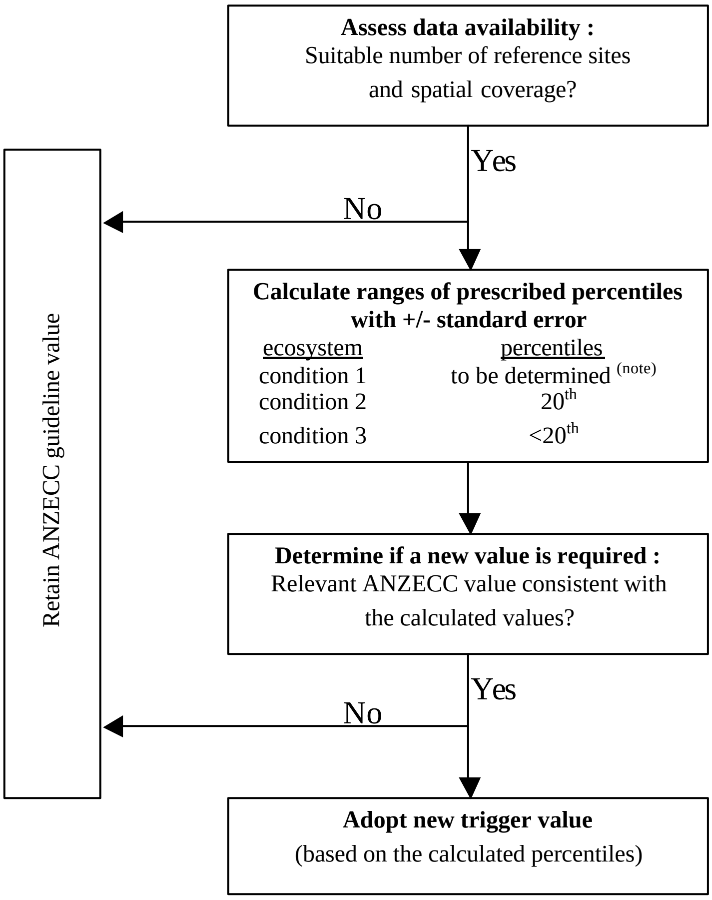
The second step in the process is to devise a sampling protocol with due consideration of the properties of dissolved oxygen. Concentration of DO is highly dependent on temperature, salinity, biological activity (microbial, primary production) and rate of transfer from the atmosphere. Under natural conditions, DO will change over a daily (or diurnal) period, and highly productive systems (e.g. tropical wetlands, dune lakes and estuaries) can become severely depleted in DO, particularly when these systems are stratified. Organic matters contributed to lakes, rivers and estuaries from the catchment also affect the DO consumption in an ecosystem. The following factors of modifiers and performance indicators need to be taken into consideration :

Modifiers : depend on the ecosystem type, and include missing condition (atmospheric O_2 transfer), photosynthetic O_2 production, rate of microbial decomposition, flow, temperature, pre-loading DO, mass of other O_2 consuming materials (e.g. nitrate).

Performance indicators : median DO concentration measured under low flow conditions for rivers and streams and during low flow and high temperature periods for other ecosystem.

The recommended minimum data requirement at the reference sites for establishing a trigger value is a minimum of two years of monthly data. Once the required amount of data have been collected, the prescribed percentiles of the data are then computed. Individual local jurisdictions should follow the risk-based decision tree to derive trigger values. A schematic diagram of the procedures involved is shown in Figure 4.2.1. In general, the recommended procedures do not require straight adherence, yet the derivation should be based on best available information and professional judgment that considered appropriate by the applying authorities. If there are problems in identification of suitable reference sites or the sampling and testing protocol involved is too resource demanding, then the ANZCEE default guideline values shown in Table 4.2.1 can be temporarily adopted as the trigger values until more information is gathered for refinement or adjustment.

Figure 4.2.1 Decision tree for deriving numerical trigger value for dissolved oxygen from reference data for waters at each level of protection (Source : ANZECC 2001).



Note : The ANZECC recommends that no departure from the natural values should be detected. The local government determines the percentiles to be used, taking the merits of the ecosystem concerned.

Condition 1 ecosystem = systems of high conservation / ecological value.
Condition 2 ecosystem = slightly to moderately disturbed.
Condition 3 ecosystem = highly disturbed systems.

More details on the derivation of the DO trigger value for application at state level could be found from the process of Victoria and Queensland. Relevant documents can be downloaded from their websites :

Victoria - http://www.epa.vic.gov.au/water/epa/wov.asp

Queensland - http://www.epa.qld.gov.au/environmental_management/water/water_quality_guidelines/

4.3 WQC FOR DISSOLVED OXYGEN (FRESHWATER) OF THE USA

The most recent USEPA guidelines for dissolved oxygen for aquatic life are outlined in Chapman (1986). Different values are proposed for different water types and different life stages of fish (Table 4.3.1).

Table 4.3.1 USEPA water quality criteria for ambient dissolved oxygen concentration

Averaging period	Coldwater Criteria		Warmwater Criteria	
	Early Life Stages [1, 2]	Other Life Stages	Early Life Stages [2]	Other Life Stages
30-day Mean	NA [3]	6.5	NA	5.5
7-day Mean	9.5 (6.5)	NA	6.0	NA
7-day Mean Minimum	NA	5.0	NA	4.0
1-day Minimum [4,5]	8.0 (5.0)	4.0	5.0	3.0

Notes :

1 These are water column concentrations recommended to achieve the required intergravel dissolved oxygen concentrations shown in parentheses. For species that have early life stages exposed directly to the water column, the figures in parentheses apply.
2 Includes all embryonic and larval stages and all juvenile forms to 30-days following hatching.
3 Not applicable.
4 For highly manipulatable discharges, further restrictions apply.
5 All minima should be achieved as instantaneous concentrations to be achieved at all times.

Information regarding the rationale and derivation of the WQC is given in the USEPA publication titled "Ambient Water Quality Criteria for Dissolved Oxygen", EPA 440/5-86-003, 1986. It can be downloaded from http://www.epa.gov/waterscience/pc/ambient2.html.

4.3.1 Overview of the approach

The approach for criteria development is to apply a desktop analysis of toxicity information on growth, development rate and survival in embryo and larval production levels in salmonids and non-salmonids. A table of risk levels of fish production impairment is drawn up, primarily based on the growth data, and other information on temperature, disease and pollutant stresses. The risk table comprises 5 levels, namely, "none", "slight", "moderate", "severe" and "limit to avoid acute mortality", which are equivalent to 0, 10, 20, 40 and $\geq$ 50% growth impairment. Professional judgment is then used in assigning DO concentrations to the criteria equivalent to each of these levels. The assignment is largely based upon examination of growth and survival data, generalization of response curve shape and assumed applicability of laboratory responses to natural populations. The following paragraphs summarize the key USEPA's considerations on the toxicity data with respect to acute and chronic effects on three classes of marine organism: salmonids, non-salmonids and invertebrates. Data and information appeared in the WQC document are tabulated in the annexes for easy reference.

4.3.2 Acute effects on salmonids

In their review on available acute toxicity data of the effect of low DO on salmonids, Doudoroff and Shumway (1970) found that the data were highly variable and differed in duration, exposure regime and endpoints. Only in a few cases could a 96-hr LC_{50} be reported. Mortality for loss of equilibrium usually occurred at concentration between 1 and 3 mg/L. Annex 1 shows a summary table of acute toxicity data cited in the WQC document. Later studies confirmed these lethal levels in chronic tests with early life stages of salmonids (Siefert et at. 1974; Siefert and Spoor 1973; Brooke and Colby 1980).

4.3.3 Chronic effects on salmonids

Extensive chronic studies on the effect of low DO concentrations on physiology, growth, reproduction, early life stages, behaviour and swimming pattern were quoted in the WQC development and they are summarized in Annex 2.

The JRB Associates (1984) used curve-fitting procedures to convert various toxicity test data to growth rate data for fish exposed to low DO concentrations and compared them with control growth rates (Figure 4.3.1). The analysis concluded that not-significantly-retarded growth was observed at DO concentration above 6 mg/L and severely-retarded below 4 mg/L. However, this conclusion was questioned by Warren et al. (1973) who pointed out that growth reduction rates were higher at elevated temperatures as revealed in their study on Chinook salmon (Figure 4.3.2, Figure 4.3.3).

Oxygen supply are important to embryonic and larval development where eggs are buried or overlaid on streambed. Intergravel DO is dependent upon the balance between the combined respiration of gravel-dwelling organisms and the rate of DO supply, which is dependent upon rates of water percolation and convection and DO diffusion. Without much information revealing the DO demand and supply mechanism, the DO concentration in the intergravel environment is taken to be at least 3 mg/L lower than the oxygen concentration in the overlying water. This 3 mg/L differential concentration was assumed in the WQC.

Figure 4.3.1 Percent reduction in growth rate of salmonids at various dissolved oxygen concentrations (Source : USEPA 1986, based on JRB Associates 1984)

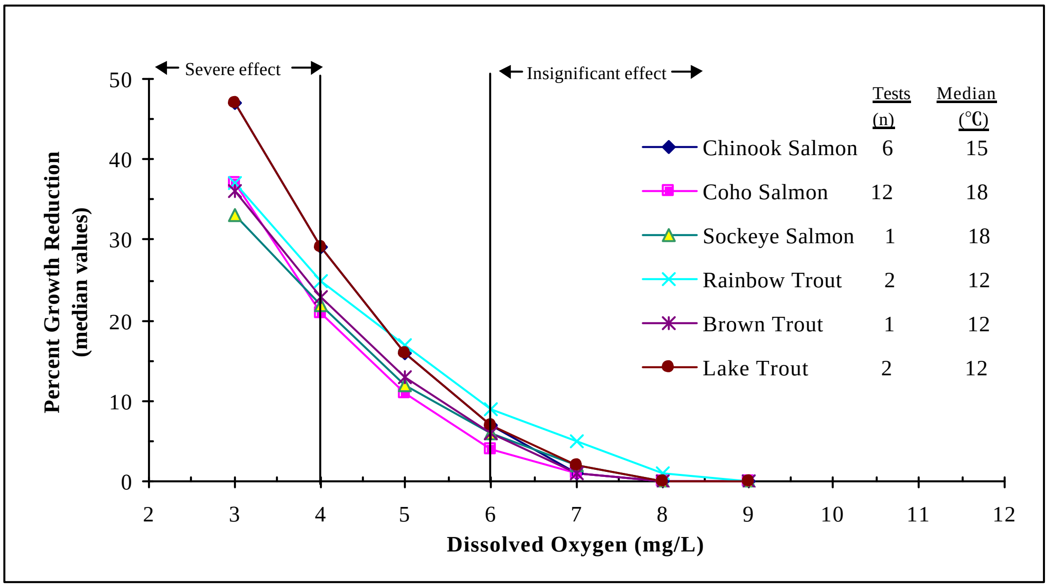


Figure 4.3.2 Influence of temperature on growth rate of Chinook salmon at various dissolved oxygen concentrations (Source : USEPA 1986, based on Warren et al. 1973; JRB Associates 1984)

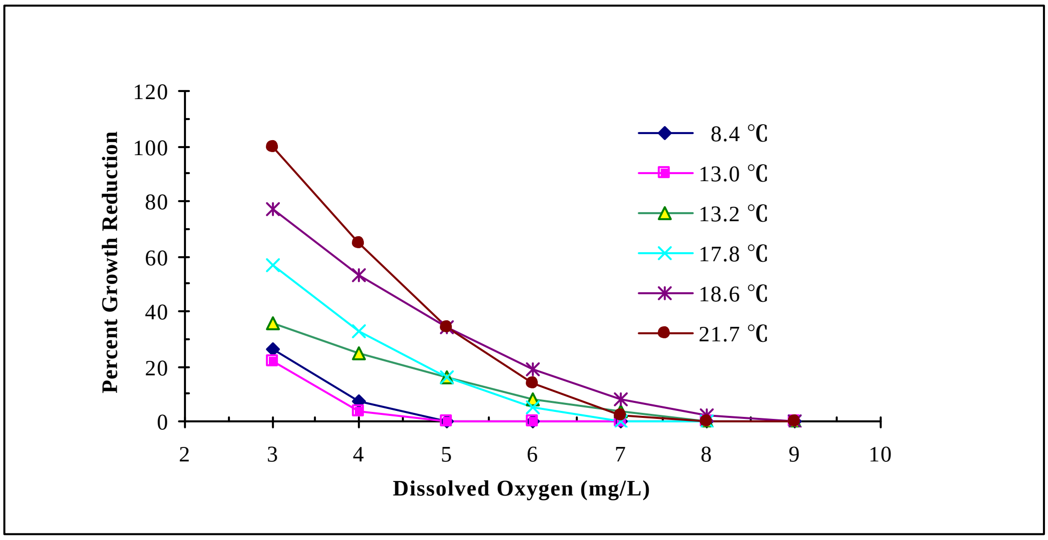
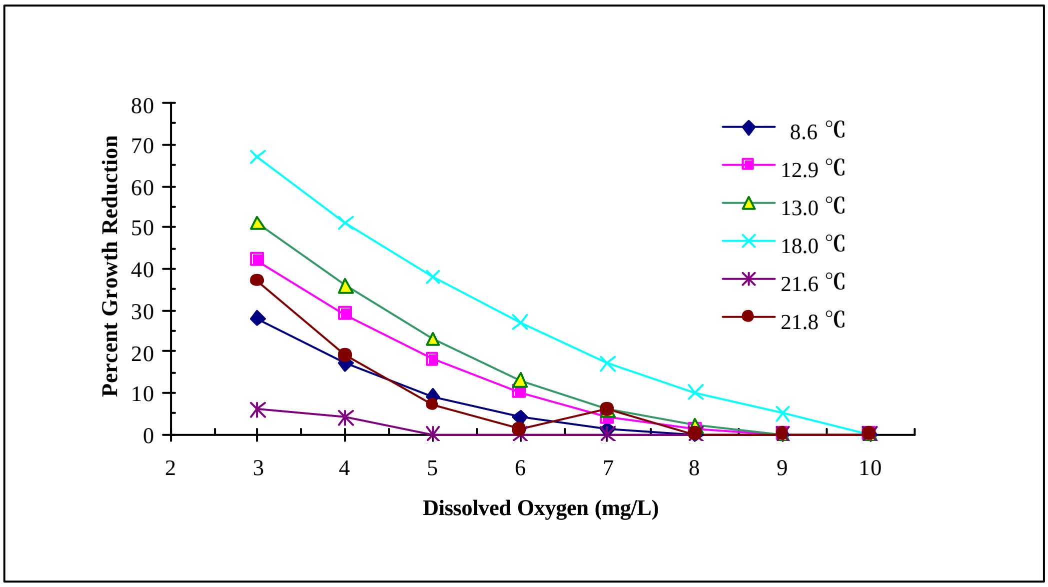


Figure 4.3.3 Influence of temperature on growth rate of coho salmon (Source : USEPA 1986, based on Warren et al. 1973; JRB Associates 1984)



4.3.4 Acute effects on non-salmonids

Based on the sparsely available acute data, many non-salmonids appear to be considerably less sensitive than salmonids. Annex 3 shows the toxicity data quoted in the USEPA derivation.

4.3.5 Chronic effects on non-salmonids

Data describing effects of low DO on non-salmonid fish were more limited than that for salmonids. Many of the study data available at that time demonstrated that the larval stage was generally the most sensitive life stage. Annex 4 shows the summary of toxicity data used in the WQC derivation.

The JCB Associates' analysis (1984) showed yellow perch appeared to be very resistant to low DO concentrations, northern pike might be about as sensitive as salmonids, and largemouth bass and channel catfish were intermediate in their response (Figure 4.3.4). Brake's study (1972) supported the idea that higher temperatures exacerbate the adverse effects of low DO on growth rate (Figure 4.3.5).

Overall, many studies have provided evidence of mortality or other significant damage to young non-salmonids in the 3 to 6 mg/L range; greater reduction in growth rate at higher temperatures; adverse effect in swimming, avoidance and other behavioral and physiological responses below 5 mg/L. Three field studies have showed that 5 mg/L appeared to be a good dividing line between bad and good conditions for fish. The results of these semi-quantitative field studies are found consistent with the derived criteria.

Figure 4.3.4 Growth reduction of some non-salmonid fish held at various dissolved oxygen concentration (Source : USEPA 1986, based on JRB Associates 1984)

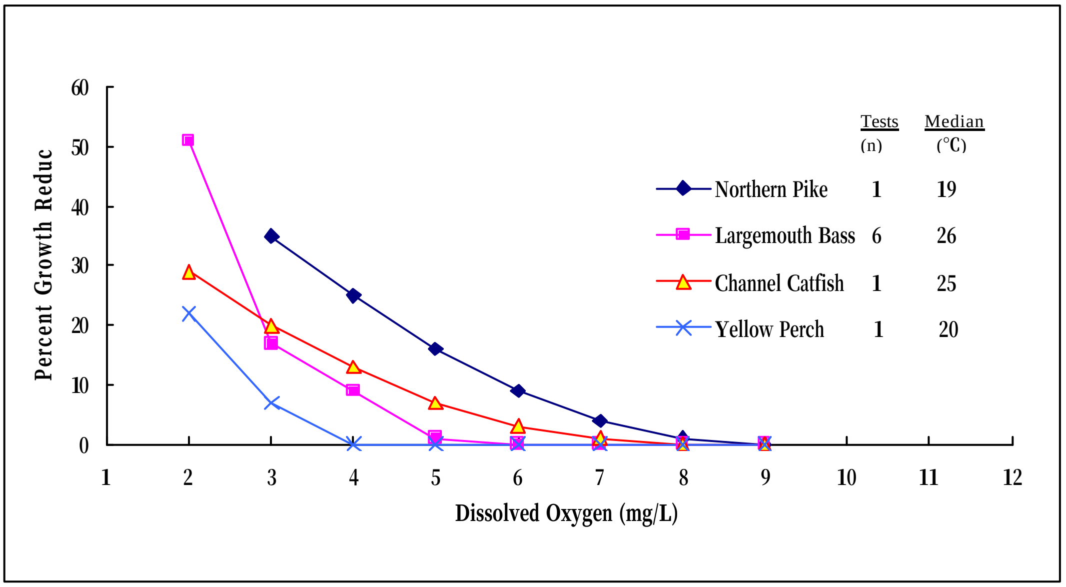
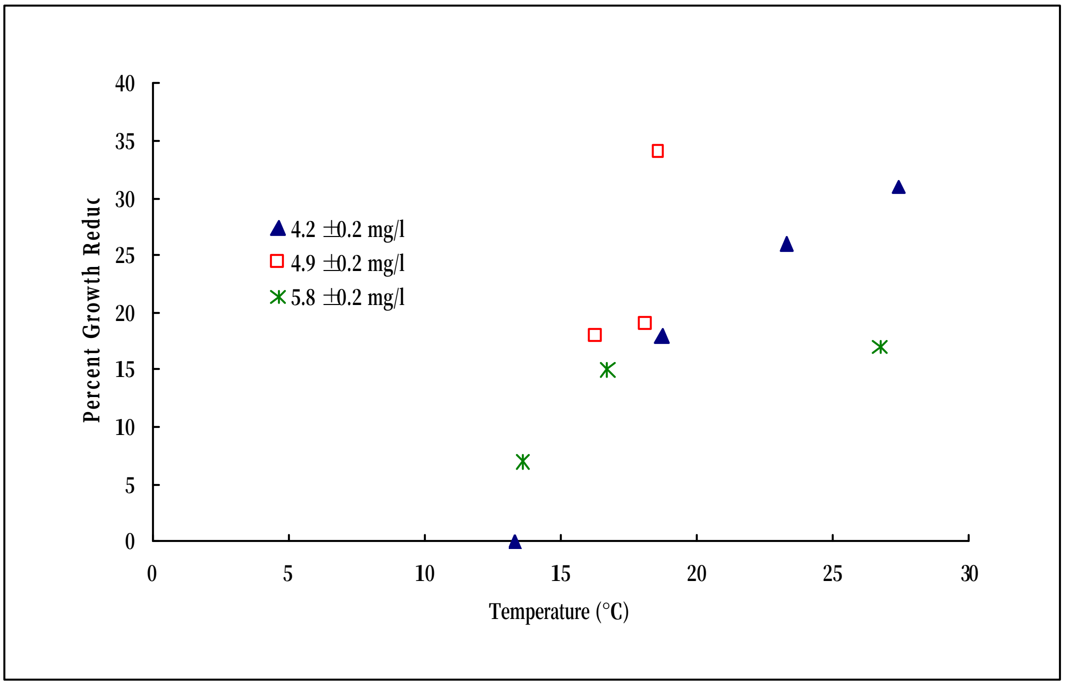


Figure 4.3.5 Effect of temperature on the percent reduction in growth rate of largemouth bass exposed to various oxygen concentrations in ponds (Source : USEPA 1986, after Brake 1972, based on JRB Associates 1984)



4.3.6 Effects on invertebrates

There is general paucity of information on the tolerance of the many forms of freshwater invertebrates to low DO. Data available mainly focus on the relationship between oxygen concentration and oxygen consumption or short-term survival of aquatic larvae of insects and on species representative of relatively fast-flowing mountain streams. The data referenced in the WQC derivation are summarized in Annex 5.

Long-term studies of freshwater invertebrate tolerance to low DO conducted by Guafin 1973) and Nebeker (1972) indicate that, though results of which being questioned, prolonged exposure to DO concentration below 5 mg/L would have detrimental effects on insects resident in Minnesota, Montana and Utah (Annex 6).

In summary, data available reveal that some species of insects and other crustaceans were killed at concentrations survived by all fish tested. While most fish survive the exposure to 3 mg/L, many species of invertebrates will die if the concentration drops below 4 mg/L. Those sensitive species common to swift flowing, coldwater streams require very high concentrations of DO. Because of long-term impacts of hypoxia are less well known for invertebrates than for fish, concentrations adequate to avoid impairment of fish production are generally considered to provide reasonable protection for invertebrates as long as lethal concentration are avoided.

4.3.7 Effects of diurnal fluctuations of dissolved oxygen

Diurnal and seasonal cycles cause the natural DO concentrations fluctuate tremendously, while in most laboratory studies the oxygen concentration are held essentially constant. Various studies to investigate the effects of fluctuating DO conditions on fish revealed by USEPA are summarized in Annex 7.

The minimum values are deemed more important than the mean level in considering daily or longer-term cyclic exposure. From previous discussion on growth studies, growth reduction is found greater at higher temperatures, in which case corresponding to warmer months and often associated with low DO. The significance of growth effect should thus be taken in consideration in WQC derivation.

4.3.8 Temperature, chemical stress and disease stress

High temperature and low DO commonly occur together in natural environment. The additive or synergistic effects of these two potential stresses warrant serious consideration. Toxicity of various chemicals exhibit certain degree of variation in reduced oxygen concentrations. Interactions between toxicants and low oxygen concentrations can greatly increase mortality of fish. Studies quoted in the WQC document are summarized in Annex 8.

4.3.9 Conclusion on toxicity studies

Determination of criteria is primarily based on laboratory data which are usually artificial in several important aspects and complicate the application of these data to natural systems. Differences in laboratory condition and the natural environment include :

- environmental stress and biological interactions that under natural conditions could not be assessed under laboratory conditions;
- organisms are given no acclimation to low DO conditions prior to test;
- unlimited food access without significant energy expenditure for search and capture;
- DO concentrations are kept constant unlike the natural fluctuations.

Several conclusions drawn from the available field and laboratory data in the toxicity data review include:

- natural DO concentrations may occasionally fall below target criteria levels due to a combination of low flow, high temperature and natural oxygen demand. Under such circumstances, failing to meet criteria should not be interpreted as violation of criteria. Effects of any reductions should be compared to natural ambient conditions and not to ideal conditions;
- attention should be given to conditions when high fish growth rate is a priority, when temperature approaches upper-lethal levels, when pollutants are present in near-toxic quantities;

- growth reduction is greatly affected by high temperatures. Critical consideration of DO requirement should be given to periods of highest temperature;
- higher DO in water column is required to provide protection of fish embryos and larvae which develop in the intergravel environment. A 3 mg/L difference is used in the criteria to account for this factor;
- the early life stages, especially the larval stage of non-salmonid fish are usually most sensitive to reduced DO stress. A separate early life stage (defined as spawning through 30 days after hatching) criterion is deemed necessary;
- a 1.0 mg/L difference is set in the criteria for other life stages of salmonid and non-salmonids. Such difference may be due to a more complete and precise database for salmonids; and the colder water temperatures at which salmonid tests are conducted and the resultant higher dissolved oxygen concentration in oxygen-saturated control water;
- a generalization is assumed, stating that if all life stages of fish are protected, the invertebrate communities should be adequately protected despite limited data on freshwater invertebrates;
- the criteria should include absolute minimum to prevent mortality due to hypoxia, but such minima alone may not be sufficient protective for the long-term persistence of sensitive populations under natural conditions. Therefore, assurance must be made available in the criteria to avoid significant physiological stress of sensitive organisms.

USEPA has drawn up a table of fish production impairment risk level, following the descriptions presented in Doudoroff and Shumway (1970) and Water Quality Criteria 1972 (NAS/MAE, 1973). Professional judgment is used in assigning DO concentrations equivalent to each of these levels based largely upon examination of growth and survival data, generalization of response curve shape and assumed applicability of laboratory responses to natural populations. In general, slight, moderate and severe impairment are equivalent to 10, 20 and 40% growth impairment respectively. Growth impairment of 50% or higher and conditions allowing a combination of severe growth impairment and mortality are considered as no protection.

Table 4.3.2 USEPA fish production impairment risk level for dissolved oxygen

Impairment	Salmonids		Non-salmonids		Invertebrates(mg/L)
	Early Life Stage (mg/L)	Other Life Stage (mg/L)	Early Life Stage (mg/L)	Other Life Stage (mg/L)	
None	11* (8)	8	6.5	6	8
Slight	9 (6)	6	5.5	5	5 (some impairment)
Moderate	8 (5)	5	5	4	
Severe	7 (4)	4	4.5	3.5	
Limit to Avoid Acute Mortality	6 (3)	3	4	3	4

* Water column concentrations recommended to achieve the required intergravel dissolved oxygen concentrations in parentheses. The 3 mg/L differential relative to overlying water is assumed.

4.3.10 Rationale for deriving the WQC for DO

The national criteria for ambient dissolved oxygen concentrations for the protection of freshwater aquatic life are presented in Table 4.3.1. The rationale and key scientific considerations for the development are summarized below :

- the average concentrations selected are values 0.5 mg/L above the slight production impairment values and between no production impairment and slight production impairment. Thus each criterion is seen as an estimate of the threshold concentration below which detrimental effects are expected;
- the coldwater minimum for other life stage is set at 4 mg/L for acquiring addition protection of the insect invertebrates which are less tolerant of acute exposure to low dissolved oxygen than are salmonids;
- the warmwater criteria are intended for protection of early life stages of warmwater fish as sensitive as channel catfish and to protect other life stages of fish as sensitive as largemouth bass;
- the criteria represent worst case conditions in which better than slight impairment is expected. In case this level of impairment is considered unacceptable, then continuous exposure conditions should use the no production impairment values as means and the slight production impairment values as minima;

- where the natural dissolved oxygen concentrations are found less than 110% of the applicable criteria means, or minima, or both, then 90% of the natural condition is to be taken as the minimum acceptable concentration criteria;
- no anthropogenic dissolved oxygen depression in the area below the 1-day minima should be allowed unless the tolerance of resident species to low dissolve oxygen is ascertain;
- daily average from the day's high and low dissolved oxygen values or a time-weight average is to account for sinusoidal and non-sinusoidal shape of the diurnal cycles;
- a 7-day averaging period is for the protection of embryonic, larval and early life stages which are the most sensitive in the entire life cycles whereas a 30-day averaging period is considered adequate for protection of other life stages;
- a daily minimum to safeguard no acute mortality due to hypoxia and protection from stresses due to periodic exposures to conditions at or near the acute lethal thresholds is set by way of (i) a 7-day average for early life stages, (ii) a 7-day mean minimum value for other life stages and (iii) additional limits for discharges.

4.3.11 Application of the criteria

In formulating the criteria, it is expected that the acceptable mean concentrations should be attained most of the time and occasional deviation below the values would cause no significant harm. However, attention should be given to the trend and frequency of occurrences. Evaluation of the significance of events failing to meet the criteria should be based on five major factors, along with the monitoring protocol:

- duration of the event;
- magnitude of the dissolved oxygen depression;
- frequency of recurrence;
- proportional area of the site failing to meet the criteria;
- biological significance of the site where the event occurs.

For situations when repeated acceptable daily minimum dissolved oxygen concentrations are observed, i.e. a condition of probable stress and adverse biological effects, guidance on improving criteria to minimize impairment risk is provided :

- limit the frequency of occurrence of values below the 7-day mean minimum (3 weeks per year is suggested by USEPA); or
- increase the acceptable 1-day minimum to 4.5 mg/L for coldwater fish and 3.5 mg/L for warmwater fish.

4.4 WQC FOR DISSOLVED OXYGEN (MARINE WATER) OF THE USA

USEPA published in 2000 a set of ambient water quality criteria for dissolved oxygen that will protect coastal and estuarine animals in the Virginian Province (Cape Cod, MA to Cape Hatteras, NC). The criteria feature a new approach which integrates exposure to low dissolved oxygen over time rather than averaging dissolved oxygen exposure conditions into one single value.

This is the very first set of marine DO criteria issued by USEPA. The Agency has spent 10 year of research effort to formulate the best DO concentrations necessary to protect aquatic life and the associated uses. State or tribal governments may use these criteria as guidance in setting water quality standards for coastal and estuarine waters. The document containing detailed information on the derivation approach is provided in "Ambient Aquatic Life Water Quality Criteria for Dissolved Oxygen (Saltwater) : Cape Cod to Cape Hatteras", EPA-822-R-00-012, November 2000. It can be downloaded from http://www.epa.gov/waterscience/criteria/dissolved/docriteria.html.

4.4.1 Overview of the approach

The approach to determine the limits of DO that will protect marine animals within the Virginian Province considers both continuous (i.e. persistent) and episodic/cyclic (i.e. diel) conditions, and covers three areas of protection : juvenile and adult survival, growth effects and larval recruitment effects.

Juvenile and adult survival - A minimum limit is calculated for continuous exposures by using Final Acute Value (FAV) calculation procedures (outlined in the derivation guideline, USEPA 1985) with juvenile or adult stage data. Limits for cyclic exposures are derived from an appropriate time-to-death curve for exposures less than 24 hour.

Growth effects – This Final Chronic Value (FCV) is derived in a similar way as the FAV. There is no time limitation in the application of this criterion. Cyclic exposures are evaluated by comparing reductions in laboratory growth from cyclic and continuous exposures.

Larval recruitment effects – A larval recruitment model is used in projecting cumulative loss caused by low DO. The maximum acceptable reduction in seasonal recruitment is set at 5% (other percentages also may be appropriate on a site-specific basis), which is equivalent to the protective limit for juvenile and adult survival. It is evaluated in terms of the number of acceptable days of seasonal exposure to low DO. The severity of cyclic exposure is evaluated with a time-to-death model.

Table 4.4.1 Summary of Virginian Province marine water quality criteria for dissolved oxygen

Endpoint	Persistent Exposure (24 h or greater continuous low DO conditions)	Episodic and Cyclic Exposure (less than 24 h duration of low DO conditions)
Juvenile and Adult Survival (minimum allowable conditions)	(1) *a limit for continuous exposure* DO = 2.3 mg/L (criterion minimum concentration, CMC)	*(4) a limit based on the hourly duration of exposure* DO = 0.370*ln(t) + 1.095 where: DO = allowable concentration (mg/L) t = exposure duration (hours)
Growth Effects (maximum conditions required)	*(2) a limit for continuous exposure* DO = 4.8 mg/L (criterion continuous concentration, CCC)	*(5) a limit based on the intensity and hourly duration of exposure* Cumulative cyclic adjusted percent daily reduction in growth must not exceed 25% $\sum_{1}^{n} \frac{t_i * 1.56 * Gred_i}{24} < 25\%$ and $Gred_i = -23.1 * DO_i + 138.1$ where: $Gred_i$ = growth reduction (%) DO_i i = allowable concentration (mg/L) t_i = exposure interval duration (hours) i = exposure interval
Larval Recruitment Effects [a] (specific allowable conditions)	(3) *a limit based on the number of days a continuous exposure can occur* Cumulative fraction of allowable days above a given daily mean DO must not exceed 1.0 $\sum \frac{t_i(actual)}{t_i(allowed)} < 1.0$ and $DO_i = \frac{13.0}{(2.80 + 1.84e^{-0.10t_i})}$ where: DO_i = allowable concentration (mg/L) t_i = exposure interval duration (days) i = exposure interval	*(6) a limit based on the number of days an intensity and hourly duration pattern of exposure can occur* Maximum daily cohort mortality for any hourly duration interval of a DO minimum must not exceed a corresponding allowable days of occurrence where: Allowable number of days is a function of maximum daily cohort mortality (%) Maximum daily cohort mortality (%) is a function of DO minimum for any exposure interval (mg/L) and the duration of the interval (hours)

A model integrating survival effects to maintain minimally impaired larval populations.

4.4.2 Persistent exposure to low dissolved oxygen

4.4.2.1 Juvenile and adult survival

The acute data used for the derivation were LC_{50} values ranging from 24-hr to 96-hr and including 12 invertebrates and 11 fish species (almost all of the data were for juveniles). The geometric means of the acceptable data for each species and genus were calculated. The FAV was calculated using the four Genus Mean Acute Values (GMAVs) with the lowest probability derived by a given equation in the 1985 Guidelines (USEPA 1985). The GMAVs for the four most sensitive genera were all fish, ranging from 1.32 to 1.63 mg/L. Since dissolved oxygen exhibits contrary effects on aquatic animals to toxicant, for which the 1985 Guidelines were created, the derivation was reversed[1]. The FAV was calculated to be 1.64 mg/L, corresponding to the 95th percentile of the data. This value was adjusted to 2.27 mg/L by multiplying by 1.38, the average LC_5 to LC_{50} ratio[2] for juveniles.

4.4.2.2 Growth effects

The criterion, representing a threshold above which long-term, continuous exposures to low DO should not cause unacceptable effects was calculated with growth data. Evaluation was based on growth data only for two reasons : (i) growth was found generally more sensitive than survival to low DO, and (ii) results based on growth data were readily available whereas only one saltwater test on reproductive effects was available. The derivation was based on 36 tests on 4 fish species and 7 invertebrates. The GMAVs for the four most sensitive genera ranged from 3.97 to 4.67 mg/L. A value of 4.8 mg/L was assigned to be the CCC for continuous exposure to low DO.

4.4.2.3 Larval Recruitment Effects

A model was used to evaluate the cumulative effects of stresses on early life stages of aquatic organisms. Larvae were more acutely sensitive to low DO

[1] The standard calculation for toxicants in the 1985 Guidelines uses the 5th percentile. The 95th percentile is used here because, unlike toxicants, DO effects decrease as the concentration of DO increases.

[2] The use of a ratio to adjust the FAV to a CMC is designed to estimate a negligible lethal effect concentration corresponding to the 5th percentile species. It may in fact represent an adverse effect concentration for species more sensitive than the 5th percentile. The Guidelines use a factor of 2; however, there were sufficient data available for low DO to use a factor specific to this stressor. There was no significant relationship between genus sensitivity and the LC_5/LC_{50} ration; therefore, all rations were included in the calculation of the final ration.

than juveniles and therefore the WQC derivation was based on a larval recruitment modal. Early life history information and exposure-response relationships were integrated with duration and intensity of exposure to provide an ecologically relevant measure of larval recruitment. The level of impairment to cumulative seasonal larval recruitment that has been selected as acceptable was 5%, which meant that this level of effect should be insignificant relative to recruitment in the absence of hypoxic events. The level of effect could be adjusted in light of other site-specific factors that may contribute to a cumulative loss in seasonal larval recruitment.

Several assumptions were made in using the model and they were :

- the period of low DO occurs within the larval season;
- hypoxic days are contiguous;
- a new cohort occurs every day of the spawning season;
- each cohort is equal in size.

Model input parameters included :

- 24-hr exposure response data;
- 5 population parameters regarding each species – length of recruitment season in days, duration of larval development in days, initial cohort size, rate of natural attrition in percent, percentage of a cohort exposed to a hypoxic event;
- hypoxic event parameters – duration of the event in days, DO value for that event, average duration to use for cohorts exposed for part of their development.

Dose-response curves (% survival against dissolved oxygen concentration) were generated with data for 9 genera and 24-hr exposures. A Final Survival Curve (FSC) was generated with data points which were calculated in the same way as the FAV and FCV using the data from the four most sensitive genera. Recruitment curves for each genus were then generated using the model. The curves showed the level of dissolved oxygen in contiguous days that offered protection against greater than 5% cumulative impairment of recruitment. A Final Recruitment Curve (FRC) was also generated in the same way as the FRC, using the four most sensitive recruitment curves. Equation for derivation the FRC and FSC is :

$$P(t) = \frac{P_0 L}{P_0 + e^{-Lkt}(L - P_0)}$$ Equation 1

where $P(t)$ = the DO concentration at time t
P_0 = the y-intercept
L = upper DO limit
k = rate constant, empirically derived

P_0 and L were first estimated by eye from the original plot and then adjusted higher or lower to minimize the residuals between the real recruitment data and that estimated from the mathematical fit of the data. Then it was established that $P_0 = 2.8$, L = 4.64 and k = 0.0222, and Equation 1 becomes :

$$DO_i = \frac{13.0}{2.80 + 1.84e^{-0.10ti}}$$ Equation 1a

where DO_i = allowable concentration (mg/L)
t_i = exposure interval duration (days)
i = exposure interval

4.4.3 Less than 24-hr episodic and cyclic exposure to low dissolved oxygen

4.4.3.1 Cyclic juvenile and adult survival

The persistent hypoxic criterion of 2.3 mg/L is found to be overprotective for exposure less than 24 hour by time-to-death (TTD) data. Criterion for exposures less than 24-hr was developed with TTD data for 2 saltwater juvenile fish and 3 larval saltwater crustaceans. The TTD data, representing a range of test conditions (different DO concentrations) and lethal endpoints (e.g. TL_5, TL_{50} and others) were used to generate 33 TTD curves. The slope and y-intercepts of these curves were then derived from regression with the mathematical expression of the form :

$Y = m (\ln X) + b$ Equation 2

where X = time
Y = DO concentration
m = slope
b = intercept

These 33 derived slopes and y-intercepts were each plotted against the DO value from each TTD curve at 24-hr. The value at 24-hr was chosen in order to generate a curve for juveniles that met the constant CMC at its 24-hr value (2.3 mg/L). After regression, the slope and y-intercept at 24-hr (i.e. DO = 2.3 mg/L) value were obtained and substituted into Equation 2 to generate the "Time-to-CMC" curve with the mathematical expression as shown in Equation 3, which represents the same protection as the CMC for juveniles for continuous exposure.

$$y = 0.370 \ln(x) + 1.095 \qquad \text{Equation 3}$$

4.4.3.2 Cyclic Growth Effects

The criterion was expressed as the cumulative percent (cyclic adjusted) daily reduction in growth not exceeding 25%. It was derived from growth data available from cyclic exposures to low DO for three species of saltwater animals. The data were from experiments in which a low DO treatment was paired with a treatment cycling between the same low DO concentration and once that was above the continuous CCC (usually saturation). The cyclic treatments had 12 hours of low DO within any one 24-hours period. Most of the cycles consisted of 6 hours at the low concentration followed by 6 hours at the high concentration. The ratio of growth reductions percentage in cyclic exposure to constant exposure was estimated to be 1.56 from the experimental data.

Larval lobster was found to be the most sensitive species tested for growth reduction. A dose-response curve for assessing the growth reduction of a species was based on that for growth of larval lobster over a range of constant DO concentration. The dose-response curve for criterion derivation was :

$$Gred = -23.1 * DO + 138.1 \qquad \text{Equation 4}$$

where Gred = growth reduction (%)
DO = dissolved oxygen concentration (mg/L)

The growth reduction (cyclic exposure adjusted) was obtained by multiplying Gred in equation 4 by 1.56. The criterion calculated as cumulative growth reduction and normalized to daily percentage is shown in Equation 5.

$$\sum_{1}^{n} \frac{ti * 1.56 * \text{Gred}i}{24} \qquad \text{Equation 5}$$

where Gred_i = growth reduction (%) in equation 4 at time *t*
DO_i = allowable concentration (mg/L)
t_i = exposure interval duration (hours)
i = exposure interval

The cumulative was defined to be less than 25% to correspond to the CCC representing the potential for an approximate 25% reduction in growth.

4.4.3.3 Cyclic larval recruitment effects

The criterion was derived from the modeled relationship between daily cohort mortality and the allowable number of days at a given maximum daily larval cohort mortality that protects against greater than 5% cumulative impairment of recruitment over a recruitment season.

Similar to the derivation of criterion for constant exposure, a set of TTD curves and modelling were used to generate the time-to-CMC curve for juveniles (see Section 4.4.2.3). The criterion was set by limiting the maximum daily cohort mortality for any hourly duration interval of a DO minimum to be less than a corresponding allowable days of occurrence.

4.4.4 Application of the criteria

In deciding to set WQC for dissolved oxygen using the protection approach as described in Section 4.4.2 and 4.4.3 above, state and tribal governments are recommended to consider the following factors :

<u>Accuracy of monitoring data</u> – decide the number and locations of sampling sties to properly represent a given area, e.g. cyclic conditions may require measurements every 30 min for several days, whereas persistent hypoxia may need only several measurements a week.

<u>Biological effects</u> – decide whether a higher or lower impairment level (other than the prescribed 5%) for seasonal larval recruitment best offer protection to juvenile and adult life stages of aquatic life residing in the given area.

Spatial extent – decide whether a hypoxic area is small enough relative to nearby unaffected areas to allow the coastal region as a whole to meet the criteria.

Freshwater versus saltwater – decide what type of DO criteria should be assigned to a water body. The stringency and application of which vary in accordance with the ecosystem type. A good start for the evaluation is by considering their biological communities. The WQC are to be applied to the alike communities.

Threatened and endangered species – decide whether WQC derivation should base on biological information of threatened or endangered species. If sufficient and high quality data are available, site-specific should criteria should be derived.

4.5 WQG FOR DISSOLVED OXYGEN (FRESHWATER) OF CANADA

The Canadian water quality guidelines (WQG) for dissolved oxygen for freshwater aquatic life, defined as the lowest acceptable DO concentrations, are 6 and 5.5 mg/L for the early and other life stages respectively in warm-water ecosystem, and 9.5 and 6.5 mg/L for the early and other life stages respectively in cold-water ecosystems (Table 4.5.1). The guidelines are derived from the USEPA's "slight production impairment" estimates (USEPA 1986, Table 4.3.2), with an additional safety margin of 0.5 mg/L to estimate threshold DO concentrations. Derivation methodologies and rationale for these generic guideline are based on the last release of generic WQG (CCRME 1987) and two supporting documents available from Alberta Environmental Protection (AEP 1997) and Ministry of Water, Land and Air Protection, British Columbia (Truelson 1997). These documents are available at the following sites:

CCME 1999: Canadian Environmental Quality Guidelines, Chapter 4, Fact sheet for Dissolved Oxygen (Freshwater)

AEP 1997: http://www3.gov.ab.ca/env/info/infocentre/PubListing.cfm

Truelson 1997: http://wlapwww.gov.bc.ca/wat/wq/Bcguidelines/do/index.html

Table 4.5.1 Water quality guidelines for dissolved oxygen in freshwater for the protection of aquatic life (based on CCREM 1987, AEP 1997, and Truelson 1997)

Ecosystem	Guideline value (mg/L) (lowest acceptable dissolved oxygen concentration)	
	Early Life Stages	Other Life Stages
Warm water	6.0	5.5
Cold water	9.5	6.5

4.5.1 Overview of the approach

The derivation of WQG for DO does not follow the standard CCME protocol (CCME 1991) because of the vast variance in toxicity endpoints and exposure times that are used for measuring the effects of DO on aquatic life. The derivation is based on literature review on endpoints most relevant to setting WQG. These endpoints include: survival/mortality over relatively short period for acute guidelines; and endpoints such as growth and reproduction over longer time period for chronic guidelines. Recent literature reviews have recognized two distinct development stages for fish where oxygen requirement and supply are essential. The stages are defined as (i) life stage (buried eggs through to emergence or a post-hatch period), and (ii) later life stage denoted by free-swimming in the water column.

Both the Alberta and British Columbia (BC) derivations have used the latest USEPA guidelines for DO (USEPA 1986) as a starting point and so the American guidelines form the basis of the CCME WQG for DO. Resembling the US derivation, the Canadian derivation separately looks at the effects on fish, invertebrates, and additionally amphibians. Alberta looks at the overall effects on fish species whereas British Columbia specifically assesses the toxicity information on salmon and salmon-alike species during the two stages of development. The Canadian guidelines of coldwater ecosystem adopt the numerical values from the USEPA's "slight production impairment level for DO" plus a safety margin of 0.5 mg/L, whereas the guidelines for warmwater ecosystems follow the 7-d and 30-d mean criteria. However, a scientific basis for adoption of the USEPA values has not been clearly provided in the guidelines documents. Findings of numerous toxicity studies used in the US derivation are also used in the Canadian derivation. These have been summarized in the previous section (Section 4.5, Annexes 1-8). Rather than reproducing the same, new study information and highlights of the derivation rationale of the Canadian system are summarized in the following paragraphs and the corresponding annexes.

4.5.2 Acute effects on fish

Since the derivation in 1986, not many acute toxicity studies concerning DO have reported the LC_{50} values. Majority of the latest studies vary in test procedures, duration, exposure regime and reported endpoints. Recent findings of acute effects on fish include those on ranges of low oxygen tolerances ascribed to various fish species, acclimation to low oxygen concentrations are given in Annexes 9, 10 and 11. Some reviews have established that observed lethal oxygen levels generally increased at higher water temperatures and longer exposure, and mortality of loss of equilibrium occurred between 1 and 3 mg/L for some juvenile/adult fish.

The need for separate consideration on supply of oxygen during the early life stages and mature life stages is supported by numerous literature reviews. It has been reported that interstitial oxygen levels commonly are 2 to 6 mg/L less than those in overlying water due to the various consumptive forces at work and the delay in re-supply by diffusion and percolation. A differential of 3 mg/L between the two sessions of water is used by BC for the purpose of the WQG derivation. The same differential is currently adopted by the USA (USEPA1986) based on measurements in natural redds.

4.5.3 Chronic effects on fish

Effects of chronic hypoxia on fish covering growth, reproduction, behaviour, physiological and teratogenic aspects are evaluated. A compendium of toxicity data are provided in Annexes 12 to 15.

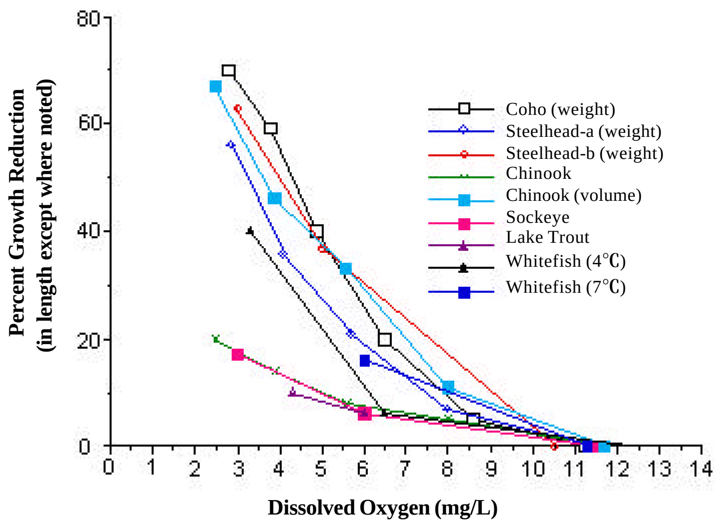
Growth - Literature review (Doudoroff and Shumway 1970) has indicated that the efficiency of yolk conversion to larval body tissue is not materially affected at dissolved oxygen concentration of 5 mg/L but yolk conversion is significantly impaired at 3 mg/L DO when water velocity was low. A later review (Alabaster and Lloyd 1982) also supports the earlier findings: a minimum value of 5 mg/L DO is satisfactory for most stages and activities in the lifecycle of fishes.

Figure 4.5.1 shows the summary of various studies on effects of lowered oxygen levels on early life stages of salmonid embryos which had been subjected to oxygen levels between 2.8 and 12.5 mg/L. The figure shows steady growth impairments as DO levels fall below 8 mg/L. Retardation is most pronounced in the early developmental stages which are characterized by less yolk utilization, retarded in fin development and smaller size. Growth and survival are serious impaired when oxygen concentration and water velocity together are very low (i.e. as low as 3 mg/L and 10 cm/h).

Several studies have found a minimum of 5 mg/L DO concentration to be a threshold for normal growth of juvenile coho salmon and rainbow trout (Thatcher 1974, Leppink and Valentine 1989). The USEPA summary of growth effects of salmon and salmon-like fishes at various oxygen levels also has shown reduction in growth is negligible above 7 mg/L but from 5 mg/L down to 3 mg/L the response curve of median impairment values slopes sharply through a range of approximately 15 to 35% (USEPA 1986). Figure 4.5.2 is a graphical representation of the data used by USEPA and data for fish species found in British Columbia.

Warren et al. (1973) studied the influence of temperature using Chinook salmon. The data show a substantive reduction in growth at progressively elevated temperatures and the effects are most profound at 5 mg/L or less and at temperatures above 13℃ (Figure 4.5.3).

Figure 4.5.1 Effects on lowered oxygen on growth of salmonid embryos at hatch (Source : Truelson 1997)



Notes:

Coho: (Warren et al. 1973)
-means of values obtained at four different water velocities (3-1400 cm/h), 10℃

Steelhead
(a): (Warren et al. 1973)
-means of values obtained at 300 cm/h, 10℃

(b): (Chapman1969)
-10℃

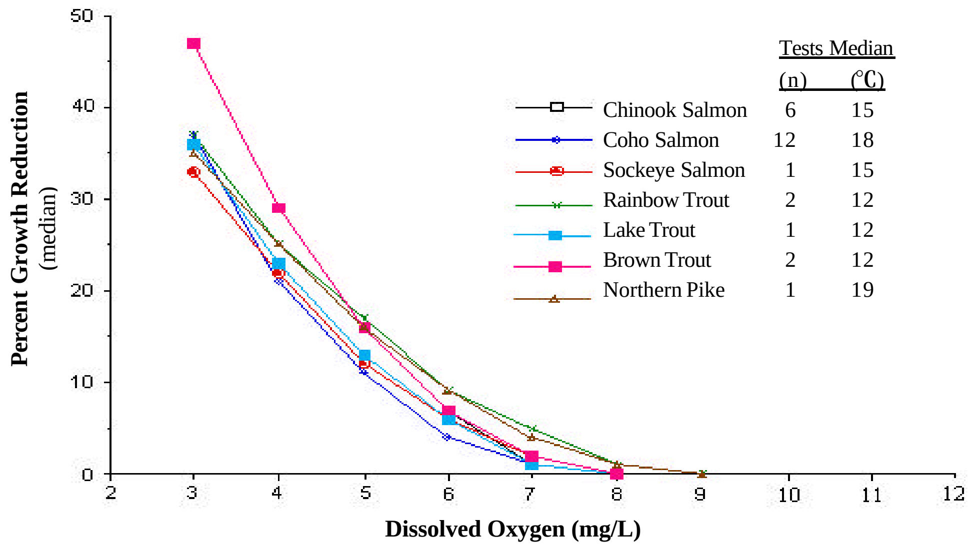
Chinook: (Silver et al., 1963)
-means of values obtained at three different water velocities (92-1350 cm/h), 11℃

Sockeye: (Brannon, 1965)
-water velocity of 30 cm/h, 7℃

Lake trout: (Carlson and Siefert, 1974)
-water velocity of 432 cm/h, 7℃

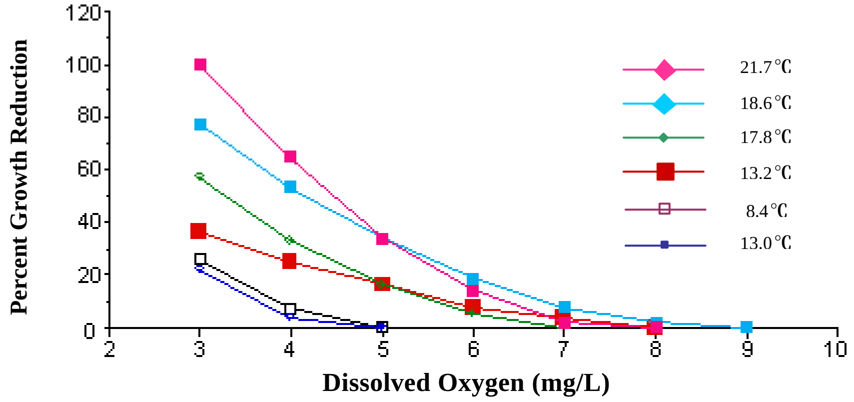
Mountain whitefish: (Siefert et al., 1974)
-water velocity of 360 cm/h, 4℃

Figure 4.5.2 Effects on growth of salmonid/salmonid-like fishes at various oxygen levels (Source : Truelson 1997)



Note: Chinook salmon data are superimposed on lake trout data.
Graphed from USEPA data 1986. Original research by Hermann et al. 1962, Fisher 1963, Adelman and Smith 1972, Warren et al, 1973, Brett et al. 1981.

Figure 4.5.3 Influence of temperature on growth of Chinook salmon at various oxygen levels (Source : Truelson 1997)



Graphed from USEPA data (1986), original research in Warren et.a1. 1973

Reproduction – Literature review (Doudoroff and Shumway 1970) has showed that low DO during embryonic development result in delayed development, and increased mortality. No difference in success of spawning, number of embryos, viability of embryos and hatching success of survival through swim up (feeding) was observed between DO levels ranging 2.5 to 6.5 mg/L for black crappie (Siefert and Herman 1977).

Behaviour – Fish compensated for hypoxia by several behavioural responses : increased use of air breathing, increased use of aquatic surface respiration (ASR), habitat changes or changes in activity level. Most fish species moved closer to the bottom of the ice as winter progressed showing a preference for areas with higher DO levels (Kramer 1987), except perch and bluegill (Casselman 1978). Walleye in their second summer remained in the shade at DO levels greater than 5.5 mg/L (Scherer 1971) and migrating salmonids avoided DO levels of 3.5 to 5 mg/L (Birtwell and Kruzynski 1989 as referenced in Barton and Taylor 1996). Juvenile Chinook salmon avoided oxygen concentrations from 1.5 to 4.5 mg/L in summer (water temperature 18°C) but did not avoid oxygen concentration at 4.5 mg/L in autumn (water temperature 12°C) (Whitmore et al. 1960).

Surfacing/gulping behaviour was seen as an alternate respiration activity when fish are subject to sever oxygen reductions. Nosing activity (move upward to most well-oxygenated water in natural situations) was observed in pike in a sealed tank at 0.25 mg/L DO level (Gee et al. 1978).

Teratogenic Effects – Low DO during embryonic development could result in structural deformities (Doudoroff and Shumway 1970). Abnormal growth was observed in several tested fish:

- chum salmon (DO threshold = 0.3 mg/L, Alderdice et al. 1958);
- largemouth bass larvae (DO threshold = 1 mg/L, Spoor 1997);
- steelhead trout (DO threshold = 2.6 mg/L, Silver et al. 1963);
- lake herring fry (DO threshold = 1 to 2 mg/L DO, Brooke and Colby 1980).

4.5.4 Effects on amphibians

Information regarding low DO effects on amphibians relates to behavioural changes in response to the lowered DO concentrations, e.g. survival of salamanders hellbenders and mud puppies in severely hypoxic water by breathing from an air pocket (Duke and Ultsh 1990, Dupre and Wood 1988); larvae of the brown-stripped frog remained at the bottom of aquaria and increased air breathing (Wong and Booth 1994); and South African clawed frog increased frequency of surfacing (Hatings and Burggren 1995).

4.5.5 Effects on invertebrates

Specific oxygen requirements of aquatic invertebrates have been studied extensively. Davis (1975) indicated that organisms tolerant of low acute oxygen conditions were capable of some form of anaerobic metabolism and behavioural changes : higher metabolic rates and hemoglobin production. Oxygen requirements of invertebrates reflect the environment they live and the invertebrates often have adapted to the stressful conditions. Sensitivities of the organisms to oxygen demand vary among major invertebrate groups rendering generalization difficult. Chronic effects of low DO have been studied on a wide spectrum of invertebrates, test conditions and endpoints. Davis concluded that knowledge of chronic effects and community oxygen requirements was not sufficient to establish a guideline to protect invertebrates. Literature reviewed by Alabaster and Lloyd (1982) indicated that many invertebrates survived DO levels substantially lower than 5 mg/L. References values in the CCME derivation are summarized in Annexes 16 to 19.

4.5.6 Effects of diurnal fluctuations of dissolved oxygen

Natural fluctuations of DO occur due to photosynthesis by plants and algae during the daylight hours and respiration of all organisms throughout the day. Minimum levels of DO occur in early morning and the largest fluctuations of DO occur when plant biomass is largest and most active (July and August). However, information regarding the effects of DO fluctuations on aquatic species or communities is sketchy (Alabaster and Lloyd 1982, Bagenal 1978, USEPA 1986).

Diurnal DO fluctuations altered the serum protein composition, which was considered as an indicator of biological stress in bluegill and largemouth bass but not in yellow bullhead (Bouch and Ball 1965). However, Bouch (1972) later considered that the biological significance of changes in serum proteins were questionable. Fluctuating DO reduced the growth rate of rock bass (Bouch 1972), juvenile largemouth bass (Stewart et al. 1967), yearling brook trout (Whitworth 1968) and coho salmon (Fisher 1963). Growth rate was found to be reduced to a larger extent in fluctuating DO levels than in constant levels (Fisher 1963; unpublished information Doudoroff and Shumway 1967 and

Shumway and Putnam cited by Doudoroff and Shumway 1970). Reduced feeding was observed in juvenile largemouth bass (Stewart et al. 1967), brook trout (Whitworth 1968) and rock bass (Bouck 1972). Non-lethal changes in DO caused more activity in roach, bream and perch (Alabaster and Robertson 1961) and largemouth bass larvae (Spoor 1977). Black crappie did not spawn when DO fluctuated between 1.8 and 4.1 mg/L or 2.6 and 5.6 mg/L while spawning occurred under all other fluctuating DO conditions with a minimum of DO level of 3.6 mg/L (Carlson and Herman 1978).

Only one study dealing with the effects on aquatic invertebrates has been identified. Higher temperatures and longer exposure durations to low DO decreased survival of amphipod *Gammarus pulex* (Grant and Hawkes 1982). The maximum DO concentrations used in the experiments (i.e. 6 or 10 at 10°C and 6 or 8 mg/L at 20°C) were found not to affect the survival of the amphipod.

4.5.7 Multiple toxicity and indirect effects

The effects of low DO levels in the presence of other stressors may also result in adverse effects and most of the time the effects are additive. Waters containing high level of chemical pollutants are often oxygen deficient and the toxicity of the pollutants become enhanced. Alabaster and Lloyd (1982) reported that a typical LC_{50} at a DO concentration of 5 mg/L would be roughly half that at 10 mg/L. Studies have demonstrated effects on fish due to the combined influence of reduced DO and ammonia, copper, lead, zinc and cyanide.

4.5.8 Rationale for deriving the WQG for DO

Cold-water / Warm-water distinction – The CCME WQG follows the USEPA (1986) and the CCREM (1987) national guidelines which present separate dissolved oxygen guidelines for cold-water (salmonid) and warm-water (non-salmonid) biota to distinguish the different oxygen requirements of these groups.

Concentration (mg/L) versus percent saturation – Concentration and percent saturation both have been used for specifying a particular level of DO in water. There is general preference for oxygen concentration in mg/L in recent years by various researchers, notably the IJC (1979), CCREM (1987) and the USEPA (1986). The main points in support of this decision are:

- oxygen transfer to fish blood depends on the diffusion of DO down a concentration gradient across the gill, relating to the minimum tissue pressure for metabolic activity. Since the minimum pressure has not been established to determine a diffusion gradient, it is not possible to calculate the oxygen demand (percent saturation). Therefore, the percent saturation in water would not provide a true indication of the needs of a fish;

- an expression of the guideline in percent saturation would result in lower DO concentration needs with increasing altitude. This contradicts the finding by Chapman that altitude has no known effect on the amount of DO needed by aquatic organisms;
- an expression of the guideline in percent saturation would result in lower DO concentration needs at higher temperature and vice versa. Available information demonstrates the contrary.

Temperature and altitude dependency – There has not been any obvious trend showing the effect of the temperature on oxygen response thresholds. Some studies have demonstrated a direct effect (e.g. Rombough 1988) but some not (e.g. Ott 1980). Figure 4.5.3 indicates that high temperatures increase the severity of hypoxia but have little influence when oxygen levels exceed 6 mg/L. Alberta has found from the plots of toxicity data against water temperatures that no clear correlation between water temperature and various response thresholds (AEP 1997). Therefore, no temperature component is included in the guideline. Altitude has no known effect on the concentration of DO needed by aquatic organisms (Chapman unpublished as cited in Truelson 1997). Altitude is therefore not incorporated in the guideline for DO.

Numerical Guideline – Few data are available on the effects of low DO on freshwater invertebrates. It is taken that if all stages of fish are protected then the invertebrate communities should also be reasonably protected. The USEPA (1986) document on DO (cold-water category) is largely based on salmonid species. It is assumed that the DO requirements of cold-water fish are similar to requirements for salmonids, although there are only a few data to support this. Maintenance of adequate oxygen at high temperatures is important for fish growth because fish normally attain high growth rates at high temperatures. The guidelines of cold-water ecosystem follow the USEPA's "slight production impairment level for DO, plus a safety margin of 0.5 applied accounting for a degree of conservatism. Whereas the guidelines for warm-water ecosystem follow the USEPA 7-day and 30-day mean criteria. The recommended guidelines are considered to protect the more sensitive populations of organisms against potentially damaging production impairment.

4.5.9 Application of the guidelines

Since intragravel DO concentrations are reduced due to sediment oxygen demand and respiring fish embryos. The guideline value of 6.5 mg/L in cold-water ecosystem for other life stage should apply to conditions in the gravel beds. CCREM (1987) has adopted a differential of 3 mg/L between the overlying water and the interstitial water to arrive at the guideline for the early life stage in cold-water ecosystems for protecting salmonid larvae in these redds.

Survival during the emergence life stage of *Leptophlebia* and *Ephemera* invertebrates was decreased at DO concentrations <8.3 mg/L (Nebeker 1972) from mid-May to end June (Leonard and Leonard 1962; Edmunds et al. 1976; Clifford et al. 1979). Same reduced survival was observed at DO <5mg/L for *Baetis* (Lowell and Culp 1996). Therefore, the early life stage guideline should be applied at those times and places where salmonid spawning and invertebrate emergence are known, or are likely, to occur.

4.6 WQG FOR DISSOLVED OXYGEN (MARINE WATER) OF CANADA

At present, only interim guideline is available for dissolved oxygen for aquatic life in marine water. It is adopted from the DO concentration corresponding to the risk level of no impairment for salmonids (other life stage) in the USEPA's fish production impairment risk estimates (Table 4.3.2). The CCME recommended minimum concentration of DO in marine and estuarine water is 8.0 mg/L and with the following application guidelines.

- Depression of the DO below the recommended value should only occur as a result of natural processes.
- When the natural DO level is < the recommended interim guideline, the natural concentration should become the interim guideline at that site.
- When ambient DO concentrations are >8.0 mg/L, human activities should not cause DO levels to decrease by >10% of the natural concentration expected in the receiving environment at that time.

Derivation methodologies and rationale could be found in Chapter 4, Fact sheet for Dissolved Oxygen (Marine) of the Canadian Environmental Quality Guidelines, CCME, 1999.

4.6.1 Overview of the approach

Similar to the derivation of dissolved oxygen for freshwater species, that for the marine species also does not follow the standard CCME protocol (CCME 1991). The derivation is based on the literature review on endpoints most relevant to setting WQG, which include survival, growth, reproduction and physiological and behavioral change. A summary of the key biological studies quoted in the derivation is given in Annex 20.

4.6.2 Rationale for deriving the WQG for DO

The Canadian guideline adopts the USEPA's fish production impairment risk level for salmonid-inhabited fresh waters, which is the protection level for the most sensitive fish species. No adjustment has been, however, made to account for the differences in the DO levels in marine waters and in fresh waters as some evidences show that adverse biological effects may not be expected occur above 8.0 mg/L (USEPA, 1986, Birtwell 1989).

The requirement to allow DO concentration to drop below the recommended guideline only as a result of natural process is included to take account of the fact that DO concentrations naturally will vary very expensively from depletion to over-saturation. Depression is not allowed when it is due to human activities. As some species may have adopted to naturally lower DO levels, such levels should be maintained and as such the natural DO level (when it is lower than the recommended interim guideline) should become the interim guideline at that site. A 10% depression in the DO guideline is allowed, taking into account the variability in diurnal and seasonal changes in the ambient concentrations.

5 WQC/WQS for Nutrients

5.1 INTRODUCTION

Nutrient enrichment has long been a major source of water pollution in many countries. In particular, enrichment of estuaries and near shore coastal waters from human-based causes is now recognized as major environmental problem. Excessive nutrient loadings will result in excess growth of macrophytes or phytoplankton and potentially harmful algal blooms (HAB) leading to oxygen declines, a general decline of aquatic resources, public health concerns and impairment to the designated use(s) of the water body or ecosystem.

The nutrient enrichment issue is not new, however the relationships between various controlling parameters within the HAB cycles are not yet fully known. It has been demonstrated that both nitrogen and phosphorus may limit phytoplankton biomass production depending on season, location along salinity gradient, resident time, light and other factors. How these factors affect each other is also under the influence of geographical, climatological and limnological conditions. While phosphorus is considered to be the limiting factor for most lakes and reservoirs, nitrogen is placed more emphasis in regions where sewage treatment plant effluent is involved. It would make little sense to develop generic nutrient criteria to be applied across the entire nation when these nutrients at the prescribed levels may not suit the characteristics of the water body.

Given the widespread occurrence of nutrient enrichment, authorities across the globe have devoted extensive effort in formulating strategies and policies to control the problem. Canada has not yet developed national water quality guidelines for nitrogen or phosphorus. This review then puts focus on the approaches used by Australia, New Zealand and the USEPA. It is found that reference condition approach is commonly adopted among the reviewed economies, where emphasis is on assessing the pre-cultural nutrient concentrations (before impairment) in a water body as a basis for establishing the allowable nutrient concentrations. Section 5.2 and 5.3 discuss the derivation process and the reference data used for derivation of default water quality guidelines or ecoregional nutrient criteria for several concerned parameters, i.e. total nitrogen, total phosphorus, chlorophyll-a, filterable reactive phosphate, turbidity and Secchi Depth. In particular Section 5.2.3 describes the work done by two Australian states, i.e. Victoria and Queensland, in deriving specific water quality guidelines and how compliance with the WQGs is assessed. Section 5.3.2 describes a mechanism to abate nutrient problem at the Chesapeake Bay adopted by Region III of USEPA. A Canadian example illustrating the derivation of provincial water quality guidelines is given in Section 5.4.

5.2 WQG FOR NUTRIENTS (FRESHWATER AND MARINE WATER) OF AUSTRALIA AND NEW ZEALAND

Total Nitrogen (TN), Total Phosphate (TP) and Chlorophyll-a (Chl-*a*) are selected as the three key performance indicators for evaluating the trophic level of a water body. Among other parameters, Filterable Reactive Phosphate (FRP) provides the best estimate of the bioavailability matters crucial for the growth of algae. The current default guideline values for TN, TP, FRP and Chl-*a* given in ANZECC (2000) are summarized in Table 5.2.1 to Table 5.2.4 They are intended for local jurisdictions to use when the recommended WQG derivation protocol cannot be used. The guidelines relate to substantially natural and slightly disturbed ecosystems. Local jurisdictions can make reference to these WQGs to derive their own water quality guidelines that are used as trigger values to assess whether a risk to the health of the ecosystem has occurred.

Table 5.2.1 ANZECC Guideline values of total nitrogen applicable to five geographic regions across Australia and New Zealand

Region	Guideline values for Total Nitrogen (µg N/L)						
	Upland River	Lowland River	Lakes & Reservoirs	Wetlands	Estuaries	Marine	
Southeast Australia	250[a]	500	350	no data	300	120	--
Tropical Australia	150	200 – 300[b]	350[c]	350-1200[d]	250	100 (Inshore)	100 (Offshore)
Southwest Australia	450	1200	350	1500	750	230 (Inshore)	230 (Offshore)
South central Australia (low rainfall area)	no data	1000	1000	no data	1000	1000	--
New Zealand	295[e]	614[f]	--	--	--	--	--

(a) value are 100 μgL^{-1} for Victoria alpine streams and 480 μgL^{-1} for Tasmania rivers;
(b) lower values from rivers draining rainforest catchments;
(c) this value represents turbid lakes only, clear lakes have much lower values;
(d) higher values are indicative of tropical Western Australia river pools;
(e) values for glacial and lake-fed sites in upland rivers are lower;
(f) values are lower for Haste River which receives waters form alpine regions.

Table 5.2.2 ANZECC Guideline values of total phosphorus applicable to five geographic regions across Australia and New Zealand

Region	Guideline values for Total Phosphorus (µg P/L)						
	Upland River	Lowland River	Lakes & Reservoirs	Wetlands	Estuaries	Marine	
Southeast Australia	20[a]	50	10	no data	30	25[f]	--
Tropical Australia	10	10	10	10 – 50[b]	20	15 (Inshore)	10 (Offshore)
Southwest Australia	20	65	10	60	30	20[c] (Inshore)	20[c] (Offshore)
South central Australia (low rainfall area)	no data	100	25	no data	100	100	--
New Zealand	26[d]	33[e]	--	--	--	--	--

(a) values are 30 µgL-1 for Queensland river, 10 µgL-1 for Victoria alpine streams and 13 µgL-1 for Tasmania rivers;
(b) higher values are indicative of tropical Western Australia river pools;
(c) summer (low rainfall) values, values higher in winter for Chl-*a* (1.0 µgL-1), TP (40 µg PL-1), FRP (10 µg PL-1);
(d) values for glacial and lake-fed sites in upland rivers are lower;
(e) values are lower for Haast River which receives waters from alpine regions;
(f) values are 20 µgL-1 for TP for offshore waters and 1.5 µgL-1 for Chl-*a* for Queensland inshore waters.

Table 5.2.3 ANZECC Guideline values of filterable reactive phosphate applicable to five geographic regions across Australia and New Zealand

Region	Guideline values for Filterable Reactive Phosphate (µg P/L)						
	Upland River	Lowland River	Lakes & Reservoirs	Wetlands	Estuaries	Marine	
Southeast Australia	15[a]	20	5	no data	5[b]	10	--
Tropical Australia	5	4	5	5 – 25[c]	5	5 (Inshore)	2 – 5[d] (Offshore)
Southwest Australia	10	40	5	30	5	5[e] (Inshore)	5 (Offshore)
South central Australia (low rainfall area)	no data	40	10	no data	10	10	--
New Zealand	9[f]	10[g]	--	--	--	--	--

(a) value is 5 µgL^{-1} for Victoria alpine streams and Tasmania rives;
(b) values is 5 µgL^{-1} for Queensland estuaries;
(c) higher values are indicative of tropical Western Australia river pools;
(d) the lower values are typical of clear coral dominated water (e.g. Great Barrier Reef), while higher values typical of turbid macrotidal systems (e.g. North-west Shelf of Western Australia);
(e) summer (low rainfall) values, values higher in winter for Chl-*a* (1.0 µgL^{-1}), TP (40 µg PL^{-1}), FRP (10 µg PL^{-1});
(f) values for glacial and lake-fed sites in upland rivers are lower;
(g) values are lower for Haast River which receives waters from alpine regions.

Table 5.2.4 ANZECC Guideline values of chlorophyll-*a* applicable to five geographic regions across Australia and New Zealand

Region	Guideline values for Chlorophyll-*a* (µg/L)						
	Upland River	Lowland River	Lakes & Reservoirs	Wetlands	Estuaries	Marine	
Southeast Australia	na[a]	5	5[f]	no data	4[b]	1[c]	--
Tropical Australia	na[a]	5	3	10	2	0.7 - 1.4[d] (Inshore)	0.5 – 0.9[d] (Offshore)
Southwest Australia	na[a]	3 - 5	3 - 5	30	3	0.7 (Inshore)	0.3[e] (Offshore)
South central Australia (low rainfall area)	no data	no data	no data	no data	5	1	--
New Zealand	na[g]	no data	--	--	--	--	--

na = not applicable
(a) monitoring of periphyton and not phytoplankton biomass is recommended in upland rivers – values for periphyton biomass (mg Chl-*a* m^{-2}) to be developed;
(b) value is 5 µgL^{-1} for Queensland estuaries;
(c) value are 20 µgL^{-1} for TP offshore waters and 1.5 µgL^{-1} for Chl-*a* for Queensland inshore waters;
(d) the lower values are typical of clear coral dominated water (e.g. Great Barrier Reef), while higher values typical of turbid macrotidal systems (e.g. North-west Shelf of Western A ustralia);
(e) summer (low rainfall) values, values higher in winter for Chl-*a* (1.0 µgL^{-1}), TP (40 µg PL^{-1}), FRP (10 µg PL^{-1}).
(f) value is 3 µgL^{-1} for Tasmania lakes;
(g) monitoring of periphyton and not phytoplankton biomass is recommended in upland rivers – values for periphyton biomass (mg Chl-*a* m^{-2}) to be developed. New Zealand is currently making routine observations of periphyton cover.

Information regarding the rationale and derivation of the water quality guidelines is given in the publication titled "Australian and New Zealand Guidelines for Fresh and Marine Water Quality", ANZECC, 2000. It can be downloaded from http://www.deh.gov.au/water/quality/nwqms/index.html.

5.2.1 Overview of the approach

The approach to derive the guideline values for nutrient parameters follows the reference condition approach as for dissolved oxygen, and other physical and chemical stressors. The approach is based on the statistical distribution of reference data collected within five geographical regions across Australia and New Zealand. The reference values for nutrient parameters were derived from the 80th percentile of the ecosystem data for undisturbed or slightly disturbed reference ecosystems.

Nutrient pollution to ecosystems has both direct and indirect effects. The ANZECC Guidelines has included additional information for water quality managers to consider the effects of nutrient pollution on ecosystem and how they come into play in the derivation process. Table 5.2.5 shows a summary of the major factors that need consideration.

5.2.2 Derivation of the ANZECC guideline values

Similar to the derivation of the guideline values for dissolved oxygen, those of nutrients are provided for the same five regions. State agencies or research organizations in each region first identified appropriate reference sites and collected the data on regular basis. The data collection period ranged from 1 to 10 years. Depending on the impairment of the water quality of the reference sites, the 80th or down to the 50th percentile of the reference data were calculated and submitted to the ANZCEE for consideration. Table 5.2.6 to Table 5.2.9 show the reference data regarding TN, TP, FRP and Chl-*a* supplied by the participating agencies and organizations for the guidelines derivation.

Table 5.2.5 A summary of major factors that need consideration in the derivation of ANZECC nutrient guidelines values

Factors	Points for Consideration
Cyanobacteria (commonly known as blue-green algae)	● The growth of cyanobacteria depends on nutrient concentration in the external medium, i.e. at low external concentration, the rate of uptake increases rapidly with an increase in external concentration, but at higher external concentration, there is less and less effect on the growth rate (Droop, 1973) ● Dissolved inorganic orthophosphate appears to be the only form of P assimilated by cyanobacteria. (Bostrom et al. 1988). P uptake is stimulated by light, depends on Mg^{2+} and is a pH sensitive process being optimum at 7 to 8.5. ● Cyanobacteria store P in excess of their immediate growth requirements as polyphosphates (Kromkamp, 1987). This will happen when P is abundant in the external medium.
Bioavailability of N and P	● Considerations on the bioavailability are to be made with a chemical, spatial and temporal context. ● The most bioavailable form of P is considered to be orthophosphate (PO_4^{3+}) and the most bioavailable forms of nitrogen are ammonia (NH_4^+) and nitrate (NO_3^-). ● The spatial and a temporal aspect also play an important role. The P entering a catchment from diffuse sources can be available for nuisance species given enough time (Harris, 1996). P entering an ecosystem from a sewage treatment plant will be available for immediate uptake but only for a short distance downstream of the discharge point. As the P moves further downstream, binding with other chemical substrates will render the P less bioavailable.
N:P ratio	● In addition to the common use of Redfield ratio which measures TN:TP, the bioavailability of these two elements should be taken into account. ● Organic P is often more readily available than organic N; FIN:FRP (filterable inorganic nitrogen : filterable reactive phosphate) will underestimate bioavailable N:P because FRP will include some organic P compounds in addition to orthophosphate, (Tarapchak et al., 1982). ● The N:P ratio is most applicable to phytoplankton community where its growth is controlled exclusively by nutrient supply. N and P can limit different species within the range of the critical N:P ratio (i.e. about 7:1 to 45:1), (Suttle & Harrison, 1988).
Nutrient concentration vs fluxes	● Other significant source of bioavailable N and P comes from the stores in sediments and associated with suspended particulate matter (SPM). The TP and TN concentrations in the water column may not necessarily be predictive of the response by aquatic plants. ● The flux, which helps transfer of the nutrients from the sediment to the water column and vice versa, is a crucial factor in estimating the effect of the nutrients uptake.
Nutrients dynamics	● It is important understand the dynamics of nutrient transport and biogeochemical cycling, as well as the interrelationships of nutrients with other ecosystem factors like current velocity, resident time, light, temperature, substrate stability and grazing by zooplankton, macroinvertebrates and waterfowl. ● A nutrient mass balance for an ecosystem will help identify major sources and sinks of nutrients.
Indicator of nutrient pollution	● Chlorophyll-*a* is often used as a general indicator of plant biomass because all plants, algae and cyanobacteira contain about 1-2% (dry wt) chlorophyll-*a*. ● Nutrients alone cannot indicate whether a water body actually has a nuisance plant problem. However, there is not always a clear relationship between Chlorophyll-*a* and biomass as it is more easily extracted from some species. It is suggested that P and Chlorophyll-*a* together is a better indicator of phytoplankton concentration, (Bowles, 1982).

Table 5.2.6 Reference data supplied by Australian state and territory, and New Zealand research and regulatory organizations for deriving default guideline values for total nitrogen

Region	States	Reference values for Total Nitrogen (µg N/L)					
		Upland River	Lowland River	Lakes & Reservoirs	Wetlands	Estuaries	Marine
Southeast Australia	Victoria	350 106[a]	422	--	--	172	--
	New South Wales	200	600 350[b]	--	--	350	110
	Tasmania	480	--	350 145[c]	--	--	--
	Queensland (SE)	215	500	--	--	310	120[e]
Tropical Australia	Queensland (Tropical)	180 130[h]	300 350[i] 175[j]	510[k]	--	230	120[d] 100[f, g]
	Northern Territory	--	300[l]	350	600	500	--
	Western Australia (Tropical)	--	--	--	1150[m]	--	140[o]
Southwest Australia	Western Australia (SW)	450[l]	1200[l]	--	1500	740	230[d]
South central Australia	South Australia	--	1000	1000	--	1000	1000
New Zealand	New Zealand	295	614	--	--	--	--

(a) values for alpine rivers
(b) values for coastal rivers
(c) values for World Heritage Area (WHA) pristine lakes;
(d) inshore values as coastal lagoons and embayments and waters less than 20m deep
(e) offshore values
(f) values are from GBRMPA/AIMS data < 10 km offshore
(g) values are from GBRMPA/AIMS data > 10 km offshore
(h) values from north Queensland EPA
(i) values from savanna catchment
(j) values from rainforest catchment
(k) values from studies on 1 naturally turbid lake
(l) values for base flow
(m) values include river pools
(n) summer values
(o) winter values
(p) values derived from data including Port Phillip Bay
(q) values are means of ongoing study
(r) values are from unfiltered reactive phosphorus data
(s) difference between west and northwest
(t) lower values (4.5 – 6.5) in highly coloured (humic) waters
(u) values from eastern highlands
(v) values from other highlands
(w) values from eastern lowlands
(x) values from western lowlands & northern plain
(y) values from eriss data

GBRMPA = Great Barrier Reef Marine Park Authority
AIMS = Australian Institute of Marine Science
eriss = The Environmental Research Institute of the Supervising Scientist

Table 5.2.7 Reference data supplied by Australian state and territory, and New Zealand research and regulatory organizations for deriving default guideline values for total phosphorus

Region	States	Reference values for Total Phosphorus (µg P/L)					
		Upland River	Lowland River	Lakes & Reservoirs	Wetlands	Estuaries	Marine
Southeast Australia	Victoria	19 13[a]	32	--	--	17 67[p]	22[d]
	New South Wales	20	50 25[b]	--	--	35	25
	Tasmania	13	--	10[c]	--	--	--
	Queensland (SE)	35	55	--	--	35	20
Tropical Australia	Queensland (Tropical)	10 13[h]	10 15[h]	60[k]	--	18	16[d] 12[f] 10[g]
	Northern Territory	--	10[l]	10	30 42[y]	18	--
	Western Australia (Tropical)	--	--	--	80[m]	--	20[d, o] 10[e, n] 20[e, o]
Southwest Australia	Western Australia (SW)	20[l]	65[l]	--	60[n]	30	20[d, n] 40[d, o]
South central Australia	South Australia	--	100	100	--	100	100
New Zealand	New Zealand	26	33	--	--	--	--

(a) values for alpine rivers
(b) values for coastal rivers
(c) values for World Heritage Area (WHA) pristine lakes
(d) inshore values as coastal lagoons and embayments and waters less than 20m deep
(e) offshore values
(f) values are from GBRMPA/AIMS data < 10 km offshore
(g) values are from GBRMPA/AIMS data > 10 km offshore
(h) values from north Queensland EPA
(i) values from savanna catchment
(j) values from rainforest catchment
(k) values from studies on 1 naturally turbid lake
(l) values for base flow
(m) values include river pools
(n) summer values
(o) winter values
(p) values derived from data including Port Phillip Bay
(q) values are means of ongoing study
(r) values are from unfiltered reactive phosphorus data
(s) difference between west and northwest
(t) lower values (4.5 – 6.5) in highly coloured (humic) waters
(u) values from eastern highlands
(v) values from other highlands
(w) values from eastern lowlands
(x) values from western lowlands & northern plain
(y) values from eriss data

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Table 5.2.8 Reference data supplied by Australian state and territory, and New Zealand research and regulatory organizations for deriving default guideline values for filterable reactive phosphate

Region	States	Reference values for Filterable Reactive Phosphate (µg P/L)					
		Upland River	Lowland River	Lakes & Reservoirs	Wetlands	Estuaries	Marine
Southeast Australia	Victoria	--	--	--	--	11[r]	--
	New South Wales	15	15 8[b]	--	--	4	10
	Tasmania	5	--	5 2[c]	--	--	--
	Queensland (SE)	20	25	--	--	--	--
Tropical Australia	Queensland (Tropical)	6 7[h]	3 4[h]	21[k]	--	4	5 3[f] 2.2[g]
	Northern Territory	--	5[y]	--	--	--	--
	Western Australia (Tropical)	--	--	--	--	--	4[d, n] 7[d, o] 5[e, n] 10[e, o]
Southwest Australia	Western Australia (SW)	12	40	--	--	5	5[d, n] 10[d, o] 5[e, n] 5[e, o]
South central Australia	South Australia	--	10	10	--	10	10
New Zealand	New Zealand	9	10	--	--	--	--

(a) values for alpine rivers
(b) values for coastal rivers
(c) values for World Heritage Area (WHA) pristine lakes
(d) inshore values as coastal lagoons and embayments and waters less than 20m deep
(e) offshore values
(f) values are from GBRMPA/AIMS data < 10 km offshore
(g) values are from GBRMPA/AIMS data > 10 km offshore
(h) values from north Queensland EPA
(i) values from savanna catchment
(j) values from rainforest catchment
(k) values from studies on 1 naturally turbid lake
(l) values for base flow
(m) values include river pools
(n) summer values
(o) winter values
(p) values derived from data including Port Phillip Bay
(q) values are means of ongoing study
(r) values are from unfiltered reactive phosphorus data
(s) difference between west and northwest
(t) lower values (4.5 – 6.5) in highly coloured (humic) waters
(u) values from eastern highlands
(v) values from other highlands
(w) values from eastern lowlands
(x) values from western lowlands & northern plain
(y) values from eriss data

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Table 5.2.9 Reference data supplied by Australian state and territory, and New Zealand research and regulatory organizations for deriving default guideline values for chlorophyll-*a*

Region	States	Reference values for Chlorophyll-a (µg/L)					
		Upland River	Lowland River	Lakes & Reservoirs	Wetlands	Estuaries	Marine
Southeast Australia	Victoria	3	8	8	--	1.5	0.7[d]
	New South Wales	--	3[b]	--	--	4	1
	Tasmania	--	--	3	--	2.27[q]	--
	Queensland (SE)	2	--	--	--	5	1.5
Tropical Australia	Queensland (Tropical)	0.5 0.5[h]	1.5 7[h]	4[k]	--	2.5	1 0.7[f] 0.5[g]
	Northern Territory	--	5[l] 4[y]	10	15 12[y]	2	--
	Western Australia (Tropical)	--	--	--	8[m]	--	1.4[d, n] 1.4[d, o] 0.9[e, n] 0.9[e, o]
Southwest Australia	Western Australia (SW)	--	--	--	30[o]	2.8	0.8[d, n] 0.7[d, o] 0.3[e,, n] 1.0[e, o]
South central Australia	South Australia	--	--	--	--	5	1
New Zealand	New Zealand	--	--	--	--	--	--

(a) values for alpine rivers
(b) values for coastal rivers
(c) values for World Heritage Area (WHA) pristine lakes
(d) inshore values as coastal lagoons and embayments and waters less than 20m deep
(e) offshore values
(f) values are from GBRMPA/AIMS data < 10 km offshore
(g) values are from GBRMPA/AIMS data > 10 km offshore
(h) values from north Queensland EPA
(i) values from savanna catchment
(j) values from rainforest catchment
(k) values from studies on 1 naturally turbid lake
(l) values for base flow
(m) values include river pools
(n) summer values
(o) winter values
(p) values derived from data including Port Phillip Bay
(q) values are means of ongoing study
(r) values are from unfiltered reactive phosphorus data
(s) difference between west and northwest
(t) lower values (4.5 – 6.5) in highly coloured (humic) waters
(u) values from eastern highlands
(v) values from other highlands
(w) values from eastern lowlands
(x) values from western lowlands & northern plain
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5.2.3 Guidance for deriving trigger value for nutrients from reference data at local jurisdiction level

Guidance is provided for local jurisdictions to derive reference data, which include guidelines to identify reference sites, to devise sampling protocol and to apply the trigger-based approach. Guideline packages detailing the derivation procedures, fact sheets showing more scientific information of the stressors and ecosystem-specific modifying factors and more guidelines on the steps involved in comparing ecosystem data with guideline trigger values are in stock. They can be found in the guideline package for nuisance growth of aquatic plants depicted in sections 3.1, 3.3.3 and 7.4.4.1 in Vol. 1 of the ANZCEE (2000) Guidelines.

The first step in the trigger value derivation from reference data is to identify reference sites. An outline of the procedures involved in selecting reference site is given in section 4.2.3 of this report. With respect to nutrients, the following factors of modifiers and performance indicators need to be taken into consideration :

Modifiers : depend on the ecosystem type, but will include hydraulic retention time (flows and volume of water body), mixing regimes, light regime, turbidity, temperature, suspended solids (nutrient sorption), grazing rates and type of substrate.

Performance indicators : median (or mean) concentrations of Chl-*a*, TP and TN measured under low flow conditions for rivers and streams and during low flow and high temperature periods for other ecosystem.

Recommendations : consideration of sediment nutrients which are affected by composition of the sediments (particularly the bioavailable organic matter, Fe, S, N, P, etc.), temperature, mixing regime of the water body and oxygen transfer rates.

Examples on the derivation of the nutrient trigger values for application at state level could be found from the processes of Victoria and Queensland. Relevant documents can be downloaded from their websites:

Victoria - http://www.epa.vic.gov.au/water/epa/wov.asp

Queensland - http://www.epa.qld.gov.au/environmental_management/water/water_quality_guidelines/

Table 5.2.10 and Table 5.2.11 show the water quality guideline / objectives derived by the Environmental Protection Agency of Victoria and Queensland. Only WQOs for freshwater (river and stream ecosystems) are available for Victoria while WQGs for inshore waters are available for Queensland. For Victoria, the WQOs are derived fom the 50^{th} percentiles (for substantially impacted areas) or 75^{th} percentiles (for slightly impacted areas) of the reference data. For Queensland, the WQGs (QWQG 2005) are still at the drafting stage. The WQGs are regional which are categorized into regional and sub-regional based on the biogeographic characteristics. Seven regions have been delineated, i.e. South-east Queensland, Central Queensland, Wet Tropics, Eastern Cape York, Gulf, Lake Eyre and Murray Darling. Sub-regional WQGs will be developed when sufficiently spatially data are available. The guidelines values for each region are detailed in tables in sections 2.6.1 – 2.6.7 of the QWQG document.

Table 5.2.11 shows the regional WQGs for South-east Queensland. The WQGs for slightly to moderately disturbed system are derived from the 80^{th} and/or 20^{th} percentile of a series of values from one or more reference sties following the ANZECC (2000) Guidelines.

Table 5.2.10 Nutrient water quality objectives for river and stream ecosystems adopted by Environmental Protection Agency, Victoria

Region	TN (µg/L)			TP (µg/L)		
	Reference data		WQO[(a)]	Reference data		WQO[(a)]
	50^{th}	75^{th}		50^{th}	75^{th}	
Highlands, >1000m altitude [(b)]	nd	nd	150	nd	nd	20
Open forest foothills [(c)]	187	251	350	15	24	25
Closed forest foothills [(c)]	350	490	500	14	25	25
Cleared Hills [(d)]	607	957	600	24	39	25
Coastal Plains [(d)]	620	970	600	48	86	45

nd = not detected

(a) Compliance with WQO is checked by comparing the 75^{th} percentile of annual monitoring data (12 monthly) of any given site.

(b) WQOs are based on the results from a study of the Thredbo River in Kosciusko National Park which suggested that the threshold concentrations at which no community disturbance was detected were 20µg/L for TP and 150 µg/L for TN.

(c) A study showed that the invertebrate community was clearly disturbed at 90µg/L TP and 600 µg/L TN; the biota appeared healthier yet still disturbed between 50-90 µg/L TP and 400-500 µg/L TN; the biota started to recover from disturbance at 30µg/L TP and <200 µg/L TN. The WQOs based on the 75^{th} percentiles of reference data are expected to provide adequate protection for streams of these regions.

(d) The TP WQO is the same as that for the other two forest hills regions. This is done in light of the once-forested nature of the region that would have been continuous with forest hills regions. Due to its degraded nature, the TN WQO is set close to the medium value of the reference data, in accordance with the ANZECC (2000) Guidelines. Yet for improving water quality the WQO is set as the annual 75th percentile. However, a value of 48 µg/L TP appeared too high as a WQO, as even the ‘best available’ streams in this region were in poor condition. Based on comparison with similar regions and expert judgment, an annual 75th percentile objective of 45 µg/L TP was set for coastal plains.

Table 5.2.11 Draft nutrient water quality guidelines proposed by Environmental Protection Agency, Queensland, for application to various segments of water body in the south-east Queensland (values based on local reference data and ANZECC guidelines)

Ecosystem	Area	TN (µg/L)	TP (µg/L)	PO4 (µg/L)	Turbidity (NTU)	Secchi (m)	Chl-*a* (µg/L)
High conservation value system	All	Each of the systems is treated as a separate sub-region which may contain one or more water types. Physio-chemcial guidelines values are expressed as three numbers (based on the 20th, 50th and 80th percentiles of the natural values in these waters) derived from a minimum of 24 samples collected over a period of 2 years.					
Slightly to moderately disturbed system	Upper Stream	250	30	15	25	n/a	2.0
	Lower Stream	500	50	20	50	n/a	5.0
	Upper Estuary	450	30	10	25	0.5	8.0
	Lower Estuary	300	25	6	8	1.0	4.0
	Enclosed coastal	200	20	6	6	1.5	2.0
	Open coastal	140	20	6	1	5.0	1.0
Highly disturbed system	All	No values are provided. Local level guidelines would need to be developed. Less stringent guidelines may be used based on (a) different reference data percentiles, e.g. 10th and 90th; (b) reference data from sties that are more disturbed but which are still considered to have significant ecological water; or (c) other local information.					

In assessing WQOs compliance, the two states have adopted slightly different methods, i.e. Victoria uses the 75th percentile of 12 monthly monitoring data to check against the WQOs while Queensland uses the median value. Victoria considers that a higher percentile, instead of the median, would give more information on the likely highest value. An investigation (Goudey 1999) has revealed that for 12 data points the highest percentile that can be meaningfully used with 95% confidence interval is the 75^{th}. For ensuring data reliability, it is desirable that the entire confidence interval lies within in the range of sample data. Using the 75^{th} percentile can achieve 95% certainty that the sample data at least contain the ‘true’ percentile which is being estimated.

5.3 WQO FOR NUTRIENTS (FRESHWATER AND MARINE WATER) OF THE USA

Expanded effort to reduce nutrient enrichment is one of the key elements of the action plan developed in response to the Clean Water Action Plan released in 1998. USEPA has spent considerable amount of resources in formulating a national nutrient strategy which calls for actions to prepare technical guidance manuals by USEPA headquarters and collect nutrient data for development of regional nutrient criteria using reference condition approach by States and Tribes. As a starting point, USEPA has delineated the nation into 14 nutrient ecoregions and development equivalents sets of ecoregional nutrient criteria for two groups of water bodies: lakes & reservoirs and rivers & streams. A summary of the core elements of the ecoregional criteria, namely, Total Phosphorus, Total Nitrogen, Chlorophyll-*a* and some measures of water clarity are summarized in Table 5.3.1 and Table 5.3.2.

Table 5.3.1 USEPA Ecoregional nutrient criteria for lakes and reservoirs

Aggregated Ecoregion	Total Phosphorus (µg/L)	Total Nitrogen (mg/L)	Chlorophyll-*a* (µg/L)	Secchi (m)
Agg Ecor II	8.75	0.1	1.9	4.5
Agg Ecor III	17	0.4	3.4	2.7
Agg Ecor IV	20	0.44	2.00 S	2
Agg Ecor V	33	0.56	2.30 S	1.3
Agg Ecor VI	37.5	0.78	8.59 S	1.36
Agg Ecor VII	14.75	0.66	2.63	3.33
Agg Ecor VIII	8	0.24	2.43	4.93
Agg Ecor IX	20	0.36	4.93	1.53
Agg Ecor X	8	0.46	2.79 S	2.86
Agg Ecor XII	10	0.52	2.6	2.1
Agg Ecor XIII	17.5	1.27	12.35 T	0.79
Agg Ecor XIV	8	0.32	2.9	4.5

see annotations appended below Table 5.3.2

Table 5.3.2 USEPA Ecoregional nutrient criteria for rivers and streams

Aggregated Ecoregion	Total Phosphorus (μg/L)	Total Nitrogen (mg/L)	Chlorophyll- *a* (*μ*g/L)	Turbidity FTU/NTU
Agg Ecor I	47.00	0.31	1.80	4.25
Agg Ecor II	10.00	0.12	1.08	1.30 N
Agg Ecor III	21.88	0.38	1.78	2.34
Agg Ecor IV	23.00	.56	2.40	4.21
Agg Ecor V	67.00	.88	3.00	7.83
Agg Ecor VI	76.25	2.18	2.70	6.36
Agg Ecor VII	33.00	0.54	1.50	1.70 N
Agg Ecor VIII	10.00	0.38	063	1.30
Agg Ecor IX	36.56	0.69	0.93 S	5.70
Agg Ecor X	128 *	0.76	2.10 S	17.50
Agg Ecor XI	10.00	0.31	1.61 S	2.30 N
Agg Ecor XII	40.00	0.90	0.40 S	1.90 N
Agg Ecor XIV	31.25	0.71	3.75 S	3.04

* This value appears inordinately high and may either be a statistical anomaly or reflects a unique condition. In any case, further regional investigation is indicated to determine the sources, i.e., measurement error, notational error, statistical anomaly, natural enriched conditions, or cultural impacts.

Chlorophyll-*a* measured by Fluorometric method, unless specified. S is for Spectrophotometric and T is for Trichromatic method. N for NTU, unit of measurement for Turbidity.

In the past years, USEPA concentrated her effort in collecting nutrient data from rivers, streams, lakes and reservoirs. Building on the established foundation, USEPA has now switched the focus to cover also wetland, estuarine and coastal areas. Accelerated efforts are being spent to collect reference data from these ecosystem types. Up-to-date summary tables of the ecoregional criteria and guidance manuals for ecoregions to develop criteria are available at the following USEPA websites:

http://www.epa./water/criteria/nutrient/ecregions/ for a summary of nutrient criteria;

http://www.epa.gov/waterscience/criteria/nutrient/guidance/ for general use according to different water body type;

http://www.epa.gov/waterscience/criteria/nutrient/guidance/marine/ for guidance especially for estuarine and coastal marine waters.

5.3.1 Overview of the approach

Nutrient criteria development cannot follow what has been traditionally done for toxic pollutants. The adverse effects of nutrients are strongly affected by regional and seasonal conditions and their effects are ultimately expressed on ecoystems as a whole. The criteria are developed on an ecoregional (water body-type and region) basis using a reference condition approach. Available data from water bodies in each ecoregion are collected to determine a best estimate of minimally impacted conditions. USEPA recommends to use the 75th percentile of a distribution of reference condition values as the target condition of a minimally impacted site. Reference condition waters that exceed criteria based on the 75th percentile are good candidates for site-specific criteria. As information about "minimally impacted sites" are unavailable on a national scale, alternatively, USEPA recommends to use the 25th percentile of a distribution of sample from the entire population of water bodies within a given physical classification (e.g. an ecoregion).

To assist States and Tribes to develop their own nutrient criteria with incorporation of site-specific conditions, USEPA has published in the guidance manual a framework illustrating the development procedures. Figure 5.3.1 presents a schematic illustration of the key steps involved and Annex 23 shows an outline with more details for the development of nutrient criteria. Once the needs and goals have been identified which are often associated with resolving over-enrichment problems, then a Regional Assistance Group (RTAG) will be established to assess and consider scientific and management issues. Data collection will be carried to build up the database of the selected criteria variables according to a defined protocol. When the data are available, they are then analyzed following steps involving the following elements:

- examination of the historical record or paleoecological evidence of a trend;
- determination of a reference condition;

- use of empirical modeling or surrogate datasets;
- objective and comprehensive interpretation of all information by a panel of specialists;
- development of criterion of each variable.

An action plan is then established to implement and assess attainment with the developed criteria. A more detailed description of the procedures involved has been included in the Phase 2 Report of this project. To better illustrate the procedures and the rationale behind, the development of nutrient criteria for Chesapeake Bay is taken as an example. The USEPA Region III has developed water quality criteria for dissolved oxygen, chlorophyll-*a* and water clarity for application in the Bay watershed. These criteria variables are considered as the best and most direct measure of the impacts of nutrients and sediment pollution on the Bay's aquatic living resources – fish, crabs, oyster and bay grasses.

A summarized account of the guidance procedures developed by USEPA Region III to guide the Bay states in adopting water quality standards in addressing nutrient problems is provided in the following section.

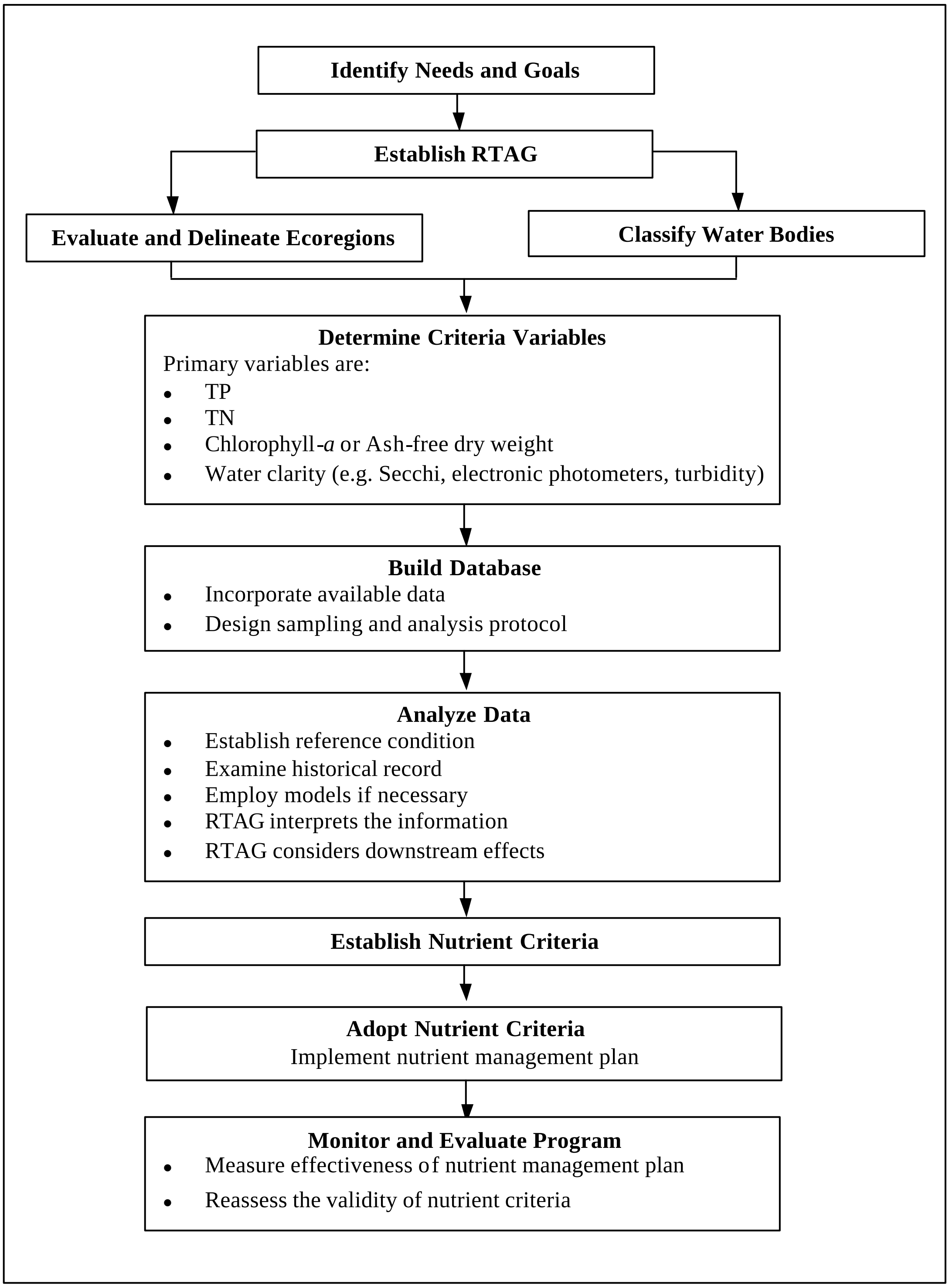
5.3.2 Development of nutrient criteria for Chesapeake Bay

5.3.2.1 The nutrient reduction goal and designated uses

National water quality inventories have repeatedly shown that nutrients are a major cause of water quality impairment along the Gulf and eastern coast, including the Chesapeake Bay and its tidal tributaries. Current designated uses applied to the Bay and tributaries water do not fully reflect natural conditions and are too broad in their definition of 'use'. Moreover, the uses change across jurisdictional borders in the same body of water. To achieve and maintain the water quality conditions to support aquatic resources in the Bay, the six Bay states, District of Columbia and USEPA in 2000 entered into an agreement stipulated below :

> *"by 2010, correct the nutrient- and sediment-related problems in the Chesapeake Bay and its tidal tributaries sufficiently to remove the Bay and tidal portions of its tributaries from the list of impaired waters under the Clean Water Act".*

Figure 5.3.1 Schematic diagram of the nutrient criteria development process (Source : USEPA)



Against this backdrop of a commitment to restore Bay water quality, it was recommended that the designated uses needed refinement. The jurisdictions concerned took into account five principal considerations in the designated use refinement :

- habitats used in common by sets of species and during particular life stages should be delineated as separate designated uses;
- natural variations in water quality should be accounted for by the designated uses;
- seasonal uses of different habitats should be factored into the designated uses;
- the Chesapeake Bay criteria for dissolved oxygen, water clarity and chlorophyll-*a* should be tailored to support each designated use; and
- the refined designated uses applied to the Bay and its tidal tributaries will support the federal Clean Water Act and goals of uses existing in these water since 1975 and for potential uses not currently met.

With the principal considerations in mind, five tidal-water designated uses were proposed and developed to account for the different tidal water habitats which base themselves on water depth, salinity and season. Descriptions of the five uses are tabulated in Table 5.3.3

5.3.2.2 Chesapeake Bay dissolved oxygen criteria

Derivation of the dissolved oxygen criteria for Chesapeake Bay tidal-water beneficial uses (see Table 5.3.3) followed three sources of information : (i) the methodologies outlined in EPA's Guidelines for Deriving Numerical National Water Quality for the Protection of Aquatic Organisms and their Uses (USEPA 1985), (ii) the risk-based approach used in the developing the Ambient Aquatic Life Water Quality Criteria for Dissolved Oxygen (Saltwater) : Cape Cod to Cape Hatteras (USEPA 2000), and (iii) the Biological Evaluation on the CWA 304(a) Aquatic Life Criteria as part of the National Consultations, Methods Manual (USEPA, US Fish and Wildlife Service and NOAA National Marine Fisheries Service, in draft).

Table 5.3.3 General descriptions of the five Chesapeake Bay tidal-water designated uses

	Designated Use	Description	Applicable Criteria	Application
1.	Migratory Fish Spawning and Nursery	Aims to protect migratory finfish during the late winter/spring spawning and nursery season in tidal freshwater to low-salinity habitats. This habitat zone is primarily found in the upper reaches of many Bay tidal rivers and creeks and the upper mainstream of Chesapeake Bay and will benefit several species including striped bass, perch, shad, herring and sturgeon.	Dissolved Oxygen	February 1 through May 31
2.	Shallow-water Bay Grass	Aims to protect underwater bay grasses and the many fish and crab species that depend on the shallow-water habitat provided by grass beds.	Water Clarity	April 1 through October 31 for tidal-fresh, oligohaline and mesohaline habitats (0 –18 ppt salinity) March 1 through May 31 and September 1 through November 30 for polyhaline habitats (>18 ppt salinity)
3.	Open-water Fish and Shellfish	Aims to protect water quality in the surface water habitats within tidal creeks, rivers embayments and the mainstream of Chesapeake Bay year-round. This use aims to protect diverse populations of various sportfish, including striped bass, bluefish, makceral and seatrout, bait fish such as menhadena and silversides, as well as the listed shortnose sturgeon.	Dissolved Oxygen Chlorophyll-*a*	Year-round March 1 through May 31 and July 1 through September 30
4.	Deep-water Seasonal Fish and Shellfish	Aims to protect living resources inhabiting the deeper transitional water column and bottom habitats between the well-mixed surface waters and the very deep channels during the summer months. This use protects many bottom-feeding fish, crabs and oysters, as well as other important species, including the bay anchovy.	Dissolved Oxygen	June 1 through September 30
5.	Deep-channel seasonal refuge	Aims to protect bottom sediment-dwelling worms and small clams that act as food for bottom-feeding fish and crabs in the very deep channel in summer. The deep-channel designated use recognizes that low dissolved oxygen conditions prevail in the deepest portions of this habitat zone and will naturally have very low to no oxygen during the summer.	Dissolved Oxygen	June 1 through September 30

The saltwater dissolved oxygen criteria, which address three areas of protection, i.e. juvenile and adult survival, growth effects and larval recruitment effects, put focus on protection of species in different life stages but it has not been designed to address natural variation in dissolved oxygen concentrations from surface waters to greater water-column depths. For Chesapeake Bay criteria, the derivation has made use of application of the saltwater criteria and the application of both USEPA published traditional toxicological and new biological-based methodologies.

The derivation follows the normal procedures as stated in the EPA guidelines by looking at the adverse effect of hypoxia on different life stages of species in the Bay. This involves an extensive review of literature research and recalculation of growth and larval recruitment effect thresholds for different designated uses by following the methods defined in the saltwater dissolved oxygen criteria guidelines. Several conclusions drawn from the available test data and literature findings that form the base of criteria derivation were:

- Dissolved oxygen criteria for freshwater and saltwater were referenced to ensure consistency with national USEPA guidelines (see Table 4.3.1and Table 4.4.1). Where necessary, the criterion values with respect to protection of juvenile and adult survival (i.e. CMC); protection of growth effects (i.e. CCC) and protection of larval recruitment effects were recalculated using Bay-specific species.
  - ⇨ The recalculated criterion minimum concentration (CMC) using Bay-specific species was found to be 2.24 mg/L which was very close to the USEPA national saltwater criterion value of 2.27 mg/L.
  - ⇨ The recalculated criterion continuous concentration (CCC) using Bay-specific species was 5 mg/L which was also close to the 4.8 mg/L national value.
  - ⇨ The recalculated dissolved oxygen concentrations for protection against egg/larval recruitment effects greater than 5% were 1.7 mg/L at all times and 3 mg/L for 30 days.
- A minimum of 5% cumulative reduction in larval seasonal recruitment due to exposure to low oxygen conditions was applied in the Bay-specific larval recruitment effects models.
- In accounting for regional species effects, tests at stressful temperatures and using invertebrates from northern and southern part of the Bay were conducted. Exposure-response relationships were found similar.
- Effect data used in the derivation showed no evidence for a temperature effect on sensitivity to hypoxia over the range of 20°C to 30°C.
- Estuarine species were tolerant of a wide range of salinities but the effect data used in the saltwater criteria were tested at salinities >15 ppt. To

bridge the gap, the freshwater national criteria of 30-day of 5.5 mg/L and 7-day mean of 4.0 mg/L were applied for the protection of open-water fish and shellfish use.

- Protection of threatened or endangered species in the Bay from effect of low dissolved oxygen was mandatory. Specific criteria were needed to derive for the only federally listed endangered species in the Bay, i.e. shortnose sturgeon. Documented evidence showed that short-term exposure (several hours) to dissolved oxygen >3.2 mg/L and long-term exposure (>30 days) to dissolved oxygen > 5 mg/L would protect the survival and growth of shortnose sturgeon.

- Literature findings showed that exposure to bottom habitats to brief period of dissolved oxygen <2 mg/L would result in adverse effects on behaviour, growth and production. The setting of a WQC at 1 mg/L instantaneous minimum would offer protection against lethal effects during June to September. This would be counterbalanced by growth during the rest of the year when dissolved oxygen are naturally > 1 mg/L.

Table 5.3.4 shows the Chesapeake Bay dissolved oxygen criteria for protection of the five tidal-water designated uses and reflection of the needs and habitats of Bay estuarine living resources.

5.3.2.3 Chesapeake Bay water clarity criteria

The derivation of the water clarity criteria was based on the level of light penetration required to support the survival, growth and repropagation of underwater bay grasses or submerged aquatic vegetation (SAV). The criteria are summarized in Table 5.3.5 as percent light-through-water (PLW) and Secchi depth equivalents over a range of application depths for four salinity regimes[3]. They are set as the minimum light requirements to protect SAV found in two sets of salinity regimes that have different growth and reproductive strategies and individual light requirements. In tidal-fresh and oligohaline habitats, the water clarity criteria address the minimum requirements of meadow-forming species which generally need more light as well as canopy-forming which require less. In mesohaline and polyhaline habitats, the criteria aim to protect two principal species – widgeon grass and eelgrass.

[3] Salinity regime is to delineate an estuary by the amount of tidal influence and salinity of the water. The regimes from least saline to most saline are :

- Tidal fresh – 0 < salinity > 0.5 ppt. At the extreme reach of tidal influence.
- Oliogaline – 0.5 < salinity > 5 ppt. In the upper portion of an estuary.
- Mesohaline – 5 < salinity > 18 ppt. In the middle portion of an estuary.
- Polyhaline – 18 < salinity > 30 ppt. In the lower portion of an estuary where the ocean and estuary meet.

Table 5.3.4 Chesapeake Bay dissolved oxygen criteria

Designated Use	Criteria Concentration/Duration	Protection Provided	Temporal Application
Migratory fish spawning and nursery use	7-day mean ≥ 6 mg/L (tidal habitats with 0-0.5 ppt salinity)	Survival/growth of larval/juvenile tidal-fresh resident fish; protective of threatened/endangered species.	February 1 - May 31
	Instantaneous minimum ≥ 5 mg/L	Survival and growth of larval/juvenile migratory fish; protective of threatened/endangered species.	
	Open-water fish and shellfish designated use criteria apply		June 1 - January 31
Shallow-water bay grass use	Open-water fish and shellfish designated use criteria apply		Year-round
Open-water fish and shellfish use	30-day mean ≥ 5.5 mg/L (tidal habitats with 0-0.5 ppt salinity)	Growth of tidal-fresh juvenile and adult fish; protective of threatened/endangered species.	Year-round
	30-day mean > 5 mg/L (tidal habitats with 0.5 ppt salinity)	Growth of larval, juvenile and adult fish and shellfish; protective of threatened/endangered species.	
	7-day mean ≥ 4 mg/L	Survival of open-water fish larvae.	
	Instantaneous minimum ≥ 3.2 mg/L	Survival of threatened/endangered sturgeon species. *	
Deep-water seasonal fish and shellfish use	30-day mean ≥ 3 mg/L	Survival and recruitment of bay anchovy eggs and larvae.	June 1 - September 30
	1-day mean ≥ 3 mg/L	Survival of open-water juvenile and adult fish.	
	Instantaneous minimum ≥ 1.7 mg/L	Survival of bay anchovy eggs and larvae.	
	Open-water fish and shellfish designated-use criteria apply		October 1 - May 31
Deep-channel seasonal refuge use	Instantaneous minimum ≥ 1 mg/L	Survival of bottom-dwelling worms and clams.	June 1 - September 30
	Open-water fish and shellfish designated use criteria apply		October 1 - May 31

* At temperatures considered stressful to shortnose sturgeon (>29 ℃), dissolved oxygen concentrations above an instantaneous minimum of 4.3 mg/L will protect survival of this listed sturgeon species

Table 5.3.5 Summary of Chesapeake Bay water clarity criteria for application to shallow-water bay grass designated use habitats (application depths given in 0.25 meter depth intervals *).

Salinity Regime	Water Clarity Criteria as Percent Light-through -Water	Water Clarity Criteria as Secchi Depth								Temporal Application
		Water Clarity Criteria Application Depths								
		0.25	0.5	0.75	1.0	1.25	1.5	1.75	2.0	
		Secchi Depth (meters) for above Criteria Application Depth								
Tidal-fresh	13%	0.2	0.4	0.5	0.7	0.9	1.1	1.2	1.4	April 1 - October 31
Oligohaline	13%	0.2	0.4	0.5	0.7	0.9	1.1	1.2	1.4	April 1 - October 31
Mesohaline	22%	0.2	0.5	0.7	1.0	1.2	1.4	1.7	1.9	April 1 - October 31
Polyhaline	22%	0.2	0.5	0.7	1.0	1.2	1.4	1.7	1.9	March 1 - May 31, September 1 - November 30

* Base on application of equation: PLW = 100exp(-K_dZ), the appropriate PLW criterion value and the selected application depth are inserted and the equation is solved for K_d. The generated K_d value is then converted to Secchi depth (in meters) using the conversion factor K_d = 1.45/Secchi depth.

Two synthesis of technical information (Batiuk et al. 1992, Batiuk et al. 2000) specifying the quantitative habitat requirements for the bay grasses along with research and field studies, model simulation and data validation provide the scientific foundation for the criteria derivation. The first synthesis of information is available for purchase and the second synthesis for download at the following website :

first synthesis : http://yosemite.epa.gov/water/owrccatalog.nsf/0/a5cc554789c119c285256b060072322a?OpenDocument
second synthesis : http://www.chesapeakebay.net/pubs/sav/index.html

The water clarity criteria were derived in four stages :

(i) determining water column-based light requirements for underwater bay grass survival and growth;

(ii) quantifying factors contributing to water-column light attenuation;

(iii) factoring contributions from epiphytes to light attenuation at the leaf surface into methods for estimating and diagnosing the components of total light attenuation;

(iv) determining a set of minimal requirements for light penetration through the water and at the leaf surface to give the water clarity criteria values.

The principal relationships between water quality conditions and light regimes for the growth of underwater bay grass are revealed in terms of light from its incidence to reaching the grass. The light is attenuated when traveling through the water column by particulate matter, organic matter and by water itself. Figure 5.3.2 shows a conceptual diagram of the phenomenon of light attenuation through the water column.

The first synthesis of information published in 1992 defined submerged aquatic vegetation habitat requirements in terms of dissolved inorganic nitrogen, dissolved inorganic phosphorus, water column light attenuation coefficient, Chlorophyll-*a* and total suspended solids based on field correlations between SAV presence and water quality conditions. However, the 1992 habitat requirements were found to contain several limitations restricting their use. A new approach was then defined in the second synthesis using two parameters, the percent-light-through-water (PLW)[4] and the percent-light-at-the-leaf (PLL)[5] based on Beer's Law, which allowed more flexibility in adjusting the criteria for variations in tidal range or for different SAVE restoration depths.

The Beer's Law is defined as : $I_z = I_0 \exp(-K_d Z)$

where I_0 = light (photosynthetically active radiation (PAR) measured just below the surface

I_z = light measure at depth Z

K_d = water-column light attenuation coefficient

Figure 5.3.3 illustrates the input, calculation and evaluation of the two percent light parameters. Based on the conceptual model illustrated by the figure and an extensive review of the scientific literature, the original 1992 K_d habitat requirements were validated and redefined as the "water-column light requirements" as shown in Table 5.3.6.

In most estuarine environments, light attenuation through water column is dominated by contributions from chlorophyll-*a* and total suspended solids. Whereas, light reaching the leaf surface is attenuated by the epiphytic materials (i.e. algae, bacteria, detritus and sediment) that accumulate on the leaves. An algorithm has been developed to compute the biomass of both algae and other materials attached to SAV leaves and to estimate light attenuation associated with these materials. This algorithm uses monitoring data for K_d (or Secchi Depth), total suspended solids, dissolved inorganic nitrogen and dissolved inorganic phosphorus to calculate the potential contribution of epiphytic materials to total light attenuation for SAV at a particular depth.

4 Percent-light-through-water (PLW) is the percent amount of ambient sub-surface light absorbed or reflected by water itself, water colour caused by dissolved organic materials, suspended organic and sediment particles, and phytoplankton in the water column down to the sediment surface at the restoration depth selected.

5 Percent-light-at-the-leaf (PLL) is the percent amount of the ambient light that actually reaches the bay grass leaf at the restoration depth selected.

Figure 5.3.2 Availability of light for underwater bay grass is influenced by water-column and at-the-leaf surface light attenuation processes. DIN = dissolved inorganic nitrogen and DIP = dissolved inorganic phosphorus (Source : USEPA 2003b).

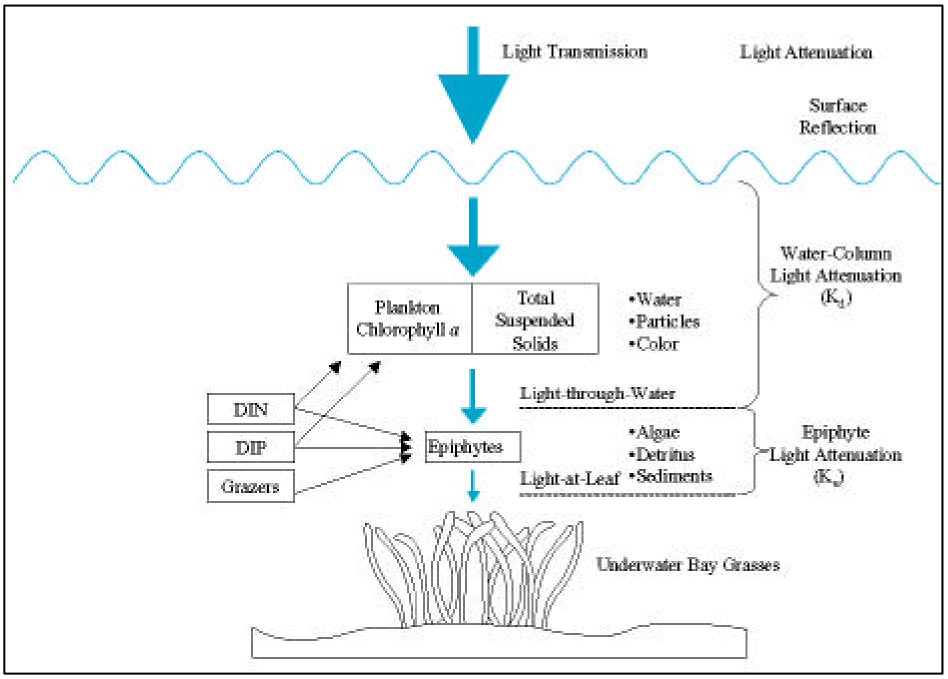


Figure 5.3.3 Illustration of the relationships between the two percent-light-parameters : percent light-through-water (PLW) and percent light-at-the-leaf (PLL) (Source : USEPA 2003b).

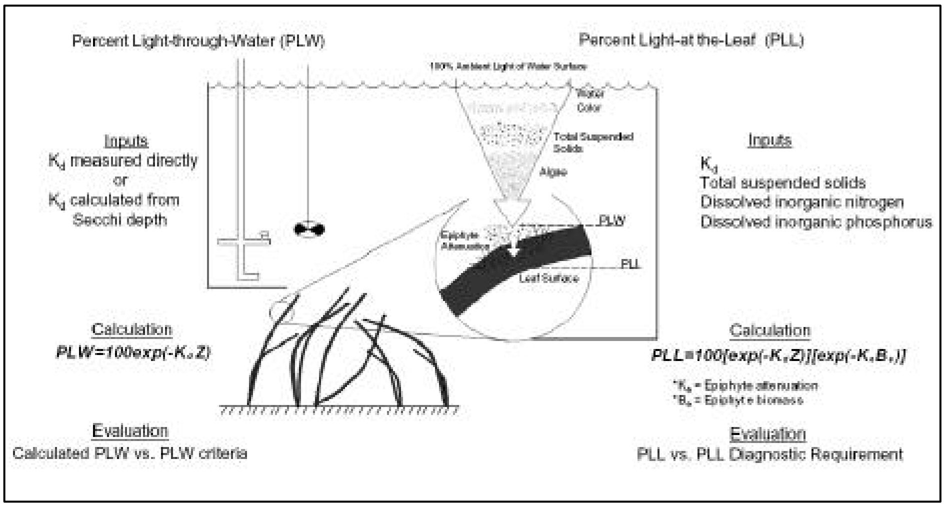


Table 5.3.6 Recommended primary and secondary SAV habitat requirements for Chesapeake Bay and Tidal Tributaries.

	PRIMARY REQUIREMENTS [1]	SECONDARY REQUIREMENTS [2] (Diagnostic Tools)					
Salinity Regime [3]	**Minimum Light Requirement**	**Water Column Light Requirement [4]**	**Total Suspended Solids (mg/l)**	**Chlorophyll-a, (µg/l)**	**Dissolved Inorganic Phosphorus (mg/l)**	**Dissolved Inorganic Nitrogen (mg/l)**	**SAV Growing Season [5]**
Tidal fresh	>9%	>13%	<15%	<15%	<0.02	none	April - October
Oligohaline	>9%	>13%	<15%	<15%	<0.02	none	April - October
Mesohaline	>15%	>22%	<15%	<15%	<0.01	<0.15	April - October
Polyhaline	>15%	>22%	<15%	<15%	<0.02	<0.15	March - May and September-November

NOTE: All the habitat requirements are independent of restoration depth Z, which is used in calculating percent light at the leaf (PLL) and percent light through water (PLW).

[1] Use the primary requirement, or minimum light requirement, whenever data are available to calculate PLL (which requires light attenuation coefficient [K_d] or Secchi depth, dissolved inorganic nitrogen, dissolved inorganic phosphorus and total suspended solids measurement). The attainment of the minimum light requirement is tested with PLL data to see if an area has water quality that is suitable for SAV growth. There is no equivalent K_d value for PLL, since other parameters are used in calculating it.

[2] The secondary requirements are diagnostic tools used to determine possible reasons for no attainment of the primary requirement (minimum light requirement) in areas with or without SAV. The water-column light requirement can also be a substitute for the minimum light requirement when data required to calculate PLL are not fully available.

[3] Tidal fresh =<0.5 ppt; oligohaline = 0.5-5 ppt; mesohaline = >5-18 ppt; and polyhaline = >18 ppt.

[4] Use the secondary light requirement, or water-column light requirement, whenever data are not available to calculate PLL, or as a diagnostic tools in conjunction with PLL. Equivalent K_d habitat requirement values can be calculated for different restoration depths Z using K_d = -In(PLW/100)Z.

[5] Date used to calculate any of the habitat requirements should be collected during these growing seasons in Chesapeake Bay, or during the local SAV growing season in other estuaries.

Sources for secondary requirements: Batiuk et al. 1992; Dennison et al. 1993.

From the latest approach, the values for the minimum light requirements (PLW) were first based on research and field findings using 1992 PLW requirements for $K_d = 1.5m^{-1}$ for mesohaline and polyhaline segments, and $2m^{-1}$ for tidal-fresh and oligohaline segments for the restoration of SAV to a depth of 1m through the Chesapeake Bay. The PLW values were calculated to be 22% and 13.5% which were supported by results of shading experiments and model findings[6]. The proposed values were then checked with the results of three lines of evidence: (i) calculating the PLL values using the 1992 habitat requirements for K_d, dissolved inorganic nitrogen, dissolved inorganic phosphorus and total suspended solids, (ii) accounting for epiphytic light attenuation, and (iii) comparison with field conditions. A summary of the findings is given in Table 5.3.7 below.

Table 5.3.7 Summary of the findings in the comparison of proposed water quality criteria with three lines of evidence

Salinity Regime	Proposed Minimum Light Requirement (PLW)	Proposed Water clarity criteria (PLW) based on the 1992 specified K_d	Lines of evidence		
			(i) PLL as calculated by using the 1992 requirements for other parameters	(ii) 1992 PLW after 30% light attenuation by epiphytic materials	(iii) comparison with field conditions
Tidal fresh	>9%	13.5%	8.3%	13%	Near shore water quality data and SAV growth showed good relationship with the minimum light requirement.
Oliogaline	>9%	13.5%	8.3%	13%	
Mesohaline	>15%	22%	17.3%	22%	
Polyhaline	>15%	22%	13.5%	22%	

The calculated percent light-at-the-leaf requirements as revealed in the first line of evidence well agreed with the proposed PLW but it had not factored in the shading effects of epiphytes. Several studies have indicated that light attenuation by epiphytic communities tends to contribute an additional 15% to 50% shading on SAV. A 30% light attenuation was assumed in the criteria derivation based on monitoring data. Recalculating the PLW by taking into this additional factor, the results were found 13% and 22% for the two sets of salinity segments. Upon further validation medians of the water quality monitoring data were assessed for relationships between calculated PLL values, SAV growth and the proposed minimum light requirements of 9% and 15%.

[6] A water-column light target of >20% was found needed for Chesapeake Bay polyhaline and mesohaline species; and a light requirement of 13% for tidal fresh and oligohaline species.

The calculated PLL values from observed water quality conditions were found either all very close to or well above the minimum light requirement.

Water clarity criteria in terms of percent light-through-water (PLW) requirements were validated through a comprehensive analysis of 13 years of water quality monitoring data. Although light is the principal factor governing the distribution and growth of SAV, other factors like availability of propagules, salinity, temperature, water depth, tidal range, grazers, suitable sediment quality may preclude the growth of SAV. However, a wealth of scientific evidence indicates that not attaining the water clarity criteria at the desired restoration depth will prevent or severely reduce survival and propagation of SAV regardless of the status of other environmental factors.

5.3.2.4 Chesapeake Bay Chlorophyll-*a* criteria

USEPA has developed a narrative chlorophyll-*a* criterion applicable to all Chesapeake Bay and tidal tributary waters through a review of other States' water quality standards. The criterion is defined as :

> *Concentration of chlorophyll-a in free-floating microscopic aquatic plants (algae) shall not exceed levels that result in ecologically undesirable consequences – such as reduced water quality, low dissolved oxygen, food supply imbalances, proliferation of species deemed potentially harmful to aquatic lie or humans or aesthetically objectionable conditions – or otherwise render tidal waters unsuitable for designated uses.*

Because of the regional and site-specific nature of algal-related water quality impairment, USEPA has not published any baywide numerical criteria but provided information as a reference for States to use or derive site-specific criteria. Included in the technical document (USEPA 2003a) are several approaches that can be used for deriving numerical criteria. These criteria are to be applied to tidal waters in which algal-related designated use impairments are likely to persist even after attainment of the applicable dissolved oxygen and water clarity criteria. Approaches include historical records, phytoplankton reference communities, trophic classification, harmful species, water quality factors, contribution to low dissolved oxygen conditions. In this report, the first two approaches are discussed in depth due to the availability of abundance information detailing the derivation. For more details on the latter approaches, readers can refer to Chapter V of the technical document (USEPA 2003a).

Historical Records Approach

The historical records approach involved analysis of decades of monitoring data. Two different analysis methods were used in this approach: the concentration trends method by Harding and Perry (1997) and the benchmark level method by Olson (2002). Harding and Perry (1997) documented significantly trends in Chlorophyll-*a* concentrations during the past several decades in the Chesapeake mainstem which had been delineated into six regions according to salinity (Table 5.3.8 and Figure 5.3.4).

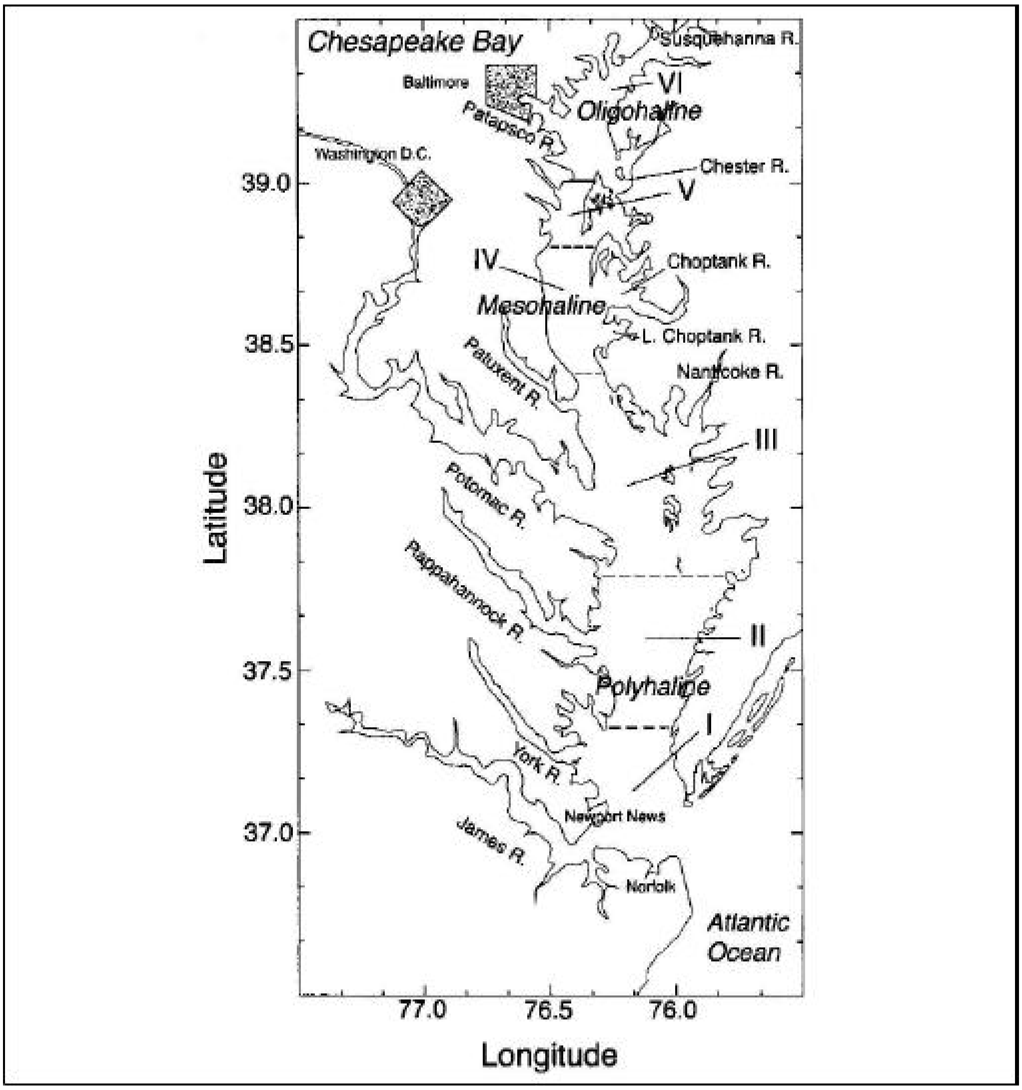
Table 5.3.8 Chesapeake Bay mainstem surface chlorophyll-a concentration (µg/L), annual means for 1950 to 1994.

Tine Period	Region	Chlorophyll-a Annual Mean	Number of Observations	Percent Difference[1]
1950-1995	I	0.46	41	-
	II	1.21	18	-
	III	3.58	108	-
	IV	4.33	7	-
	V	3.19	15	-
	VI	2.51	18	-
1960-1969	I	1.89	8	310
	II	2.61	9	115
	III	7.09	28	98
	IV	7.48	58	73
	V	7.79	97	144
	VI	15.59	295	521
1970-1979	I	4.39	101	853
	II	6.89	31	468
	III	7.95	100	122
	IV	7.29	206	68
	V	13.12	324	311
	VI	12.90	845	414
1985-1994	I	5.49	1862	1093
	II	7.40	2350	510
	III	8.03	1261	124
	IV	8.20	1022	89
	V	10.86	1164	240
	VI	5.57	1005	122

[1] Percent difference of annual mean Chlorophyll-*a* concentration for each region is based upon a comparison with the corresponding Chlorophyll-*a* concentration in 1950-1959.

Source: Harding and Perry 1997.

Figure 5.3.4 The Chesapeake Bay showing locations of the six regions chosen in the historical trends analysis



Olson (2002) used data in the same period and calculated the decadal spring, summer and annual median chlorophyll-*a* across five decades. Benchmark concentrations were derived from a set of data from 1985 to 1996. Each datum was categorized according to the 4 salinity regimes based on the accompanying salinity data. For each station and depth layer, the data were averaged by month within year and within a each salinity regime, the 5th and 95th percentiles were calculated. These two percentiles were empirical endpoints representing the extremes of "good" and "bad". This constitutes the benchmark data set (Table 5.3.9) for ranking a specific condition into three grades : "good", "fair" and "bad". The benchmarks were applied to the entire 1950s through 1990s data set by scoring each datum from the most recent 3 years relative to the benchmarks : each datum was first categorized according to its associated salinity and scored as a percentage (1 to 100) of the distance between the benchmark endpoints for that salinity regime. A composite score for the station or the segment status was obtained by finding the median monthly score. However, this method yielded unequal distribution of the ranking which might be to wrong assumption that the measurements could be partitioned into three status of "good", fair" and "poor".

Table 5.3.9 Historical chlorophyll-*a* concentration (µg/L) derived through applying relative status benchmark data.

Season	Salinity Zone	Chlorophyll-*a* Median	Chlorophyll-*a* Mean	Chlorophyll-*a* 90th percentile	Number of Observations
Annual	Tidal-Fresh	3.1	4.2	10.2	972
	Oligohaline	4.7	6.0	10.8	910
	Mesohaline	7.3	7.2	10.9	4192
	Polyhaline	4.4	4.3	7.0	1132
Spring	Tidal-Fresh	3.1	3.7	4.2	488
	Oligohaline	5.1	5.9	9.8	279
	Mesohaline	6.9	7.2	11.0	708
	Polyhaline	3.4	4.1	12.9	91
Summer	Tidal-Fresh	7.3	7.0	8.7	423
	Oligohaline	8.0	7.6	10.8	566
	Mesohaline	8.4	7.9	11.1	1677
	Polyhaline	4.3	3.7	6.0	341

Phytoplankton Reference Community Approach

In this approach, the seasonal and salinity-specific reference communities were used to quantity chlorophyll-*a* concentrations in the least-impaired water quality conditions found in the Chesapeake Bay. For the purpose of deriving reference phytoplankton communities, the least impaired water quality conditions were defined as the co-occurrence of high light penetration, low dissolved inorganic nitrogen (DIN) and low dissolved inorganic phosphorous ($DIPO_4$) concentrations. Low DIN and ($DIPO_4$) concentrations were below the threshold concentrations shown to limit phytoplankton growth in (Fisher et al. 1999) whereas high light penetrations were the Secchi depth values identified as 'good' (Olson 2002). Table 5.3.10 shows the classification criteria in terms of DIN, DIPO4 and Secchi depth for summer and spring.

Water quality and phytoplankton data[7] between 1984 and 2001 were analyzed and grouped into six categories according to the grouping criteria (see Table 5.3.11). The ranges of chlorophyll-*a* concentrations (5^{th} – 95^{th} percentile) observed in the phytoplankton reference communities indicate the peak concentrations that should be expected in population currently inhabiting unimpaired waters (see Table 5.3.12). chlorophyll-*a* above these peak values constitute excess phytoplankton production fueled by high nutrients concentrations and are potentially harmful to the Chesapeake Bay ecosystem.

These data should be used with caution as they were selected from samples subject with least-improved water quality which came from generally nutrient- and sediment-enriched waters. Under better water quality conditions, the chlorophyll-*a* values might be lower. This approach does not show any direct relationship between chlorophyll-*a* concentration and designated use impairments but it is able to show the likely trend in chlorophyll-*a* concentration as water quality improves. chlorophyll-*a* concentrations do not always show a high correlation with algal biomass because after a bloom, some species of non chlorophyll-*a*–bearing phytoplankton can feed on organic material (Livingston 2001).

[7] Phytoplankton parameters measured : chlorophyll-*a*, pheophytin, species abundances, biomasses of individual in the nano (2 – 20 micron) and micro (20 – 200 micron) size fractions, phytoplankton biomass in pico (< 2 micron) size fractions, average cell size of the nano-micro phytoplankton and the ratio of phytoplankton biomass (as carbon) to chlorophyll-*a*.

Table 5.3.10 Classification criteria for determining 'worst', 'poor', 'better' and 'best' water quality parameter conditions

Spring (March through May)								
Parameter		Selected Spring Classification Criteria				Relative Status Method		
		Worst	Poor	Better	Best	25th%	median	75th%
Secchi	TF	<0.7	=<0.9	>0.9	>1.1	*0.7*	*0.9*	*1.10*
Secchi	OH	<0.5	=<0.7	>0.7	>1.1	*0.5*	*0.7*	*1.10*
Secchi	MH	<1.35	=<1.8	>1.8	>2.25	*1.35*	*1.80*	*2.25*
Secchi	PH	<1.6	=<2.15	>2.15	>2.55	*1.6*	*2.15*	*2.55*
		Worst	Poor	Better	Best	25th%	median	75th%
DIN	TF	>.585	>0.070	=>0.070	<0.030	*.585*	*.434*	*.290*
DIN	OH	>.885	>0.070	=>0.070	<0.030	*.885*	*.680*	*.464*
DIN	MH	>.265	>0.070	=>0.070	<0.030	*.265*	*.150*	*.070*
DIN	PH	>.070	>0.070	=>0.070	<0.030	*.063*	*.020*	*.011*
		Worst	Poor	Better	Best	25th%	median	75th%
PO_4 (SRP)	TF	>0.020	>0.003	=<0.003	=<0.003	*.020*	*.136*	*.010*
PO_4 (SRP)	OH	>0.010	>0.003	=<0.003	=<0.003	*.010*	*.005*	*.004*
PO_4 (SRP)	MH	>0.003	>0.002	=<0.002	=<0.002	*.003*	*.002*	*.0006*
PO_4 (SRP)	PH	>0.005	>0.003	=<0.003	=<0.003	*.005*	*.004*	*.0007*

Summer (July though September)								
Parameter		Selected Summer Classification Criteria				Relative Status Method		
		Worst	Poor	Better	Best	25th%	median	75th%
Secchi	TF	<0.6	=<0.8	>0.8	>1.0	*0.6*	*0.8*	*1.0*
Secchi	OH	<0.55	=<0.6	>0.6	>0.7	*0.55*	*0.6*	*0.7*
Secchi	MH	<1.2	=<1.45	>1.45	>1.7	*1.2*	*1.45*	*1.7*
Secchi	PH	<1.55	=<1.85	>1.85	>2.35	*1.55*	*1.85*	*2.35*
		Worst	Poor	Better	Best	25th%	median	75th%
DIN	TF	>.390	>0.070	=>0.070	<0.030	*.390*	*.240*	*.125*
DIN	OH	>.090	>0.070	=>0.070	<0.030	*.090*	*.050*	*.028*
DIN	MH	>.074	>0.070	=>0.070	<0.030	*.074*	*.035*	*.014*
DIN	PH	>.070	>0.070	=>0.070	<0.030	*.028*	*.011*	*.008*
		Worst	Poor	Better	Best	25th%	median	75th%
PO_4 (SRP)	TF	>0.025	>0.003	=<0.003	=<0.003	*.025*	*.020*	*.010*
PO_4 (SRP)	OH	>0.010	>0.003	=<0.003	=<0.003	*.010*	*.0009*	*.004*
PO_4 (SRP)	MH	>0.008	>0.002	=<0.002	=<0.002	*.008*	*.005*	*.0035*
PO_4 (SRP)	PH	>0.010	>0.003	=<0.003	=<0.003	*.010*	*.008*	*.005*

Table 5.3.11 Grouping criteria for determining a water quality category

Water quality conditions	Class	Grouping criteria based on Secchi Depth, DIN, PO_4 (SRP)
Impaired	Worst	all 3 parameters classified as ‘worst’
	Poor (include worst)	all 3 parameters classified as ‘worst’ or ‘poor’ excluding mixed poor light class
	Mixed poor light	if Sccehi depth classified as ‘worst’ or ‘poor’ and one or both the nutrient parameters as “best” or “better”
Unimpaired	Mixed better light	if Sccehi depth classified as ‘best’ or ‘better’ and one or both the nutrient parameters as “poor” or “worst”
	Better (include best)	all 3 parameters classified as ‘best’ or ‘better’ excluding mixed better light class
	Best	all 3 parameters classified as “best”

Table 5.3.12 Chlorophyll-a concentrations in the salinity- and season-based Chesapeake phytoplankton reference communities (mg/L).

Salinity Regime	Spring		Summer	
	median	(5% - 95% percentile)	median	(5% - 95% percentile)
Tidal-Fresh	4.3	(1.0 – 13.5)	8.6	(3.2 – 15.9)
Oligohaline	9.6	(2.4 – 24.3)	6.0	(2.5 – 25.2)
Mesohaline	5.6	(2.2 – 24.6)	7.1	(4.4 – 14.0)
Polyhaline	2.9	(1.1 – 6.7)	4.4	(1.7 – 8.7)

Source: Chesapeake Bay Water Quality and Phytoplankton Monitoring Programs Databases
http://www.chesapeakebay.net/data

5.4 WQG FOR NUTRIENTS (FRESHWATER) OF CANADA

Surface water or otherwise termed freshwater is important water resource for various uses in Canada. Nutrient management in lakes and rivers has gradually gained recognition over the past years to tackle problems associated with over-enrichment. While national nutrient WQGs have not been designated, nutrient WQGs are found to have been adopted in two provinces : narrative WQG in Saskatchewan and numerical in British Columbia (Table 5.4.1).

Table 5.4.1 Water quality criteria for nutrients and algae for surface waters adopted by Saskatchewan and British Columbia, Canada

Province	Nutrient Water Quality Objectives/Criteria		
Saskatchewan	Nitrogen or phosphorus or other nutrient concentrations should not be altered from natural levels by discharges of effluents such that nuisance growths of algae or aquatic weeds result.		
British Columbia	**Water Use**	**Phosphorous µg/L (total)**	**Chlorophyll *a* (mg/m^2)**
	Protection of aquatic life in streams	none proposed	100 (maximum)
	Protection of aquatic life in lakes where salmonides are the predominant fish species	5 to 15 (inclusive)	none proposed

In April 2000, Manitoba Environment released an information paper on development of nutrient management strategy for surface waters in southern Manitoba for public consultation. The strategy outlines two tasks to tack the eutrophication problem. The first task involves a background analysis to assess the water quality conditions in the territory and to initiate work to remedy information gap. The second task is to derive numerical objectives for two types of nutrient variables : derivation of regional based objectives and objectives based on receiving waters. The final strategy has not yet been released.

Recognizing the considerable variation that exists between aquatic systems in different watersheds, three approaches are proposed for the derivation of regional based objectives. Site-specific objectives will be derived to address special characteristics of individual stream or aquatic system. The derivation approaches are (i) reference condition approach based on information obtained from reference stream conditions, (ii) water use approach based on prediction relationships between nutrient concentrations and acceptable levels of primary productivity, and (iii) literature review approach based on recommendations in the scientific literature and existing objectives/guidelines derived for other jurisdictions in Canada, the USA and elsewhere.

Objectives based on receiving water are derived in light of the effect that stream nutrient load have on the lakes and reservoirs. The derivation will consider the carrying capacity of the receiving water body and the nutrients loads from streams entering into the water body based on field data, statistical analysis and modelling.

Little is known about the adoption narrative nutrient WQG of Saskatchewan. British Columbia has published use-based water quality criteria for the protection of aquatic life in streams and lakes. Numerical criteria are designated for two principles nutrient variables, i.e. total phosphorous and chlorophyll-*a*. No criteria for protection of estuarine or marine waters from eutrophication are proposed due to the lack of information available on levels of nutrients or algal biomass which would be desirable in B.C. coastal waters. The derivation rationale and method for criteria for stream and lakes are described in details in the technical publication titled "Water Quality Criteria for Nutrients and Algae" issued in 1985. The gist of the criteria development for the protection of aquatic life, which falls within the scope of this project, is given the following sections. Detailed information can be retrieved from the websites below :

Manitoba :
http://www.gov.mb.ca/waterstewardship/water_quality/nutrmgt.pdf

British Columbia :
http://www.env.gov.bc.ca/wat/wq/BCguidelines/approv_wq_guide/approved.html

Saskatchewan :
http://www.se.gov.sk.ca/environment/protection/water/surface.asp

5.4.1 Overview of the approach

The WQGs, for chlorophyll-*a* and phosphorus have been proposed to protect water resources in British Columbia from degradation caused by excessive amounts of algae which may impair human use of lakes and streams. The derivation is based on literature review of the ecological impact of the nutrient variables on three groups of beneficial uses of the receiving water body, which include protection of aquatic life, recreation and aesthetics, and drinking water supply. Scientific data were carefully analyzed and correlated with the problems occurred in waters of British Columbia with a view of quantifying the amounts of algae which caused problems and the concentrations of phosphorus which might be associated with algal problems. For lakes, a clear relationship has been established between phosphorus and algal biomass whereas no such relationship exists for streams. Thus phosphorus concentration provides the best indicator of actual or potential problems for lakes. For streams there are many factors which determine the amount of algae which will be present and phosphorus is much less important. Thus the algal biomass itself is the principal indicator which should be measure to determine actual or potential problems for streams.

The technical publication on the derivation is available at the following website for download :
http://www.env.gov.bc.ca/wat/wq/BCguidelines/nutrients/nutrientstech.pdf

5.4.2 Derivation of nutrient WQG for streams and lakes

The relationship between algal biomass and nutrients concentration is complex and the dynamics of which is still not yet full known. Only WQG for phosphorus was designated when British Columbia developed WQGs for nutrient and algae in the 1980s. This was attributed to the fact that phosphorus was considered to be the principal limiting factor in the freshwater system and there was limited information and viable analytical methods.

Because of fundamental differences between streams and lakes, particularly in terms of water residence times, orthophosphorus (or soluble reactive phosphorus) and total phosphorus were defined used for moving water (rivers and streams) and lakes respectively. In streams, algae could only make use of phosphorus that is dissolved and directly available for uptake due to low water residence time whereas in lakes, other forms of phosphorus were also available due to the relatively rapid cycling of phosphorus from particulate to dissolved and the much longer water residence time compared to streams. Biomass instead of algal growth rate was considered more appropriate to be used for purpose of specifying WQG. Chlorophyll-*a* was defined because of its relative simplicity and general usage among several techniques for measuring biomass.

Streams

It was considered that a trophic classification of streams could offer assistance to developing criteria to protect water quality. A summary of factors affecting visible algal biomass then developed is shown in Table 5.4.2. It was hard to elucidate the cause and effect relationship because streams did not always respond directly to nutrient input and these factors can override the potential of nutrient or add synergistic effects to cause algal growth. Because of this fact, it was considered difficult to suggest a criterion for phosphorus. If a criterion were to be specified for phosphorus to protect fisheries for all situation, orthophosphorus at greater than 3 µg/L was regarded as having the potential to cause a deterioration in stream quality based on an interpretation of a compendium of non-conclusive researches. In terms of biomass, a 100mg/m^2 chlorophyll-*a* was defined to protect against undesirable changes in aquatic life. Annex 21 shows the summary of research studies quoted in the WQG derivation.

Table 5.4.2 Factors contributing to high risk of excessive stream algal biomass

Factors	Effect
1. Temperature	● Warm water temperature (>15°) increase risk of heavy algal growth and biomass
2. Hydrology	● Smooth flow (i.e. stream has a more or less smooth gradient) as opposed to a stream with turbulent flow (i.e. rapids and falls) ● Stream velocity of 10-50 cm/s ● Annual flow variability is low (mean monthly high flow : mean monthly low flow is less than 10:1) ● Steam velocity during potential growing period is relatively steady (little "flashiness", effect of storm events is minor)
3. Light	● Water clarity is high (<5 NTU turbidity, <3 mg/L suspended sediments) ● Stream is open to direct sunlight (not shaded by trees or high stream banks)
4. Substrate	● Substrate is stable and has a relatively high surface area (i.e. gravel and cobble as opposed to mud or sand which are poor algal substrates due to instability)
5. Invertebrate Grazers	● A high risk exists if numbers of invertebrate grazers are low
6. Nutrients	● Biologically available phosphorus greater than 3ug/L (with phosphorus the limiting nutrient) or inorganic nitrogen greater than 25ug/L (N-limited)

<u>Lakes</u>

A variety of relationships have been described which allow correlation of phosphorus loading with chlorophyll-*a* with water clarity and with hypolimnetic oxygen deficit (see Table 5.4.3). WQG for phosphorus was proposed based on phosphorus concentrations measured at spring overturn when the lake was free of ice and the water column was isothermal. This was when the condition is assumed to give a good representation of the supply of phosphorus to the lake over the following summer growing period. A WQG of total phosphorus of the range 5-15µg/L was defined based on the research findings that the concentrations would not affect the production of important fish species, namely, salmon and trout. Annex 22 shows the summary of research studies quoted in the WQG derivation.

Table 5.4.3 Conversions for phosphorus to chlorophyll-*a*, water clarity and hypolimnetic oxygen depletion

Conversion	Reference
A. Phosphorus: Chlorophyll	
$\log_{10}$ (Chl-*a*) = 1.168 $\log_{10}$ (P) + 2.783	Recknow 1978
$\log_{10}$ (Chl-*a*) = 1.449 $\log_{10}$ (P) - 1.136	Dillon and Rigler 1974
$\log_{10}$ (Chl-*a*) = 0.9873 $\log_{10}$ (P) - 0.6231	Nordin and McKean 1984
$\log_{10}$ (Chl-*a*) = 0.92 $\log_{10}$ (P) - 0.09	Stockner and Shortreed 1985
B. **Chlorophyll: Water Clarity (Secchi depth)**	
Secchi depth = 17.28 x $(1 + 0.963 \text{ Chl-}\underline{a})^{-1}$	Chapra 1978
$\log_{10}$ (Secchi depth = -0.473 $\log_{10}$ (Chl-*a*) + 0.803	Rast and Lee 1978
C. Phosphorus: Water Clarity	
$\log_{10}$ (P) = 0.818 – 1.307 $\log_{10}$ (Secchi depth)	Recknow 1978
D. Phosphorus: hypolimnetic oxygen depletion (HOD)	
areal HOD (g/m^2/d) = $0.467 \log_{10} \left(\frac{L(P)}{q_s} + \frac{1}{TW} \right) - 1.07$	Rast and Lee 1978

P = phosphorus concentration in mg/L (generally at spring overturn)
Chl-*a* = growing season mean of chlorophyll-*a* (mg/m^2)
q_s = water overflow rate (m/yr)
L = phosphorus loading (g/m^2/yr)
TW = water retention time (yr)
Secchi depth = water clarity (m)

6 Conclusion

The jurisdictions reviewed in this phase have generally followed the framework and technical guidance on development of WQC/WQS provided by their national environment protection agencies. Though alternative methods have been used, e.g. in the case of dissolved oxygen criteria for marine water in the USA, the modification falls within the scope of the nationally endorsed protocol which allows flexibility to suit the site-specific conditions. Provided the development approach is scientifically defensible and subject to acceptance by the stakeholders, numerous ways of achieving the derivation goals have arisen among the reviewed economies.

The following observations are noted in this review of the derivation of numerical WQC/WQS for dissolved oxygen and nutrients by the selected economies and their local jurisdictions :

- A clear framework provided by the national authority is in place specifying the principles related to goals, methodologies and implementation.
- A critical review of the relevant information is conducted at the outset, e.g. literature data describing the toxic or harmful effects and information published in peer-reviewed literature, monitoring data revealing the historical and prevailing conditions of the water bodies, etc.
- A collaborative effort by different stakeholders is involved. Often as a result of the necessity to conduct a sound scientific assessment and to foster broad participation for more transparent decision making, task groups comprising external experts and policy makers from different disciplines are established to undertake the criteria development.
- Modeling techniques are widely applied to predict the relationship of the parameters of concern with the changes in the attributes of the water bodies based on limited field data, e.g. regression models are used to quantify light availability at different depths underwater, the larval recruitment model to estimate the cumulative impacts of low DO and express the criteria as a number of days a given DO concentration can be tolerated without causing unacceptable effects on total larval survival for the entire recruitment.
- At the latter stages of the process, the proposed WQS/WQC is subject to validation by modeling, field data or other lines of evidence given in earlier literature studies so as to reaffirm the applicability of the WQC/WQS.
- Each of the derivation processes requires sufficient data. According to the information reviewed, the data collection may take years, e.g. Australia and New

Zealand have spent as long as 10 years to collect the data from reference sites, and the USA has taken 10 years to produce the required information to support the development of DO water quality criteria for marine water.

- Every methodology has its own specific focus. The saltwater DO WQC puts its focus on diel, tidal or episodic cycles of hypoxia in the marine environment rather than on a direct behavioural response or the issue of spatial extent of a DO problem. The reference condition approach sets the statistical value (e.g. 20th, 50th or 80th percentile in the case of Australia and New Zealand) of reference data as the site-specific WQC/WQS. However, the success of this approach needs the identification of suitable reference sites for data collection. Environmental managers will have to decide which method is best for application to their sites of concern based on robust evidence and professional judgment.

- A suite of nutrient WQC/WQS, instead of one single criterion, is applied to national or regional systems for achieving the management goal. Estuarine and near shore coastal waters naturally vary in type, physical and biological characteristics as well as geographic conditions. The factors associated with this variability are numerous but include principal qualities such as water residence time, depth, water column stratification, salinity and temperature. Nutrient criteria have been developed in a manner that is consistent with the uniqueness of system types.

This project has moved towards its final stage with a view to presenting a literature review of the WQC/WQS adopted by the member economies for the protection of aquatic resources and uses, and the approach/methodology/rationale for derivation with examples given to illustrate the processes involved. The next step of this project is to compile all the findings in the previous phases in a final report and to construct a database of the WQC/WQS of the economies concerned. The 14 economies that are covered in this project will be contacted to ask for comments on the draft final report before its formal release.

Annex 1 Acute studies on salmonids quoted by USEPA in WQC derivation for dissolved oxygen (freshwater) (Source : USEPA 1986)

Species	Effect Level (mg/L)			Temperature (°C)	Reference
Brook trout	1-hr	mortality	1.2	10	Shepard 1955
	10-hr	mortality	1.5	10	
Trout	3.5-hr	mortality	1	10	Downing and Merkens 1957
	3.5-hr	mortality	1.6	20	
	3.5-d	mortality	1.3	10	
	3.5-d	no mortality	1.9		
	3.5-d	mortality	2.4	20	
	3.5-d	no mortality	2.7		
Lake trout		lethality	4.5	10	Carlson and Siefert 1974

Annex 2 Chronic studies on salmonids quoted by USEPA in WQC derivation for dissolved oxygen (freshwater) (Source : USEPA 1986)

Response	Species	Inference	Reference
Growth	Various	Curve fitting and statistically analysis of 30+ growth studies varying in test species, temperature, food types and fish types, three classifications of effect of low DO on growth reduction were concluded taking account of the inherent variability Figure 4.3.1): Significant – above 6 mg/L DO levels; Severe – below 4 mg/L DO levels; Moderate to slight – between 4 mg/L and thresholds of effect (between 6 to 10 mg/L) if the exposure are sufficient long.	JRB Associates 1984
	Chinook and coho salmon	Greatest effect and highest threshold of effects observed at high temperatures (17.8 to 21.7°C), leading to the conclusion that effects of low DO become more severe at higher temperatures, and growth tests conducted at 10-15°C would underestimate the effects (Figure 4.3.2) DO levels down to 5 mg/L probably have little effect on growth rate at temperatures below 10°C (Figure 4.3.3).	Warren et al. 1973
	coho salmon	A DO concentration of 5 mg/L might restrict swimming and foraging.	Thatcher 1974
	coho salmon	No growth reduction at 5 mg/L at a current of 8.5 cm/s but 15% decrease at 20 cm/s.	Hutchins 1974
Reproduction	--	No studies were found at the time of criteria development.	--
Embryonic and larval development	Salmon eggs	Flow rate below 100 cm/h past salmonid eggs directly influenced the DO supply. Delayed hatching and longer hatching time was observed below 6 mg/L of DO.	Silver et al. 1963, Shumway et al. 1964
	--	The considerable developmental growth implications if the time of emergence from gravel, or first feeding, was critically related to the presence of specific food organisms, stream flow or other factors.	Carlson and Siefert 1974, Siefert and Spoor 1974
	Embryos	Effects were found most significant during later embryonic development when critical DO concentrations were highest. Found no effect of 7-day exposure at concentrations above 2 mg/L at a water flow of 85 cm/hr.	Alderdice et al. 1958

Response	Species	Inference	Reference
	Mountain whitefish embryos	Severe mortality at 3.3 mg/L DO (mean); reduction in survival and delayed hatching at 4.6 mg/L DO (mean).	Siefert et al. 1974
	Salmon and trout	Weight decreased by 30% under continuous exposure to concentrations down to 3 mg/L with flow $\geq$ 100 cm/hr	Brannon 1965, Chapman and Shumway 1978
	Salmon	Found from measurements in 30+ salmon redds that the minimum DO concentration in the redds averaged about 3 mg/L below those of the overlying water and probably during later stage of larval development.	Koski 1965
	Brook trout	Mean DO concentration in redds averaged 2.1, 2.8 and 3.7 mg/L. DO concentration showed greater intergravel depletion during years of low water flow.	Hollander 1981
Behaviour	Chinook and coho salmon	Strong preference for oxygen levels of 9 mg/L or higher.	Whitmore et al. 1960.
	Young Atlantic salmon and brown trout	Response to low DO depended on fish age. Older fry was found less tolerable to low oxygen level : • fry 4-16 weeks of age showing avoidance of concentrations up to 4 mg/L • fry 26 weeks of age showed avoidance up to 3 mg/L.	Bishai 1962
	Rainbow trout	Harvest rate decreased at DO level below 6 mg/L. Lowering the daily minimum from 6 mg/L to 5.4 and 3 mg/L reduced the harvest rate by 20, 40 and 60%.	Weithman and Hass 1984
	Coho salmon	Lowered activity at 5mg/L in laboratory growth study.	Thatcher 1974
	Chinook and coho salmon	Growth impairment at low DO levels was likely related to a function of lower food intake.	Warren et al. 1973
Swimming	--	Maximum sustained swimming speeds (in the rage of 30 to 45 cm/s) were reduced by 8.4, 12.7 and 19.9% at DO concentration of 6, 5 and 4 mg/L respectively. Speed reduction was slightly more severe at cooler temperature (ranged from 10 to 20°C).	Davis et al. 1963
	--	30 and 45% of swimming speed reduction was observed at DO concentration of 5.1 (14°C) and 3.8 (22°C) respectively.	Jones 1971

Response	Species	Inference	Reference
	Chinoook and coho salmon	Salmons were able to swim for 24 hours at a DO concentration of 3 mg/L and above.	Katz et al. 1959
Population	--	River systems in which trout or other salmon were most likely found were reported with DO concentration 5mg/L or above (90% of the values exceeded 7 mg/L).	Ellis 1937

Annex 3 Acute studies on non-salmonids quoted by USEPA in WQC derivation for dissolved oxygen (freshwater) (Source : USEPA 1986)

Species	Effect Level (mg/L)			Reference
Largemouth bass	3-hr	lethality	2.5	Spoor 1977
Various	24-hr	no lethality	3	Moss and Scott 1961, Downing and Merkens 1957
	96-hr	no lethality	3	
	Found subject species still survived several days at a DO level below 1 mg/L			

Annex 4 Chronic studies on non-salmonids quoted by USEPA in WQC derivation for dissolved oxygen (freshwater) (Source : USEPA 1986)

Response	**Species**	**Inference**	**Reference**
Growth	Juvenile largemouth bass	Reduced growth rate at 5.9mg/L and below. Deduced that decreased food consumption was the primary cause of reduced growth.	Stewart et al. 1967
	Channel catfish fingerlings	Significant reduction in feeding and weight gain in 6-wk exposure to 5 mg/L DO with plentiful food supply. Fish exposed to 3 mg/L was affected in swimming, feeding and tolerance to loud noise.	Andrews et al. 1973
	Channel catfish	Each mg/L increase in DO concentrations between 3 and 6 mg/L increased growth by 10 to 13%.	Raible 1975
	Juvenile channel catfish	Weight gain (%) / Reduced Growth rate (% / DO conc. (mg/L) 14 / 5 / 5.0 39 / 18 / 3.4 54 / 23 / 2.1 JRB Associates pointed out when of sufficient duration, large effects on growth rate may had little effect on annual weight gain if they occurred only over small proportion of the annual growth period.	Carlson et al. 1980, JRB Associates, 1984
	Yellow perch	JRB Associates' analysis showed yellow perch appeared to be superior in resistance to influence of low DO concentration than northern pike, largemouth bass and channel catfish (Figure 4.3.4).	Carlson et al. 1980, Stewart et al. 1967, Adelman and Smith 1972, JRB Associates 1984
	Juvenile largemouth bass	Results showed at DO concentration between 4 and 6 mg/L the growth rate of bass in ponds was reduced 17 to 34% rather than the 1 to 9% mg/L in the Stewart's laboratory studies (Figure 4.3.5). Studies supported the idea that higher temperature exacerbated the adverse effects of low DO on growth rate and suggested that the ease of food capture in laboratory studies might result in underestimating effects of low DO on growth rate in nature.	Brake 1972, Stewart et al. 1967

Response	Species	Inference	Reference
	Largemouth bass, carp, coho salmon, young coho and sockeye salmon	Reanalysis of growth study data published by other authors and their own results for coho and sockeye argued that decrease in growth data and food consumption in DO level at 4.0 to 4.5 mg/L were not statistically significant in these test of short duration under pristine laboratory environment.	Brett and Blackburn 1981
Reproduction	Juvenile fathead minnow	Found the larval stage was the most sensitive stage to low DO level. No spawning occurred at 1 mg/L and no. of eggs reduced at 2 mg/L. No effect on hatching of embryos but incubation time prolonged from normal 5 days to 8 days with decreasing DO concentration. Mean responses when compared to control were : Mean larval response (%) — DO conc. (mg/L) 6% survival — 3 25% survival — 4	Brungs 1971
	Mature black carppie	Number of spawnings, embryo viability, hatching success and survival through swim-up were similar at all exposures to constant 2.5 mg/L DO to saturation and temperature of 13-20°C.	Siefert and Herman 1977
Early Life Stages	Northern pike, bluegill, pumpkinseed, smallmouth bass	Studies results indicated 4 mg/L DO was tolerable by northern pike, perhaps smallmouth bass, and 2.2 mg/L was found lethal. Because the studies were not carried out at the most sensitive stage of each of the tested species, the test might not conclude the effect of DO concentration. Data were : DO (mg/L) — Effect *northern pike –* 0.6 — 0% mortality for embryos; 100% mortality for larvae 8-hr test : 1.6 — 100% mortality for larvae; 0% mortality for larvae *Smallmouth bass –* 6-hr test : 2.2 — 100% mortality for larvae; 0% mortality for larvae	Peterka and Kent 1976

Response	Species	Inference	Reference
		Bluegill – 4-hr test : 0.5 tolerable for embryos 1.8 tolerable for sac-larvae	
	Larval northern pike	Reduced survival at 2.9 and 3.4 mg/L DO at 15 and 19°C when larvae initiated feeding. Greater oxygen demand at that life stage appeared to be the determining factor for survival.	Siefert et al. 1973
	Walleye embryos and larvae	20-day survival test showed reduction at 3.4 mg/L.	Siefert and Spoor 1974
	Smallmouth bass embryos and larvae	20% reduction at 4.4 mg/L and complete lethality at 2.5 mg/L in the first 5 days after hatching. At 4.4 mg/L, early hatching occurred and growth among survival reduced.	Siefert et al. 1974
	Largemouth bass	10 to 20% growth reduction at 1.7 to 6.3 mg/L. Premature hatching and delayed feeding at 4.5mg/L, both factor could indirectly influence survival.	Carlson and Siefert 1974
	Channel catfish embryos and larvae	Data of 2- or 3-week exposure were reported : Condition Effect *at 25°C -* 5mg/L survival slightly reduced 4.2mg/L survival sign. Reduced *at 28°C –* 3.8mg/L, 4.6mg/L, 5.4mg/L survival slightly reduced 2.3mg/L total mortality	Carlson et al. 1974
	Black crappie embryos and larvae	No effect on survival observed at 2.5mg/L.	Siefert and Herman 1977
	White bass, white sucker	Adverse effect to embryo larval at 1.8 and 1.2 mg/L.	Siefert et al. 1974, Siefert and Spoor 1974
Behaviour	Largemouth bass	Degree of Avoidance — DO conc. (mg/L) Slight — 3.0 - 4.6 Definite — 1.5	Whitemore et al. 1960
	Bluegills	Definite — 1.5	

Response	Species	Inference	Reference
	Largemouth bass embryos and larvae	In a few hours of exposure at 23-24°C and 4–5 mg/L, bottom-dwelling yolk-sac larvae swam a few inches upwards, which behaviour would cause mortality due to predation and displacement from the nesting area.	Spoor 1977
Swimming	Largemouth bass	Results found similar to those for salmonids in that swimming performance appeared to be more sensitive to low DO at lower temperature. No swimming observed for 24 hours at 0.8 ft/sec flow on the following conditions : Temp(°C) — DO (mg/L) 25 — < 2 20 — 2.8 16 — 5	Katz et.al. 1959, Dahlberg et al. 1968
	--	Effects on swimming speed at 25°C were found : Reduction (%) — DO (mg/L) <10 — 3 - 5 10-16 — 2 - 3 30-50% — 1 - 1.5	Dahlberg et al. 1968
Field Studies	Various	Field studies at 982 stations on freshwater streams and rivers concluded that 5 mg/L appeared to be the lowest concentration for protection of warmwater fish species.	Ellis 1937 and 1944
	Various	A 2-year biological survey of the Ohio River Basin showed that fish were more abundant in zone where DO was 3 to 5 mg/L but showed a tendency to sickness, deformity and parasitization.	Brinley 1944
	Sport fish (percids and centrarchids)	A 3-year study of fish populations in the Wisconsin River showed fish were more abundant at sites having mean summer DO greater than 5 mg/L.	Coble 1982
	Steelhead trout embryos	Good survival occurred when mean intergravel dissolved oxygen conc. exceeded 6.0 mg/L and velocity exceeded 20 cm /sec.	Coble 1961
	Rainbow trout embryos	2 out of 19 rainbow trout redds under study confirmed the results of Coble's (1961) study with 29% average survival. Critical intergravel water velocity appeared to be 15 mg/L below which even good DO conc. did not produce reasonable survival. Field data with flow >15 cm/sec agreed quite well with the USEPA fish production impairment levels.	Sowden and Power 1985

Annex 5 Toxicity studies on invertebrates quoted by USEPA in WQC derivation for dissolved oxygen (freshwater) (Source : USEPA 1986)

Response	Species	Inference	Reference
Survival	European mayfly numphs	Critical DO concentration ranged from 2.2 – 1.7 mg/L.	Fox et al. 1937
	European stonefly	Critical DO concentration in water flowing at 10 cm/sec were 7.3 and 4.8 mg/L.	Benedetto,1970
	European aquatic insects	Mean LC_{50} of 22 species was about 3 mg/L, but with large variance : 8 species having an average below 1 mg/L and 4 species in excess of 7 mg/L.	Jacob et al. 1984
	North American stonefly	Critical DO concentration about 7mg/L at a flow of 0.32 cm/sec and temperature 20°C.	Kapoor and Griffiths 1975
	Aquatic insects	Two studies showed that 96-hr LC_{50} data for 26 species ranged from <0.6 to 5.2 mg/L. Half of the data had DO between 3 and 4 mg/L, apparently denoting 4 mg/L was the minimum level for survival.	Gaufin 1973, Nebeker 1972
Behaviour	Caddisfly	DO (mg/L) — Effect on respiratory movement 5 — Doubled 1 – 2 — 3- to 4-fold	Fox and Sidney 1953
	Stonefly	Significant increases in movement occurred in situations : • < 5 mg/L at 16°C • < 2 mg/L at 10°C • at higher DO concentrations when water flow was 1.5 cm/sec than 7.6 cm/sec.	Knight and Gaufin 1963
	Stonefly	Stonefly lacking gills were more sensitive to low DO than were gilled forms.	Knight and Gaufin 1965
Growth	Daphna magna	26-day exposure test results were : DO (mg/L) — Effect 1.8 — sign. reduced fecundity 2.7 — 17% weight reduction 3.7 — no effect observed	Homer and Waller 1983

Annex 6 Acutely lethal concentrations of dissolved oxygen to aquatic insects (Source : USEPA 1986, based on Gaufin 1973 and Nebeker 1972)

Species	96-h LC50 (mg/l)	Source*
Stonefly		
Acroneuria Pacifica	1.6 (H) **	G
Acroneuria lycorias	3.6	N
Acrynopteryx aurea	3.3 (H)	G
Acrynopteryx paralleta	< 2 (H)	G
Diura knowitoni	3.6 (L)	G
Nemoura cinctipes	3.3 (H)	G
Pteronarcys californica	3.9 (H)	G
Pteronarcys californica	3.2 (H)	G
Pteronarcys dorsata	2.2	N
Pteronarcella badia	2.4 (H)	G
Mayfly		
Baetisca laurentina	3.5	N
Callibaetis montanus	4.4 (L)	G
Ephemerella doddsi	5.2 (L)	G
Ephemerella grands	3.0 (H)	G
Ephemerella subvaria	3.9	N
Hexagenia limbata	1.8 (H)	G
Hexagenia limbata	1.4	N
Leptophlebia nebulosa	2.2	N
Caddisfly		
Brachycentrus occidentalis	< 2 (L)	G
Drusinus sp.	1.8 (H)	G
Hydropsyche sp.	3.6 (L)	G
Hydropsyche betteri	2.9 (21℃)	N
Hydropsyche betteri	2.6 (18.5℃)	N
Hydropsyche betteri	2.3 (17℃)	N
Hydropsyche betteri	1.0 (10℃)	N
Lepidostoma sp.	< 3 (H)	G
Limnophilus ornatus	3.4 (L)	G
Neophylax sp.	3.8 (L)	G
Neothremma alicia	1.7 (L)	G

Species	96-h LC50 (mg/l)	Source*
Diptera		
Simulium vittatum	3.2 (L)	G
Tanytarsus dissimilis	< 0.6	N

* G = Gaufin (1973) -- all tests at 6.4℃
N = Nebeker (1972) -- all tests at 18.5℃ except as noted/flow 125 ml / min.
** H = high flow (100 ml/min); L = low flow (500 ml/min).

Annex 7 Toxicity studies on effects on fluctuating dissolved oxygen level quoted by UESPA in WQC derivation for dissolved oxygen (freshwater) (Source : USEPA 1986)

Species	Condition	Inference	Reference
Juvenile coho salmon, brook trout, rock bass	--	Growth of fish fed with unrestricted food was markedly less than would be estimated from the daily mean DO concentration.	Fisher 1963, Whitworth 1968, Bouck 1972
Bluegill, largemouth bass, yellow bullhead	3 mg/L for 8 hours per day for 9 days and 8.3 mg/L for the remaining time	Produced significant stress pattern in the serum protein fractions of all fish but yellow bullhead. During low DO level, fish lost natural colour, increased ventilation rate, remained very quiet and vomited food.	Bouck and Ball 1965
Juvenile largemouth bass	Daily minima near 2 mg/L and daily maxima from 4 to 17 mg/L	Growth under fluctuating conditions found less than in conditions with a constant concentration equal to the mean concentration	Stewart et al. 1967
Juvenile channel catfish, yellow perch	Four conditions of different fluctuating DO conc. (mg/L) : (i) 3.5 (constant), (ii) 6.2 to 3.6, (iii) 4.9 to 2, (iv) 3.1 to 1	Channel catfish and yellow perch consumed less food at mean conc. but growth was not impaired until conc. below 3.1 mg/L. Growth not affected by fluctuations from about 3.8 to 1.4 mg/L. No mortalities observed. Growth rate under fluctuating conditions constantly below the rate under constant condition.	Carlson et al. 1980
Mature black crappies	Constant conc. (mg/L) : 2.5, 4, 5.5 and 7 mg/L Fluctuating conc. ranged from 0.8 to 1.9 mg/L	Successful spawning occurred at all exposures except the fluctuation between 1.8 and 4.1 mg/L.	Carlson and Herman 1978

Annex 8 Toxicity studies on effects of temperature and chemical stress quoted by UESPA in WQC derivation for dissolved oxygen (freshwater) (Source : USEPA 1986)

Species	Inference	Reference
--	Reduced survival when DO conc. lowered from 7.4 to 3.8 mg/L under exposure to lethal temperature.	Alabaster and Welcomme 1962
Rainbow trout, perch, roach	Over a range from 10 to 20°C, lethal DO conc. increased by an average factor of 2.6, ranging from 1.4 to 4.1 depending on fish species tested and test duration.	Downing and Merkens 1957
Salmon	General requirements for DO probably increases with increasing temperature.	Warren et al. 1973
Largemouth bass		Brake 1972
--	Provided excellent in-depth evaluation of potential effects of DO on fish growth.	Cuenco et al. 1985a, b, c
--	Toxicity of zone, lead, copper and monohydric phenols increase at DO 6.2 mg/L as compared to DO 9.1 mg/L. Greater toxic effect of these chemicals at 3.8 mg/L. Toxicity of ammonia was enhanced more than that of the other. Theorized that the increase in toxicity was due to increased ventilation, which had promoted diffusion of toxicant through fish's gills.	Lloyd 1961
Rainbow trout	Survival at lethal ammonia conc. decreased from 8.5 to 1.5 mg/L DO conc.	Downing and Merkens 1955
Rainbow trout	96-hr LC_{50} study indicated ammonia became more toxic from DO conc. 8.6 to 2.6 mg/L and the max. toxicity doubled. Positive relationship between LC_{50} values and low DO conc. was more pronounced in shorter time exposure in 12-, 24-, 48- and 72-hr study. Recommended that DO standards for protection of salmonids should reflect background conc. of ammonia which might present and the likelihood of temporary increases in those conc.	Thurston et al. 1981

Species	Inference	Reference
Goldfish	Less than doubling toxicity of hydrogen sulphide and little difference with regard to prior acclimation to reduced DO conc. LC_{50} (mg/L) DO (mg/L) / no acclimation / acclimation 6 / 0.071 / 0.062 5.1 / 0.053 / 0.048	Adelman and Smith 1972
Bluegill	Less tolerant to zinc, naphthenic acid and potassium cyanide at periodic low DO conc.	Cairns and Scheier 1957
Bluegill	Increased mortality when exposed to zinc under low DO conc. Mean LC_{50} between 1.8 mg/L and 5.6 mg/L DO differed by a factor of 1.5	Pickering 1968
--	Hypoxia considered as a major factor in outbreak of *Aeromonas liquefascines* (a common bacterial pathogen of fish) during summer months.	Meyer 1970
--	Low DO stress was a major factor of the fish kill incident in San Joaquin River when DO conc. was found 1.2 to 2.6 mg/L.	Haley et al. 1967
--	Hypoxia triggered the proliferation of facultative fish pathogen which continuously present in most water.	Wedemeyer 1974
--	Outbreaks of diseases were more likely if the occurrences of stress coincide with the presence of pathogenic micro-organisms.	Snieszko 1974

Annex 9 Toxicity studies on short-term effects to fish quoted by AEP in WQC derivation for dissolved oxygen (freshwater) (Source : AEP 1997)

Species	Acute Effects (in mg/L dissolved oxygen unless otherwise indicated)	Temperature (℃)	Reference
91 species	3		Doudoroff and Shumway 1970
bluegill	0.25	2.5 - 4	Petrosky and Magnuson 1973
4 species	1.2[1]	25	Matthews and Maness 1979
grayling cutthroat trout	< 2.2 < 1.7	18 18	Feldmeth and Eriksen 1978
rainbow trout	< 2.6	12.4 - 13.3	Thurston et al. 1981
rainbow trout	1.5, 1.6	15	Wirosoebroto-Hartadi 1986, as referenced in Truelson 1997
Salmonids non-salmonids	3.4 3.0		Alabaster and Lloyd 1982; Slavonic literature
brown trout	3.2	16.3 - 16.6	Garric et al. 1990
central stoneroller minnow	2.33, 1.91	7.5, 23	Hlohowskyj and Chagnon 1991
6 species	< 8.4 Torr[2]	20	Castleberry and Cech 1992
paddlefish	5-10 mmHg[3]	24	Burggren and Bemis 1992
35 species	< 1.6	26	Smale and Rabeni 1995a

1 survival time varied from 60 min for emerald shiner to 118 min for plains minnow

2 1 Torr=1 mmHg, <1.07 mg/L DO calculation according to Davis (1975) at 20 ℃ (test condition) and assuming 760 mmHg air pressure

3 <0.1 mg/L DO calculation according to Davis (1975) at 24 ℃ (test condition) and assuming 760 mmHg air pressure

Annex 10 Acute studies on some British Columbia fishes (Juvenile / Adult life stages) quoted by MWLAPBC in WQC derivation for dissolved oxygen (freshwater) (Source : Truelson 1997)

SPECIES/ (DEVELOPMENT)	LETHAL LEVEL ($mg\ O_2/L$)	TEST CONDITIONS	REFERENCE
Coho salmon (under yearling)	1.2 (24-h TL_m)[1] 2.0 (24-h TL_m)	constant O_2, 12-16 ℃ constant O_2, 23.5 ℃	Davison et al. 1959
(juvenile)	1.7-2.0 (0-90% died)	24-hr constant O_2 20-22 ℃	McNeil 1956
(juvenile)	2.3-3.3 (20-d TL_m)	20 ℃	
Chinook salmon (juvenile)	1.7-1.8 (24-h TL_m)	constant O_2 20 ℃	Katz et al. 1959
(juvenile)	1.9 (died in <2 h)	caged fish, Neroutsos Inlet	Kruzynski, unpublished
Brook trout (juvenile)	1.75 (83-h TL_m) 1.5 (near complete mortality < 83 hr)	9-10 ℃	Shephard 1955
Rainbow trout (6 mo.)	1.3-1.6 (24-h LC_{50}) 2.6-2.7 (24-h LC_{50})	24-h constant O_2, no CO_2 added, 13-20 ℃ (as above) but CO_2 at 30 mg/L	Alabaster et al. 1957
(under yearling)	< 2.6	12.5 ℃ 24-hr constant O_2	Thurston et al. 1981
(juvenile)	1.6-1.7 (50-70% died)	16-20 ℃ 3-8 mg/L CO_2	McNeil 1956
(juvenile)	1.5, 1.6 (72-h LC_{50}) 1.8, 1.86 (these were standard dose responses-stepdown tests had 0.2-0.4 mg/L lower limits)	15C, acclimated at 4.2 mg O_2/L 15 ℃, acclimated at 6 mg O_2/L	Wirosoebroto-Hartadi 1986
(10 cm Juvenile)	2.4-3.1 (7-d LC_{50})	constant O_2 16-20 ℃	Downing and Merkens 1957
Northern Pike (adult)	< 0.25 (5 days)	no acclimation, 2.5-4.0 ℃	Petrosky and Magnuson 1973

[1] TL_m-the median tolerance limit (in terms of concentration) that lethal to half of the organisms over a specified period

Annex 11 Acute studies on some British Columbia fishes (Embryo / Alevin life stages) quoted by MWLAPBC in WQC derivation for dissolved oxygen (freshwater) (Source : Truelson 1997)

SPECIES/ (DEVELOPMENT)	LETHAL LEVEL[1] (mg O_2/L)	TEST CONDITIONS [2]	REFERENCE
Chinook salmon (embryo)	1.6 (100% mortality) >2.5 (most survived)	11 ℃, 88-1310 cm/h	Silver et al. 1963
Chum salmon (egg to fry emergence)	2.6 (Tl_m)	0-15 ℃ artificial channel	Koski 1975
(egg to fry emergence)	0.4 (TL_m early eggs) 1.4 (TL_m pre-hatch) 7-d exposure	10 ℃ 1.4 cm/h	Alderdice et al. 1958
Coho salmon (egg/embryos)	2.8 (42-52% mortality)	10 ℃ 3, 12 cm/h	Shumway et al. 1964
(egg to fry emergence)	<6 (survival <4%)	Natural redds	Koski 1975
Rainbow trout (embryo)	1.5-1.85 (89% mortality-72h) 2.0-3.25 (29% mortality-210h)	10-12 ℃ prior to hatch	Gottwald 1965
(embryo)	<4.3 (no survival) 4.3-5.3 (<1.0% survival)	natural redds (silted) 34.8 cm/h (mean)	Sowden and Power 1985
Brook trout (egg to feeding fry)	2.3 (85% mortality), 1.5 (complete mortality prior to hatch)	8 ℃ 200 cm/h (mean)	Siefert and Spoor 1974
Steelhead trout (embryo)	1.6 (complete mortality) 2.5 (most survived)	9.5 ℃ 6-750 cm/h	Silver et al. 1963
(embryo)	2.8, 3.0 (46-78% mortality)	10-10.8 ℃ 3, 300 cm/h	Shumway et al. 1964
(embryo)	2.6-6.5 (16-26% survival) 6.4-9.2 (36-62% survival)	artificial redds 5-26 cm/h >23 cm/h 5-12 ℃	Coble 1961
(embryo/alevin)	3-4 est. (rate of oxygen uptake half of routine rate)	6-15 ℃ respirometer 500 cm/h	Rombough 1988
Lake trout (embryo/alevin)	4.5 (nearly all died) 4.3 (38% mortality) 2.4 (complete mortality)	10 ℃ 7 ℃ 7 ℃	Carlson & Siefert 1974
(embryo)	4.2 (died before hatch) 2.6 (hatched but some abnormalities)	10 ℃ 2.5-7.5 ℃	Garside 1959
Mountain whitefish (embryo)	3.3 (14-20% survival) 3.1 (no survival)	4 ℃, 210 cm/h 7 ℃	Siefert et al. 1974
Northern pike (embryo)	2.6 (near complete mortality) 2.9 (near complete mortality)	15 ℃, 20 days 198 cm/h, 19 ℃	Siefert et al. 1973
(embryo/alevin)	0.6 (complete mortality) 2.2 (considered lethal) 4 (no mortality)	in situ 8 h exposure	Peterka & Kent 1976
Lake herring[3] (egg to fry emergence)	<4 (poor survival and abnormalities)	2-8 ℃ 1728 cm/h	Brooke and Colby 1980

1 With the exception of lake trout, whitefish, pike, and herring (broadcast spawners) the developmental stages indicated above are well-buried and the oxygen levels cited are for the interstitial environment (hence, water column concentrations can be expected to be at least 3 mg O2/L higher)

2 cm/h refers to interstial water velocity (centimetres per hour) in the natural or artificial test environment

3 Coregonus artedii is not native to BC; however, similar ciscoes are found here

Annex 12 Chronic studies on fish growth or feeding quoted by AEP in WQC derivation for dissolved oxygen (freshwater) (Source : AEP 1997)

Species	Effect Level	No Effect Level	Temperature (℃)	Reference
Literature review	3	5		Doudoroff and Shumway 1970
Literature review: at moderately high temperature		5		Alabaster and Lloyd 1982
Northern pike juveniles	2.6 fed ad libidum	>5.4	18.6 - 18.7	Adelman and Smith 1970
Fathead minnow fry	5	7.3	17.5 - 24	Brungs 1971
Channel catfish	below 36% air sat (3mg/L) @ 3% BW(body weight)feeding, at 60% air sat. (5mg/L) ad libidumfeeding	5 mg/L @ 3% BW feeding 8 mg/L ad libidumfeeding	26.6	Andrews et al. 1973
Channel catfish	3.5, 5.1	4.9, 6 .3	25	Carlson et al. 1980
Walleye embryo	3.4	4.8	17.2	Siefert and Spoor 1974
Coho salmon	5.8	11	7 – 10	Siefert and Spoor 1974
Coho salmon	4	5	15	Brett and Blackburn 1981
White sucker	2.5	4.9	18	Siefert and Spoor 1974
White bass		1.8 to 9.2	16	Siefert et al. 1974
Smallmouth bass	6.3 6	8.6 8.3	20 23	Carlson and Siefert 1974
Arctic char larvae	25% air saturation (<3.4)	normoxic (<12.3)	6.5	McDonald and McMahon1977
Yellow perch	growth 2.1 food consumption 3.5	growth 3.4 food consumption 4.8	20	Carlson et al. 1980
Sockeye salmon	4	5	15	Brett and Blackburn 1981
Rainbow trout		7, 10 and 14	9	Smart 1981
Rainbow trout	6	7	15	Pedersen 1987

Annex 13 Chronic studies on hatching and survival of fish embryos quoted by AEP in WQC derivation for dissolved oxygen (freshwater) (Source : AEP 1997)

Species	Effect Level	No Effect Level	Temperature (℃)	Reference
Fathead minnow	eggs/female 2; survival 4	eggs/female 3; survival 5	17.5 - 24	Brungs 1971
Northern pike	20-d survival 2.6	20-d survival 4.9	15	Siefert et al. 1973
Northern pike	8-hr 2.2	8-hr 4	19	Peterka and Kent 1976, as referenced in Truelson 1997
White sucker	22-d survival 1.2; hatch time 2.5	22-d survival 2.5; hatch time 4.9	18	Siefert and Spoor 1974
Coho salmon	119-d survival, hatch time 5.7	119-d survival, hatch time 11	7 - 10	Siefert and Spoor 1974
Brook trout	133-d survival, hatch time 2.3	133-d survival, hatch time 2.9	8	Siefert and Spoor 1974
White bass	11-d survival 1.8	11-d survival 3.4	16	Siefert et al. 1974
Mountain whitefish	193-d survival 4.6 158-d survival 3.1	193-d survival 6.5 158-d survival 6.0	4 7	Siefert et al. 1974
Mountain whitefish	yolk area 5	Mortality same 3 to 13.5 mg/L; yolk area 7	2-10.5	Giles and Van der Zweep 1996
Smallmouth bass	14-d survival 4.4	14-d 8.7	20	Siefert et al. 1974
Smallmouth bass	20-d survival 3.1 20-d survival 1.7; hatch time 4.2	20-d survival 4.5 20-d survival 3.0; hatch time 6	20 23	Carlson and Siefert 1974
Lake trout	131-d survival, hatch time 4.3 108-d survival, hatch time 5.6	131-d survival, hatch time 6.0 108-d survival, hatch time 10.5	7 10	Carlson and Siefert 1974
Walleye	20-d survival 3.4	20-d survival 4.8	17.2	Siefert and Spoor 1974
Black crappie		survival, # embryos, hatch 2.5	20	Siefert and Herman 1977
Scale carp (India)	% hatch 6	% hatch 9	25	Kaur and Toor 1978
Lake herring	size of fry 2	size of fry 3,4	2, 4, 6, 8	Brooke and Colby 1980
Bull trout	yolk area 5; hatch time 3	mortality same 3 to 13.5; yolk area 7; hatch time 5	2 – 10.5	Giles and Van der Zweep 1996
Burbot		survival eggs same at 6 and 13	3	Giles et al. 1996
Nase	0.7	7.5	15.9	Keckeis et al. 1996

Annex 14 Chronic studies on teratogenic effects on fish embryos quoted by AEP in WQC derivation for dissolved oxygen (freshwater) (Source : AEP 1997)

Species	Effect Level	No Effect Level	Temperature (℃)	Reference
Chum salmon	below 0.3 mg/L DO		10	Alderdice et al. 1958
steelhead trout	2.6 mg/L		9.5	Silver et al. 1973
Largemouth bass	1 mg/L DO for 3 hr on 6th day after fertilization		20	Spoor 1977
Lake herring	1 mg/L DO at temperature of 2 and 4℃ and 2 mg/L at temperature of 6 and 8℃		2, 4, 6, 8	Brooke and Colby 1980
Bull trout		3 to 13.5 mg/L	2-10.5	Giles and Van der Zweep 1996
Mountain whitefish		3 to 13.5 mg/L	2-10.5	Giles and Van der Zweep 1996
Nase	0.7 mg/L DO during gastrula or eyed embryo stage		15.9	Keckeis et al. 1996

Annex 15 Chronic studies on delays in hatching and feeding of some British Columbia fishes (Embryo / Alevin life stages) quoted by MWLAPBC in WQC derivation for dissolved oxygen (freshwater) (Source : Truelson 1997)

Species	Hatch	1st Feeding	Other Influences	Ambient O_2 (mg O_2/L)	Reference
Coho salmon	3-5.5 d delay 11 d delay (25% longer)	12 d delay 22 d delay		3.0, 6.0 6.0 3.0 2.8	Siefert and Spoor 1974, Shumway et al. 1964
Sockeye salmon	no delay no delay		- additional 2 weeks for yolk absorption - additional 3 weeks for yolk absorption	6.0 3.0	Brannon 1965
Chum salmon	typically delayed, but advanced eggs premature			<4	Alderdice et al. 1958
Brook trout	delayed duration	delayed		2.3-5.8	Siefert and Spoor 1974
Brook trout Lake trout Rainbow trout	delayed		- reduced circulatory development and abnormalities	2.9	Garside 1959 & 1965
Lake trout	delayed several days	7-12 d delay		4.3, 6.0	Carlson and Siefert 1974
Steelhead trout	5-8 d delay delayed		- abnormalities, weak alevins - small alevins	2.6 2.8-4.5	Silver et al., 1963, Shumway et al. 1964, Chapman 1969
Mountain whitefish	15-17 d delay			6.5	Siefert et al. 1973
Northern pike	delayed	delayed	- high mortality	<3	Siefert et al. 1973
Lake herring	delayed		- fry abnormalities	<4	Brooke and Colby 1980

Annex 16 Acute studies on invertebrates quoted by AEP in WQC derivation for dissolved oxygen (freshwater) (Source : AEP 1997)

Species	Acute Effects (in mg/L dissolved oxygen unless otherwise indicated)	Temperature (℃)	Reference
Daphnia magna	48-hr LC50 0.6-0.7	-0.7	Nebeker et al. 1992
Daphnia magna	72-hr LC_{50} 1.27-3.19 male 72-hr LC_{50} 1.77-3.26 female 72-hr LC_{50} 0.94-1.91 juvenile	10, 20, 25	Hoback and Barnhart 1996
Daphnia pulex	96-hr LC_{50} 0.4-0.7	-0.5	Nebeker et al. 1992
Hyalella azteca	96-hr LC_{50} <0.3	16.8	Nebeker et al. 1992
Hyalella azteca	24-hr LC_{50} 0.7	20	Sprague 1963
Gammarus lacustris	7-d LC50 <0.2 (access to surface), 7-d LC50 0.6-0.4 (no access to surface)	12.9	Nebeker et al. 1992
Gammarus pulex	24-hr LC_{50} 1.63 adult 24-hr LC_{50} 1.26 juvenile	15	Maltby 1995
Gammmarus fasciatus	24-hr LC_{50} 4.3	20	Sprague 1963
Gammarus pseudolimnaeus	24-hr LC_{50} 2.2	20	Sprague 1963
Gammarus limnaeus	96-hr LC_{20} 3	6.4	Gaufin 1973
Pteronarcys dorsata	96-hr LC_{50} 2.2	18.5	Nebeker 1972
Pteronarcys californica	96-hr LC_{50} 3.2-3.9	6.4	Gaufin 1973
Acroneuria lycorias	96-hr LC_{50} 3.6	14	Nebeker 1972
Acroneuria pacifica	96-hr LC_{50} 1.6	6.4	Gaufin 1973
Hexagenia limbata	96-hr LC_{50} 1.4	18.5	Nebeker 1972
Hexagenia limbata	96-hr LC_{50} 1.8	6.4	Gaufin 1973
Ephemera simulans	96-hr LC_{50} <1.5	18.5	Nebeker 1972
Ephemeralla subvaria	96-hr LC_{50} 3.9	18.5	Nebeker 1972
Ephemerella doddsi	96-hr LC_{50} 5.2	6.4	Gaufin 1973
Ephemerella grandis	96-hr LC_{50} 3.0	6.4	Gaufin 1973
Leptophlebia nebulosa	96-hr LC_{50} 2.2	18.5	Nebeker 1972
Baetisca laurentina	96-hr LC_{50} 3.5	18.5	Nebeker 1972
Hydropsyche betteni	96-hr LC_{50} 1.0-2.9	10-21	Nebeker 1972
Hydropsyche sp.	96-hr LC_{50} 3.6	6.4	Gaufin 1973
Tanytarsus dissimilis	96-hr LC_{50} <0.6	18.5	Nebeker 1972
Asellus aquaticus	24-hr LC_{50} 0.32 male 24-hr LC_{50} <0.25 juvenile	15	Maltby 1995
Asellus intermedius	24-hr LC50 0.03	20	Sprague 1963
Dinocras cephalotes	45-hr LOEC (LC_{60}) 80% sat (9.6mg/L)* 45-hr NOEC (LC_0) 90% sat (10.8mg/L)*	7.5	Benedetto 1970

Species	Acute Effects (in mg/L dissolved oxygen unless otherwise indicated)	Temperature (℃)	Reference
Diura knowltoni	96-hr LC_{50} 3.6	6.4	Gaufin 1973
Diura bicaudata	50-hr LOEC (LC_{100}) 40% sat (4.8mg/L)* 50-hr NOEC (LC_{0}) 60% sat (7.2 mg/L)*	7.5	Benedetto 1970
Nemoura cinerea	50-hr LOEC (LC_{40}) 40% sat (4.8mg/L)* 50-hr NOEC (LC_{0}) 60% sat (7.2 mg/L)*	7.5	Benedetto 1970
Nemoura cinctipens	96-hr LC_{50} 3.3	6.4	Gaufin 1973
Arcynopteryx aurea	96-hr LC_{50} 3.3	6.4	Gaufin 1973
Arcynopteryx parallela	96-hr NOEC (LC_{0}) 2-5	6.4	Gaufin 1973
Brachyptera nigripennis	96-hr LC_{40} 2.3	6.4	Gaufin 1973
Pteronarcella badia	96-hr LC_{50} 2.4	6.4	Gaufin 1973
Callibaetis montanus	96-hr LC_{50} 4.4	6.4	Gaufin 1973
Rhithrogena robusta	96-hr LC_{50} 3.3	6.4	Gaufin 1973
Baetis bicaudata	72-hr LC_{90} 3.8	6.4	Gaufin 1973
Brachycentrus occidentalis	96-hr LC_{10} 2-4	6.4	Gaufin 1973
Drusinus sp.	96-hr LC_{50} 1.8	6.4	Gaufin 1973
Lepidostoma sp.	96-hr LC_{20} 3-4	6.4	Gaufin 1973
Limnephilus ornatus	96-hr LC_{50} 3.4	6.4	Gaufin 1973
Neophylax sp.	96-hr LC_{50} 3.8	6.4	Gaufin 1973
Neothremma alicia	96-hr LC_{50} 1.7	6.4	Gaufin 1973
Simulium vittatum	96-hr LC_{50} 3.2	6.4	Gaufin 1973

* assuming 760 mm Hg air pressure at 7.5℃ (test temperature)

Annex 17 Chronic studies on invertebrates quoted by AEP in WQC derivation for dissolved oxygen (freshwater) (Source : AEP 1997)

Species	Effect Level (in mg/L dissolved oxygen unless otherwise indicated)	No Effect Level (in mg/L dissolved oxygen unless otherwise indicated)	Temperature (℃)	Reference
Daphnia magna	21-d survival LOEC 0.5 5-d reproduction LOEC <0.9 19-d reproduction LOEC 0.6	21-d survival NOEC 0.9 5-d reproduction NOEC 0.9 19-d reproduction NOEC 0.9	17 - 19.2	Nebeker et al. 1992
Daphnia magna	26-d reproduction, time to 1st brood LOEC 1.8; final weight LOEC 2.7	26-d reproduction, time to 1st brood NOEC 2.7; final weight LOEC 3.7	21	Homer and Waller 1983
Daphnia pulex	10-d survival LOEC 0.8-1.1; reproduction LOEC 1.6-2.2	10-d survival NOEC 1.1-1.6; reproduction LOEC 2.1->2.2	16.4-16.9	Nebeker et al. 1992
Hyalella azteca	30-d LC_{50} <0.3; survival LOEC <0.3; growth and reproduction LOEC 1.2	survival NOEC 0.3; growth and reproduction NOEC >1.2	16.8	Nebeker et al. 1992
Gammarus lacustris	7-d survival LOEC <0.2	7-d survival NOEC 0.2	12.9	Nebeker et al. 1992
Pteronarcys dorsata	30-d LC_{50} 4.8-4.4		18.5	Nebeker 1972
Ephemera simulans	30-d LC_{50} 4.5		18.5	Nebeker 1972
Baetisca laurentina	30-d LC_{50} 5.0		18.5	Nebeker 1972
Tanytarsus dissimilis	30-d LC_{50} <0.6		18.5	Nebeker 1972
Most sensitive of several species	111-d LC_{50} 5.8		10	Gaufin 1973
Diura nanseni		1-month prior to emergence LC_5 5.1; close to emergence LC_5 7.1	8	Nagell and Larshammer 1981
Taeniopteryx nebulosa		1-month prior to emergence LC5 3.1; close to emergence LC5 5.3	8	Nagell and Larshammer 1981
Cloeon dipterum		>200-hr LC_5 2.2	8	Nagell and Larshammer 1981
Baetis tricaudata	14-d survival, food removal lower at 5	14-d survival, food removal higher at 11	4.5	Lowell and Culp 1996
Hexagenia limbata	21-d survival and growth LOEC 2.44	21-d survival and growth NOEC 6.17	14 - 15	Winter et al. 1996, analysis raw data

Annex 18 Chronic studies on hatching of invertebrates quoted by AEP in WQC derivation for dissolved oxygen (freshwater) (Source : AEP 1997)

Species	Effect Level (in mg/L dissolved oxygen unless otherwise indicated)	No Effect Level (in mg/L dissolved oxygen unless otherwise indicated)	Temperature (℃)	Reference
Ephemera simulans	30-d LC_{50} 4.5 emergence 20% at 7.6, 15% at 6.1, 0% at 4.1	emergence 40% at 9	18.5	Nebeker 1972
Leptophlebia nebulosa	emergence 30% at 7.6, 20% at 6, 10% at 4, 0% at 2.4	emergence 70% at 9	18.5	Nebeker 1972
Baetisca laurentina	emergence 30% at 6, 0% at 4	emergence 70% at 7	18.5	Nebeker 1972
Tanytarsus dissimilis	emergence 0% at 0	emergence >80% at <0.6	18.5	Nebeker 1972

Annex 19 Chronic studies on some BC invertebrates (Juvenile / Alevin Life Stages)) quoted by MWLAPBC in WQC derivation for dissolved oxygen (freshwater) (Source : Truelson 1997)

Classification[2]	Habitat (where specified or known)	Response to Low Oxygen ($mg\ O_2/L$)	Reference
Annelida: (leech) *Erpobdella testacea*	(varied)	regulated oxygen uptake and lowered its Pc (critical O_2 tension) following acclimation to low oxygen	Davis 1975
Gastropoda: (snails) *most littoral snails*		oxygen dependent, as respiratory rate falls progressively with oxygen content	Moss 1980
Lymnaeidae, Physidae		withstood 6 h of anaerobiosis	Davis 1975
Planorbidae and operculates		withstood 24 h of anaerobiosis	
Ancylus fluviatilus		climbed to the water's surface when dissolved oxygen declined	
Acroloxus lacustris	(stagnant)	survived long anaerobic exposures	
Pelecypoda: (clam) *Anadontoides ferrussacianus*	(low oxygen, muddy bottom)	survived several days of anaerobic conditions	Davis 1975
Decapoda: (crayfish) *Pacifastacus leniusculus*		oxygen utilization was elevated below 5.7 and ventilation was depressed below 3.6	Davis 1975
Procambarus simulans	(muddy streams and ponds)	similar oxygen dependence and increased ventilation in lower oxygen	
Astacus fluviatilus		moved from low to high oxygen concentrations when exposed to gradient	
Isopoda: (aquatic sow bug) *Ascellus intermedius*	(polluted and de-oxygenated water)	24-h LC_{50} - 0.03 (20 ℃)	Sprague 1963
Amphipoda: (scuds, sideswimmers) *Hyalella azteca*	(well-oxygenated, unpolluted waters)	24-h LC_{50} 0.7 (20 ℃) 96h/30d LC_{50} 0.30 (20 ℃) lowest no-adverse-effect >1.2	Sprague 1963, Nebecker et al. 1992
G. fasciatus		24-h LC_{50} 4.3 (20 ℃)	
G. lacustris		7d LC_{50} <0.2 (13 ℃) lowest no-adverse-effect<0.1	Nebeker et al. 1992
G. pulex		increased its pleopod movement in low oxygen to move away; had a slow developing avoidance reaction at 7 (25 min) but quicker at < 1 (1-2 min)	Davis 1975
G. limnaeus		96h LC_{50} <3 20d LC_{50} 2.8	Gaufin 1973
Cladocera: *(Water fleas)* *Daphnia*	(varied)	produced haemoglobin and turned red after stimulation with low oxygen for about 10 days	Davis 1975

Classification[2]	Habitat (where specified or known)	Response to Low Oxygen ($mg\ O_2/L$)	Reference
D. magna		preferred fully saturated water over water 15 percent saturated although more than an hour was required for the response to develop; 1.8 reduced fecundity in 26-d 2.7 reduced final weight by 17% 3.7 had no effect 48-h LC50 0.6, 0.7 (12 ℃) lowest no-adverse-effect 0.9	Homer and Waller 1983, Nebeker et al. 1992
D. pulex		48-h LC_{50} 0.5 (17 ℃) 96-h LC_{50} 0.4 and 0.7 lowest no adverse effect 2.1 (based on reproduction)	Nebeker et al., 1992
Coleoptera: Ephemeroptera *(Mayflies)*		Critical oxygen tension (Pc) below which respiratory dependence occurred	Davis 1975
Baetis	(swift streams)	17.00	
Leptophlebia	(lakes)	3.60	
Cloean	(ponds)	2.86 96-h LC_{50} at 18.5 ℃:	Nebeker 1972
Hexagenia limbata		1.4	
Baetisca laurentina		3.5	
L. nebulosa		2.2	
Ephemerella subvaria		3.9	
Ephemera simulans		30-d LC_{50} at 18.5 ℃: 4.5	
B. laurentina		5.0	
L. nebulosa		% emergence at mg O_2/L: 70/20/0 9.0/6/2.4	
B. laurentina		70/0 7.0/4.0	
E. simulans		40/0 9.0/4.1	
Plecoptera: (Stoneflies) *Pteronarcys*	(well-oxygenated, moving water)	96-h LC_{50}: 2.2 (18.5 ℃)	Nebeker 1972
Acroneuria lycoria		96-h LC_{50}: 3.6 (14 ℃)	
P. dorsata		30-day LC_{50}: 4.4 - 4.8	
Trichoptera: (caddis flies) *Hydropsyche betteni*	(well-oxygenated water)	96-h LC_{50}: 2.9 (21.0 ℃) 2.6 (18.5 ℃) 2.3 (17.0 ℃) 1.0 (10.0 ℃)	Nebeker 1972

Classification[2]	Habitat (where specified or known)	Response to Low Oxygen ($mg\ O_2/L$)	Reference
Coleoptera: (beetle) *Donacia*	(emergent vegetation)	Became less active in low oxygen; survived 168 h in closed bottles that initially contained 0.37.	Davis 1975
Diptera: (midges) *Chironomids*	(bottom organisms)	Regulated oxygen uptake and lowered Pc following acclimation to low oxygen suspended feeding when oxygen levels dropped to 5-7.5 percent of saturation	Davis 1975
Chironomus authracinus		At 1 **$mg\ O_2/L$**, growth stopped (limited respiration produced only enough energy for maintenance of vital functions).	
Tanytarsus dissimilis	(sluggish water)	96-h LC_{50} at 18.5 degrees C: <0.6 30-d LC_{50} at 18.5 degrees C: <0.6 % emergence at mg O2/L: 80+/0 <0.6/0	Nebeker 1972

[1] Some species may not be native to British Columbia

[2] Species are grouped under commonly used group classifications (usually Orders but in some cases Phyllum names are used)

Annex 20 Biological studies on aquatic species quoted by CCME in WQG derivation for dissolved oxygen (marine water) (Source : CCME 1999)

Stimulant	Species	Effect	Reference
Depressed DO level	Dragonet	Increased ventilatory muscle activity. Increased heart rate at 5.58-5.67 mg/L DO.	Hughes and Ballintijn 1968
	Sockeye salmon	Elevated blood and buccal pressure and increased breathing rate at <5.07 mg/L DO.	Randall and Smith 1967
	Fish	Restricted ability.	Birtwell 1989
	Juvenile Chinook Salmon	Avoidance behavior at <7mg /L DO.	
	Salmon	Reduced growth rate at DO levels as high as 7 mg/L.	USEPA 1986
	Walleye	Avoidance behaviour at DO levels ranging from 5.5 to 4.0 mg/L.	Scherer 1971
	Largemouth bass	Avoidance behaviour at 4.5 mg/L and the effect was distinct at 1.5 mg/L DO.	Whitmore et al. 1960
	Coho salmon	Erratic avoidance behavior at <4.5 mg/L DO.	
	Coho salmon	Reduced maximum swimming speed at 11.3 – 9.17 mg/L DO.	Davis et al. 1963
	Sockeye salmon	Reduced maximum swimming speed at 9.17 – 8.53 mg/L DO.	Brett 1964
	Fish	Reduced disease resistance and fecundity	Davis 1975a, 1975b, Sprague 1985
	Fathead minnow	Reduction in number of eggs produced at 4 mg/L and cessation of spawning at 1mg/L.	Brungs 1971
	Atlantic salmon	Alevins reared in 4.5 – 5.0 mg/L did not absorb their yolk sacs effectively and weighed one-half the weight of those larvae reared in 6.8 – 7.5 mg/L DO.	Nikiforov 1952
	Lugworm	Could not withstand DO above 4 mg/L	Johansen and Vadas 1967
Fluctuated DO level	Local biotic communities	Diversity of benthic species in Petpeswick Inlet Nova Scotia, changed as the levels of DO where species intolerant of depressed oxygen died or migrated and the more tolerant species colonized.	Hoos 1973
Toxic pollutants	Juvenile coho salmon	Median survival time exposed to kraft pulp mill effluent dropped from 56 hour when DO at 8.1mg/L to 11hour when DO at 3.4 mg/L.	Hicks and DeWitt 1971
	Rainbow trout fingerlings	A positive linear correlation between the LC_{50} of aqueous ammonia and DO. Ammonia toxicity increased as DO level decreased.	Thurston et al. 1981
	Rainbow trout	100% mortality at 20ug/L of pentachlorophenate solution but lethality at 10ug/L.	Chapman and Shumway 1978
	--	Dehydroabietic acid and zinc damaged gill tissue and exacerbated effects of reduced DO concentrations	Tuurula and Soivio 1982

Annex 21 Phosphorus and chlorophyll-*a* concentrations affecting algal growth in streams quoted by British Columbia in WQG derivation for nutrient and algae (Source : Nordin 1985)

Inference	Reference
25µg/L orthophosphate represented a threshold above which nuisance level would occur	Horner et al, 1982
Several Swedish streams developed heavy localized filamentous mats at SRP of 20µg/L or greater.	Jacoby et al. 1983
SRP of 15-25µg/L were the threshold of critical phosphorus concentrations for running water based on a biomass of 100mg/m^2 chlorophyll-*a*.	Horner et al, 1983
No significant different existed in biomass accumulation rates between phosphorus concentrations of 15 and 20µg/L. The threshold should be less than 15µg/L.	Perrin and Bothwell 1984
Supported the results of Perrin and Bothwell using nutrient additions to a trough system in Switzerland.	Wuhumann 1974
Occurrence of large amount of biomass in Thompson River with SRP and TDP at less than 5µg/L.	Derken 1981a
Under nutrient limited conditions, even at low temperatures (<10°), algae only became phosphorus limited when SRP fell below 3-4µg/L.	Bothwell 1985a
Chlorophyll-*a* greater than 100mg/m^2 with no apparent negative consequences to fish in an experiment conducted in Keogh River. The salmonids in the river showed enhanced growth and the fish appeared to benefit significantly. However, the high biomass did not persist for long periods.	Perrin and Bothwell 1984
Benthos were affected from 60-700 m downstream from some hatchery discharges which were considered to result in nutrient enrichment rather than degradation of habitats. The mean chlorophyll-*a* was less than 50mg/m^2 and peak values at 140-150mg/m^2.	Munro et al. 1985

Annex 22 Phosphorus and Chlorophyll-*a* concentrations affecting algal growth in lakes quoted by British Columbia in WQG derivation for nutrient and algae (Source : Nordin 1985)

Inference	Reference
Hypolimnetic oxygen depletion (HOD) was correlated with the trophic state of the lake.	Walker 1979
HOD could be predicted from the phosphorus retention of the lake.	Cornett and Rigler 1979
Rate of winter HOD was related to the trophic status of the lake but the relationship should also consider basin morphometry.	Mathias and Barica 1980
A correlation between winter HOD and phosphorus existed.	Welch et al. 1976
A correlation between HOD and P loading existed.	Welch and Perkins 1979
Some lakes might have marginal hypolimnetic oxygen concentrations at phosphorus concentration as low as 7 or 8µg/L.	Nordin and Mckean 1984
Suggested that an average summer Chl-*a* of 2µg/L and a corresponding mean summer Secchi disc of 4.5m imply a hypolimnetic oxygen depletion of 0.3g O_2/m^2/day at a loading rate on the threshold between oligotrophy and mesotrophy. Excess loading were defined as : 6µg/L average summer Chl-*a*, 2.7m average summer Secchi depth and a HOD of 0.6g O_2/m^2/day.	Rast and Lee 1978

Annex 23 Draft Outline for the Development of Nutrient Criteria for Streams and Rivers, Lakes and Reservoirs, and Estuaries and Coastal Marine Waters.

I. Introduction

Concept of Nutrient Criteria

- Regional in nature
- Methods and guidance to support development of nutrient criteria
- Discussion of criteria vs. standards
- Narrative criteria vs. numeric, but always quantitatively based

Uses of Nutrient Criteria

- Basis for State/Tribal Water Quality Standards
- Resource assessment
- Setting of management priorities
- Evaluation of management projects
- Long-range planning
- Coordination of nutrient management planning and implementation with other related programs

Rationale for Trophic Classification and Tiered Sampling Design

- Discussion of deriving nutrient reference conditions
- Discussion of cost-effectiveness of tiers, potential to evolve toward more detailed sampling as needed
- Detailed discussion of importance of adequate data for decision making compared to budget and level of certainty needed

II. Conducting Nutrient Surveys

Classification of the surface waters

Indicators

- How analyzed
- When to sample
- Where to sample

Survey Design

Data Storage and Processing

Interpretation

III. Trophic Classification

How to establish regions

Size classifications

Watershed classifications

Cultural development classes

IV. Indicators

For each indicator:

- — Method of collection
- — Storage and time constraints
- — Method(s) of analysis
- — expected range of results and trophic state indicated by geographic region and season

V. Sampling Design

Number of stations based on water body size

Placement of survey stations relative to characteristics of the water body and suspected loading sites

Time of year and frequency of sampling

VI. Data Processing and Storage

Discuss models and software packages

Regional databases and multi-State coordination of efforts

VII. Interpretation

Synopsis of indicator meanings

Discussion of interrelationships of trophic state and over enrichment indicators

Comprehensive interpretations

VIII. Detailed Nutrient Investigations for Cause and Effect Determination

Follow-up on initial surveys to generate definitive information

Seasonal adjustments

Relocation of some stations and addition of others

— Importance of basic survey continuity

IX. Management Response

Should be broad-based and general to indicate potential as opposed to a directive to the community

Types of loadings the indicators reflect

— BMPs and other protection or mitigation measures available

Approaches to achieve protection or change

— Local government
— Communities
— Property owners
— Businesses

Management Planning

— Incorporate the 10-step approach described in Chapter IV of this nutrient strategy document

X. Evaluation Monitoring

A variation on the original survey plan is used to keep track of the response of the water body to the protection or remediation effort

This information is used to assess the relative success of the project and to plan future courses of action

— Evaluation of "before, during, and after" project data

Close the loop in the management process by returning to step 1 of the 10-step process to plan the next phase of management or to apply these results to other similar, nearby water bodies.

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NEW PROJECT PROPOSAL

Name of Committee / Working Group:

Marine Resource Conservation Working Group (MRC WG)

Title of Project:

Water quality criteria or standards adopted in the Asia Pacific region

Proposing APEC Member:

Hong Kong, China

Project Overseer:

Dr. Malcolm Broom

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Water Policy and Planning Group
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Financial Information:

TOTAL COST (US$): Undetermined

Amount being sought from APEC Central Fund

No fund will be sought from the APEC Central Fund for executing the project.

Proposed Project Start Date: 7/2002 – 6/2003

Project Purpose:

The objectives of the project are to collect and compile the water quality criteria (WQC) or standards (WQS) adopted in the APEC economies, and identify the ways these WQC/WQS are derived.

Amongst the APEC economies, most members have established their own WQC/WQS for the protection of aquatic resources and uses. The values of these criteria or standards may vary among different economies because of the need to protect different resources or beneficial uses or because of the different ways these criteria or standards are derived. However, information on these WQC/WQS and the ways they are derived is usually not readily available or accessible.

The APEC economies are united by the oceans and seas. The health of the marine environment is therefore critical to their continuing economic well-being and sustainable development. To enhance cooperation and collaborative effort amongst the member economies to achieve sustainability of the marine environment in the region, it would be beneficial to have accessible information on the WQC/WQS adopted in individual member economies.

The APEC's Strategy to Address Sustainability of the Marine Environment has identified three key objectives, namely, (a) integrated approaches to coastal management; (b) prevention, reduction and control of marine pollution; and (c) sustainable management of marine resources. To achieve these objectives, the Strategy also identifies three central tools: (a) research, exchange of information, technology and expertise; (b) prevention, reduction and control of marine pollution; and (c) sustainable management of marine resources. The proposed project, which is conducted through the identified tools, will help achieve the objectives of the Sustainability of the Marine Environment in the APEC region. Specifically, it will facilitate the attainment of an integrated approach to coastal management by use of the tool of research, exchange of information, technology and expertise. By establishing the water quality requirements needed to protect specific resources or uses, and by identifying the underlying rationales for the setting of those requirements in different economies, the project will provide coastal zone managers with a better information base for making water quality management decision.

A questionnaire-based survey will be carried out to collect the information from the member economies. Information required will be of technical nature and relating to the values of the WQC/WQS and the approach and scientific rationales for deriving these values. Follow-up with individual economies may be needed for clarification purposes or for additional information. The collected data will be assimilated and compiled. Findings will be presented in the format of report with tables summarizing the WQC/WQS used in different member economies.

Hong Kong, China will be responsible for implementing the project, from preparation of questionnaire, through compilation of collected data, to preparation of a report. Findings, in electronic format, will be given to APEC for placing on the APEC Website to facilitate public access.

Strategic Objective:

The objectives of the project are to collect and compile the WQC/WQS adopted in the APEC economies and identify the ways they are derived. The findings of the project will provide the APEC economies with a better understanding of the WQC/WQS adopted in other member economies and thus enhance better cooperation and collaborative work in the region. This will better allow member economies the opportunity to develop clear water quality targets aimed at protecting specific marine resource functions, in circumstances which allow those targets to be tailored to the particular needs of individual economies.

Specific Objectives:

- collect information from member economies concerning the WQC/WQS and how they are derived;
- review the collected information particularly the approach / methodology and the scientific rationales for deriving the WQC/WQS;
- summarize and compare the WQC/WQS adopted in different member economies and outline the approach and rationales for their derivation.

Suggested Review Outcomes:

- identify the WQC/WQS adopted in the member economies for the protection of the aquatic resources and uses;
- identify the approach / methodology and the scientific rationales for deriving the WQC/WQS in the member economies;
- summarize the review findings in the form of report.

Linkages:

The proposed project is to collect information on the WQC/WQS adopted in the APEC economies. A questionnaire-based survey will be conducted to collect the required information and individual member economies will be approached. Support from the APEC economies is essential for completion of this project. Since the required information will be of technical nature, it is suggested that a contact point be identified in each member economies to facilitate the collection of information and liaison.

Dissemination of Project Output:

The project output will be documented in the form of a report in paper format. Copies of the report will be disseminated to all APEC economies for their reference.

The report, in electronic format, will be given to APEC for placing on the APEC Website to facilitate access to the findings by the public and private/business sector.

Meeting APEC Project Criteria:

This proposal has been prepared in accordance with APEC Guidelines.

______________________________ **Malcolm Broom**
Signature of Project Overseer

Date: 17/6/02

____
Signature of Committee / WG Lead Shepherd

Date: 18/6/02

APEC Marine Resource Conservation Working Group
2006 Project Proposal

Project Title
Water Quality Criteria or Standards adopted in the Asia Pacific Region (self-funded)

Proponent
Hong Kong, China

Co-sponsor

P.R. China
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APEC PROJECT PROPOSAL

Facesheet

Name of Committee/Working Group: Marine Resource Conservation Working Group (MRC WG)

Title of Project: Water Quality Criteria or Standards adopted in the Asia Pacific Region (Phase 3)

Proposing APEC Economy: Hong Kong, China

Co-sponsoring APEC Economies: P.R. China, Republic of Korea, Peru, Indonesia

Project number: *(To be filled in by Secretariat)*	Date received by Secretariat: *(To be filled in by Secretariat)*

(Tick ✓ one) [✓] **Project seeking APEC ~~funding~~ approval** [ ] **Progress Report** [ ] **Evaluation Report**

(Tick ✓ one if applicable) [ ] **Operational Account** [ ] **TILF Special Account** [ ] **APEC Support Fund**

(Tick ✓ if applicable) [ ] QAF attached QAF not applicable [ ] QAF attached

Financial Information	Total cost of proposal (US$):	**Amount being sought from APEC funding (US$):**
	Nil	Nil

Type of Project: [] seminar/symposium [] short-term training course [✓] survey or analysis and research
[ ] database/website [ ] others *(Please specify)*

Project start date: 9/2005	Project end date: 7/2007

Brief Description of Project -- its purpose and the principal activities (including when and where):

Purpose

To collect and compile the water quality criteria (WQC) or standards (WQS) adopted in the APEC economies, and identify the ways these WQC/WQS are derived.

Principal activities

- Questionnaire-based surveys to collect the information from the member economies.
- Follow-up with individual economies for clarification purposes or for additional information.
- Compilation of the collected data.
- Reporting of the findings.

Project Overseer: Name, Title and Organization (M/~~F~~)

Dr Hung Yiu YEUNG, Principal Environmental Protection Officer (Acting), Water Policy Group, Environmental Protection Department, Hong Kong Special Administration Region Government

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Signature of Project Overseer:

(Separate written confirmation acceptable for email submission) Date:

Signature of Committee Chair/WG Lead Shepherd: *(Not applicable to Progress Report and Evaluation Report)*

(Separate written confirmation acceptable for email submission) Date:

Details of the Project Proposal

Please provide your answers in point form or as succinctly as possible below each paragraph heading.

A. Project Design

Project Objectives

1) Describe briefly how this project directly responds to the priorities set by APEC Leaders and Ministers and/ or the vision of the host economy. Please make reference to the relevant parts of APEC documents.

The health of the marine environment is crucial to its continuing economic well-being and sustainable development. Among the APEC economies, most members have established their own water quality criteria/standards to protect aquatic resources and uses. This project collates the information on the water quality criteria/standards and helps make available a reference guide for member economies to access the information.

The output of the project presents a global review of the water management systems adopted in the Asia-Pacific economies. It will enable economies to more fully understand various approaches and tools used in the system, which will in turn, help economies develop and integrate regional strategies for further sectoral and multi-sectoral ocean management

This project responds to :

1. **Priorities identified in Manila Declaration (1996)**
   - Harness technologies for the future – to promote information flow and technology
   - Safeguard the quality of life through environmental sound growth – to promote sound policies and practices taking into account concerns about sustainable development

2. **Objectives and Tools identified in The Strategy to Address Sustainability of the Marine Environment within APEC (1997)**
   Objectives
   - Integrated approaches to coastal management
   - Prevention, reduction and control of marine pollution
   - Sustainable management of marine resources

   Tools
   - Research, exchange of information, technology and expertise
   - Capacity building, training and education

3. **Priorities identified in Seoul Oceans Declaration (2002)**
   - Develop and promote the use of integrated coastal zone management policy and frameworks
   - Improve the conservation and sustainable management of important and critical coastal and marine habitats and related ecosystem
   - Strengthen cooperation for building capacity, sharing information and expertise

2) Describe the **key objectives** of the project – *usually no more than three*

- Collect information from member economies concerning the water quality criteria/standards and how they are derived;
- Review the collected information particularly the approach/methodology and the scientific rationales for deriving the water quality criteria/standards;
- Summarize and compare the water quality criteria/standards adopted in different member economies and outline the approach and rationales for their derivation.

3) **Assessment.** With reference to each objective in paragraph 2), provide the **current status** and expected **end-of-project target,** so that the success of the project can be measured over the short and medium term. *The targets should be quantitative but if this is not possible then a precise description of the change aimed at should be given. Where appropriate, sex-disaggregated data should be used for assessment in order to detect any differential impact of the project on men and women.*

Current Status

- The project is carried out in phases.
- Phase 1 started in September 2002 and ended in August 2003. A report was prepared presenting the initial findings of the questionnaire-based surveys involving 15 economies (Hong Kong, China included), with focus on the general framework of the individual water quality criteria systems, the classification of beneficial uses and the values of the criteria.
- Phase 2 started in early 2004 and completed in May 2005. A report was prepared presenting an overview of the approach/methodology and the scientific rationales used by some economies for deriving the water quality criteria/standards.
- Phase 3 will commence after obtaining APEC approval. Phase 3 involves (i) an in-depth review on water quality criteria/standards for two parameters, namely dissolved oxygen and nutrient, for purpose of illustrating the designation rationale and derivation process, and (ii) preparation of the final report.

End-of-project target

- Identify the water quality criteria/standards adopted in the member economies for the protection of the aquatic resources and uses;
- Identify the approach/methodology and the scientific rationales for deriving the water quality criteria/standards in the member economies;
- Summarize the review findings in the form of report.

4) Explain who the intended beneficiaries of this project are.

All member economies are the intended beneficiaries of this project, primarily the water quality management authority of each economy, which is tasked with the development and implementation of the water quality criteria/standards. Other water quality professionals could also benefit from this project, e.g. scientists, consultants, etc.

5) Describe precisely the expected **project outputs**. Describe how these outputs will benefit the targeted beneficiaries.

The objectives of the project are to collect and compile the water quality criteria/standards adopted in the APEC economies and identify the ways they are derived. The findings of the project will provide the APEC economies with a better understanding of the water quality criteria/standards adopted in other member economies and thus enhance better cooperation and collaboration work in the region. This will better allow member economies the opportunity to develop clear water quality targets aimed at protecting specific marine resource functions, in circumstances which allow those targets to be tailored to the particular needs of individual economies.

The project output will be documented in the form of a report. Copies of the report will be disseminated to all APEC economies for their reference. An electronic copy will also be given to APEC for place on the website to facilitate access by the public and private/business sector.

6) For applications under the TILF Special Account: Describe briefly how this project will contribute to the APEC Trade and Investment Liberalization and Facilitation (e.g. relevance to specific parts of the Osaka Action Agenda).

Not applicable.

Linkages

7) Which other APEC fora have been consulted about this project and what were the results?

No other APEC fora have been consulted.

8) **Active Participation** Describe how the intended beneficiaries among APEC stakeholders –APEC fora, governments, private sector and civil society, men/women- will participate in the planning, implementation and evaluation of the project.

The 14 member economies covered by this project, namely, Australia, Brunei Darussalam, Canada, Chile, People's Republic of China, Malaysia, New Zealand, Papua New Guinea, Peru, Republic of Philippines, Singapore, Chinese Taipei, Thailand, United States of America, will be contacted in the beginning and at the end of the third phase to obtain comments on the report(s) prepared and further information on specific topics relating to the in-depth review on the two selected water quality criteria/standards.

9) **Project influence** Describe how this project might contribute to any current or completed projects or activities in APEC or elsewhere. Why is APEC the most appropriate institution to fund the project?

The coastal marine environments of Asia-Pacific region are important natural resources in terms of fisheries, aquaculture, tourism and recreation. Coastal and ocean environments are subject to pollution from anthropogenic wastes resulting in loss of economic and social benefits that these resources otherwise provide. To address the problems of maintaining viable marine environments within the context of sustainable growth and development, many economies undertake the development of water quality criteria/standards that limit the extent to which marine environments can be altered by human activities. This project helps disseminate the important and crucial information on the development processes that have been established by some member economies, facilitating other members in their water quality policy and strategy development.

Methodology

10) Describe the project's **methodology**. Break down the project implementation into discrete functional steps over time with the associated outputs clearly specified. Identify the principal risks involved in each step if any, and explain how they will be managed. *Risks may include major delays and failures, expected cooperation not materializing, etc.*

Step		**Method**	**Output**	**Risk**
1.	Seeking comments from concerned economies on Phase 2 Report and recommendations for improvement	• Written correspondence	Comments of economies	Nil
2.	Collation of information relating to the two selected parameters for in-depth review	• Internet search • Written correspondence	Draft Phase 3 Report	Nil
3.	Seeking comments from concerned economies on the draft Phase 3 Report	• Written correspondence	Phase 3 report	Nil
4.	Preparation of the final report	• Internet search • Report writing	Draft final report	Nil
5.	Seeking comments from concerned economies on the draft final report	• Written correspondence	Final Report	Nil

11) Which APEC member economies will participate in each component of this project and what contributions are they expected to make?

The 14 economies covered in this project will be contacted to provide comments and further information pertaining to the completion of this project. Please see the answers to question no. 8 and no. 10 for more details.

Dissemination of Project Output

12) Please include a plan for the publication and dissemination of the results of the project, including:

a. the nature of the target audience;

All interested water management authorities and water quality professionals.

b. the form and content;

A report comprising an account of the water quality criteria/standards adopted in the member economies for the protection of the aquatic resources and uses; the approach/methodology and the scientific rationales for deriving the water quality criteria/standards in the member economies; and an in-depth review on two parameters, namely, dissolved oxygen and nutrients. A database of the adopted water quality criteria/standards is also included.

c. format (e.g. hard copies, floppy discs, internet uploading);

Hardcopy, Softcopy, Internet uploading.

d. number of copies for the publication;

50 nos.

e. a publicity plan for: Not applicable.

i) briefing the general or specialist media about key components of the project;

ii) the promotion of sales or other dissemination of the final product; and

f. a budget for publication and dissemination, to form part of the itemized budget.

Not applicable.

Gender Concerns

13) Many projects have the potential to affect men and women differently because of their different roles and positions in many societies. What steps does this project take to ensure that it benefits both groups and in particular does not disadvantage women? *(Common responses include: using gender analysis to design project methodologies and inputs (e.g. surveys); including women in the planning, management, allocation of resources and implementation of a project; taking steps to ensure equitable participation by men and women; making special efforts to disseminate project results to women; and using sex-disaggregated data for project assessment.)*

There is no limitation to any gender in any form of participation in this project.

14) Show how the objectives of the project provide benefits for women. APEC Ministers have indicated (*Framework for the Integration of Women in APEC*) that benefits might include: increasing the involvement of women in the economy and economic institutions; integrating women into the global economy; strengthening small and medium sized enterprises; and reducing gender inequalities, including through education and training.

Women from all APEC economies are free to get involved in this project and they will not be limited to gain access to the materials prepared. The information presented in the reports would help build their capacity in water quality management.

Budget

15) Please attach an itemized budget for the project in the format at Annex A1. Where appropriate, provide details of the project's budget that are allocated to activities that address the specific needs of women. The budget should illustrate the assumptions adopted (e.g. unit costs) for the computations. *Remember to include all self-funding and to consult the list of eligible expenses in the Guidebook to APEC Projects. Advice on budget formulation, including acceptable unit costs, can be sought from the APEC Secretariat.*

A1
A2

Not applicable. This is a self-funded project, hence the budget estimate is not attached.

16) A timetable for the drawdown of APEC funding requested for the project, including details of any advance payment or instalment payment requested and justifications for such requests.

Not applicable.

17) Details of any request for waiver or exception from the normal APEC financial rules with justifications. (*Examples are from tendering requirements; for advance payment; for government officials to receive funding; for active participants from travel-eligible economies to receive per diems*)

Not applicable.

18) **NOT required for projects for consideration at BMC II (July/ August meeting) or for ASF projects but required for all others.** Give reasons for the urgency of the project. (*These projects should relate to previous APEC Ministers' or Leaders' Declarations or current host economy's priorities. Reasons may include the project output as contributing to one of the major deliverables for the year)*

Not applicable.

APEC Project

Itemized Budget for Financial Year _______*

(Please tick ✓.)

This project is:

- ☐ a seminar, symposium or short-term training course
- ☐ a survey or analysis and research project
- ☐ neither the above but involves the provision of equipment

Items	No. of Units	Unit Rate	**APEC Funding (USD)**	**Self Financing (USD)**
Direct Labour				
Speaker's Honorarium (*government officials ineligible)*	(no. of speakers)			
- Translator's Fees	(no. of pages)			
- Short-term clerical and secretarial staff remuneration	(no. of hours)			
- Consultant (including Researcher) Fees	(no. of hours)			
- Consultant's Secretary Cost	(no. of hours)			
Travel (Speakers/Experts/ Researchers)				
- Per Diem (incl. accommodation and "additional payment")	(no. of persons and days)			
- Airfare	(no. of persons and trips)			

* If project will continue for more than one year, please indicate the amount of funds required for each of the two financial years in question.

Travel (Active participants/ participants/trainees) *(only from travel-eligible economies)*				
- Per Diem (incl. accommodation and "additional payment") (*active participants)*	(no. of persons and days)			
- Airfare (*restricted economy class)*	(no. of persons and trips)			
Other items				
Publication of report (including distribution)	(no. of copies)			
Equipment / Materials (*describe briefly what is required and why*)	(no. and type of equipment) (no. of days for rental)			
Photocopying	(no. of copies)			
Communications (Phone/ Fax/ Mail/ Courier)				
*Hosting (*pl. briefly describe, e.g., conference room rental, stationery)	(units as appropriate) (no. of days for rental)			
Total				

Appendix B

Information on Water Quality Criteria / Water Quality Standards

Contact Person List

	APEC Economy	Contact Person	Email Address	Authority	Phone No.	Fax No.
1.	Australia	Mr. Richard Nott	richard.nott@deh.gov.au	**Department of the Environment and Heritage** Water Quality Section Land Water and Coasts Division GPO Box 787 Canberra ACT Australia, 2601	(61) 2 6274 1636	(61) 2 6274 1006
2.	Brunei Darussalam	Mr. Sabri Hj mohd Taha	sabri_taha@fisheries.gov.bn	**Fisheries Department** PDQC Division Ministry of Industry and Primary Resources	(673) 2 770234	(673) 2 770237
3.	Canada	Mr. J. Roderick Forbes	forbesr@dfo-mpo.gc.ca	**Fisheries and Oceans Canada** International Policy Coordination 200 Kent Street Ottawa, KIA OE6, Canada	(613) 993 2539	(613) 990 9574
4.	Chile	Mr. Pablo Daud Miranda	pabarca@conama.cl pgabarca@terra.cl	**National Commission for the Environment** Jefe Deaprtamento de Operaciones Comisi-n Nacional del Medio Ambiente Teatinos 254 Santiago, Chile	(56) 2 240 5676 (direct) (56) 2 240 5600 (Central)	(56) 2 244 1262 (56) 2 240 5782
5.	P.R. China	Ms. Yue Chen	zzh@soa.gov.cn	**State Oceanic Administration** Department of Cooperation 1 Fuxingmenwai Avenue Beijing, China 100860	(86) 10-68019791	(86) 10-68048051
6.	Hong Kong	Dr. HungYiu Yeung	hyyeung@epd.gov.hk	**Environmental Protection Department** Water Policy Division The Government of the HKSAR 33/F, Revenue Tower, 5 Gloucester Road,Wan Chai Hong Kong, China	(852) 2594 6321	(852) 2827 8040
7.	Malaysia	Dr. Kamaruzaman Bin Hj Salim	kamsal01@dof.moa.my	**Department of Fisheries** Ministry of Agriculture Wisma Tani Jalan Sultan Salahuddin 50624 Kuala Lumpur	(620) 3 295 4620 (620) 3 298 2011 (ext 4620)	(620) 3 291 0305 (620) 3 297 9744 (620) 3 294 2984

	APEC Economy	Contact Person	Email Address	Authority	Phone No.	Fax No.
8.	New Zealand	Mr. Brigit Stephenson	brigit.stephenson@mfe.govt.nz	**Ministry for the Environment – Manat-M-Te Taiao** Oceans Policy Secretariat Level 11, Grand Annexe, 84 Boulcott Street PO Box 10-362 Wellington, New Zealand	(64) 4 917 7550 – direct line (64) 4 917 7400 – Ministry of the Environment 0274 535 599 (Mobile)	(64) 4 917 7521
9.	Papua New Guinea	Mr. Luke Tanikrey	odir@daltron.com.pg	**Department of Environment & Conservation** Office of Environment and Conservation Cnr. Sir John Guise Drv. 7th Floor Somare Foundation Building P O Box 6601, Boroko, NCD Papua New Guinea	(675) 325 0194	(675) 325 0182
10.	Peru	Mr. Sulma Carrasco Barrera	dinama@minproduce.gov.pe	**Ministry of Production** National Direction of Environment Calle Uno Oeste Nº60, Corpac San Isidro Peru	(51) 1 224 3231	(51) 1 224 3231
11.	Philippines	Mr. Jim Tito B. San Agustin	jbsanagustin@dfa.gov.ph	**Office of the Undersecretary for International Economic Relations** Department of Foreign Affairs 14/F Office of the Undersecretary for International Economic Relations 2330 Roxas Boulevard, Pasay City The Philippiness	(632) 834 3033	(632) 834 1451
12.	Singapore	Mrs. Renee Chou	chew_hong@ava.gov.sg	**Agri-food & Veterinary Authority of Singapore** Food Supply & Technology Department Technology Division 5 Maxwell Road #03-00 Tower Block MND Complex Singapore 069110	(65) 6325 7637	(65) 6325
13.	Chinese Taipei	Ms. Sun Hone Ling	hlsun@sun.epa.gov.tw	**Bureau of Water Quality Protection Environmental Protection Administration** 41, Sec.1, Chung-Hwa Road, Taipei Taiwan 100 Chinese Taipei	(886) 2 2311 7722 ext 2842	(886) 2 2387 9860
14.	Thailand	Ms. Nipavan Bussarawit	ta_pmbc@yahoo.com bnipavan@hotmail.com	**Head of the Fishery Oceanography Unit** Phuket Marine Biological Center Department of Fisheries P.O. Box 60 Phuket 83000 Thailand	(66) 76 391128 (66) 76 391438	(66) 76 391127

APEC Economy		Contact Person	Email Address	Authority	Phone No.	Fax No.
15.	USA	Mr. Patrick J. Cotter	cotter.patrick@epa.gov	**U.S. Environmental Protection Agency** International Activities Specialist U.S. Environmental Protection Agency Office of International Affairs (2660R) 1200 Pennsylvania Avenue, N.W. Washington, D.C. 20460-0001	202-564-6414	202-566-2409

Appendix C : On-line Access to WQC/WQS

APEC Economy	Listing of WQC/WQS can be found at :
Australia	Water Quality Guidelines : http://www.ea.gov.au/water/quality/nwqms/index.html#quality Microbiological Water Quality Guidelines : http://www.mfe.govt.nz/publications/water/microbiological-quality-jun03/ Water Quality Targets : http://www.ea.gov.au/water/quality/targets/ Monitoring Guidelines : http://www.ea.gov.au/water/quality/nwqms/index.html#quality
Brunei	Government of Brunei Darussalam: http://www.brunei.gov.bn/government/index.htm
Canada	Water Quality Guidelines : http://www.ec.gc.ca/ceqg-rcqe/English/Ceqg/Water/default.cfm#dri Drinking Water Quality Guidelines : http://www.ec.gc.ca/ceqg-rcqe/English/Ceqg/Water/default.cfm#dri Recreational Water Quality Guidelines : http://www.ec.gc.ca/ceqg-rcqe/English/Ceqg/Water/default.cfm#rec
Chile	Government website : http://www.conama.cl/portal/1255/channel.html
China	Environmental Protection Standards : http://www.zhb.gov.cn/english/standards.php3
Hong Kong	Water Quality Objectives (Water Pollution Control Ordinance, Cap 258) : http://www.justice.gov.hk/home.htm Effluent Standards : http://www.epd.gov.hk/epd/english/environmentinhk/water/guide_ref/guide_wpc_wpco_1.html
Malaysia	Department of Environment : http://www.doe.gov.my/index.php?option=com_frontpage&Itemid=1&lang=en
New Zealand	Water Quality Guidelines : http://www.ea.gov.au/water/quality/nwqms/index.html#quality Microbiological Water Quality Guidelines : http://www.mfe.govt.nz/publications/water/microbiological-quality-jun03/ Water Quality Targets : http://www.ea.gov.au/water/quality/targets/ Monitoring Guidelines : http://www.ea.gov.au/water/quality/nwqms/index.html#quality
Papua New Guinea	Government of Papua New Guinea : http://www.pngonline.gov.pg/government/entry.nsf
Peru	Website in Spanish.
Philippines	Environmental Management Bureau: http://www.emb.gov.ph/wqms/water1.htm
Singapore	Effluent discharge standards : http://app.nea.gov.sg/cms/htdocs/article.asp?pid=963
Chinese Taipei	Effluent discharge standards : http://www.epa.gov.tw/english/offices/g/effluentstd.htm Drinking water management : http://www.epa.gov.tw/english/webezA-6/code/main1.asp?catNo=3&cat=Drinking%20Water%20Mgmt.
Thailand	Water Quality Standards : http://www.pcd.go.th/info_serv/en_reg_std_water.html
USA	Quality Criteria for Water : www.epa.gov/waterscience/criteria Water Quality Standards : http://www.epa.gov/waterscience/standards/

Appendix D : References

Economy	Title/Description	Available on internet
Australia and New Zealand	ANZECC & ARMCANZ 2000a. ***Australian and New Zealand guidelines for Fresh and Marine Water Quality***: National Water Quality Management Strategy Paper No. 4, Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, Canberra.	Yes
	ANZECC & ARMCANZ 2000b. ***Australian Guidelines for Water Quality Monitoring and Reporting.*** National Water Quality Management Strategy Paper no 7, Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australian and New Zealand, Canberra.	Yes
	ANZECC 1992, ***Australian Water Quality Guidelines for Fresh and Marine Waters***, National Water Quality Management Strategy Paper No. 4, Australian and New Zealand Environment and Conservation Council, Canberra.	Yes
	EPA, Queensland 2004. ***Information Report Environmental Values Projects – Moreton Bay / South-east Queensland, Mary River Basin / Grate Sandy Region and Douglas Shire Waters.*** Environmental Protection Agency, Queensland, Australia.	Yes
	EPA, Queensland 2005. ***Draft Queensland Water Quality Guidelines 2005*** Environmental Protection Agency, Queensland, Australia.	Yes
	EPA, Victoria 2003. ***Water Quality Objectives for Rivers and Streams – Ecosystem Protection.*** Publication 791.1. Environmental Protection Authority, Victoria, Australia.	Yes
	EPA, Victoria 2003. ***Nutrient Objectives for Rivers and Streams – Ecosystem Protection.*** Publication 792.1. Environmental Protection Authority, Victoria, Australia.	Yes
Canada	AEP 1996. ***Protocol to Develop Alberta Water Quality Guidelines for Protection of Freshwater Aquatic Life.*** Environmental Assessment Division, Environment Regulatory Service, Alberta Environment Protection, Canada.	Yes
	AEP 1997. ***Alberta Water Quality Guideline for the Protection of Freshwater Aquatic Life, Dissolved Oxygen.*** Standards and Guidelines Branch, Environmental Assessment Division, Environmental Regulatory Service, Alberta Environment Protection, Canada.	Yes
	CCME 1999. ***Canadian Environmental Quality Guidelines – Canadian Water Quality Guidelines for the Protection of Aquatic Life, Dissolved Oxygen (Marine).*** Canadian Council of Ministers of the Environment, Winnipeg, Canada.	No
	CCME 1999. ***Canadian Environmental Quality Guidelines – Canadian Water Quality Guidelines for the Protection of Aquatic Life, Dissolved Oxygen (Freshwater).*** Canadian Council of Ministers of the Environment, Winnipeg, Canada.	No
	CCREM 1987. ***Canadian Water Quality Guidelines.*** Task Force on Water Quality Guidelines, Canadian Council of Resource and Environment Ministers.	No
	Manitoba Conservation 2000. ***Information Bulletin – Development of a Nutrient Management Strategy for Surface Waters in Southern Manitoba.*** 2000-02E. Water Quality Management Section, Manitoba Conservation, Winnipeg, Canada.	Yes

Economy	Title/Description	Available on internet
Canada	Nordin 1985. ***Water Quality Criteria for Nutrients and Algae, Technical Appendix.*** Nordin, R.N. Prepared for Ministry of Environment, Province of British Columbia, Canada.	Yes
	Saskatchewan Environment, 1997. ***Surface water Quality Objectives.*** MB 117. Environmental Protection Branch, Saskatchewan Environment and Resource Management, Canada.	Yes
	Truelson 1997. ***Ambient water Quality Criteria for Dissolved Oxygen.*** Prepared for Water Management Branch, Environment and Lands Headquarters Division, Ministry of Environment, Lands and Parks, British Columbia, Canada.	Yes
USA	Ebersole, E., Lane, M., Olson, M., Perry, E., Roman, B. 2002. ***Assumptions and Procedures for Calculating Water Quality Status and Trends in Tidal Waters of the Chesapeake Bay and its Tributaries, A Cumulative History.*** DNR, Old Dominion University, NOAA Chesapeake Bay Office.	Yes
	Kenneth, A., Moore, David J. Wilcox, Britt Anderson, Thomas A., Parham, Micheal D. Naylor 2004. ***Historical Analysis of Submerged Aquatic Vegetation (SAV) in the Potomac River and Analysis of Bay-wide SAV data to Establish a New Acreage Goal.*** The Virginia Institute of Marine Science, School of Marine Science, College of William and Mary Gloucester Point, Virginia 23062, The Maryland Department of Natural Resources, Maryland 21401.	Yes
	USEPA 1985. ***Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and their Uses.*** EPA-822-R-8510, Jan 1985. USEPA Office of Research and Development, Environmental Research Laboratories Duluth, Minnesota.	No
	USEPA 1986. ***Ambient Water Quality Criteria for Dissolved Oxygen***. Criteria and Standards Division. US Environmental Protection Agency, Washington, D.C. EPA. 440/5-86-003.	Yes
	USEPA 1998. ***National Strategy for the Development of Regional Nutrient Criteria.*** EPA-822-R-98-002, June 1998. USEPA Office of Water.	Yes
	USEPA 2000a. ***Ambient aquatic life Water Quality Criteria for Dissolved Oxygen (saltwater) : Cape Cod to Cape Hatteras.*** EPA-822-R-00-012, November 2000. USEPA Office of Water.	Yes
	USEPA 2000b. ***Chesapeake Bay Submerged Aquatic Vegetation Water Quality and Habitat-based Requirements and Restoration Targets : a Second Technical Synthesis.*** Chesapeake Bay Program.	Yes
	USEPA 2000c. ***Nutrient Criteria Technical Guidance Manual, Lakes and Reservoirs.*** EPA 822-B00-001, Apr 2000. USEPA Office of Water and Office of Science and Technology.	Yes
	USEPA 2000d. ***Nutrient Criteria Technical Guidance Manual, Rivers and Streams.*** EPA 822-B-00-002, Jul 2000. USEPA Office of Water and Office of Science and Technology.	Yes
	USEPA 2001. ***Nutrient Criteria Technical Guidance Manual, Estuarine and Coastal ,Marine Waters.*** EPA 882-B-01-003, October 2001. USEPA Office of Water.	Yes

Economy	Title/Description	Available on internet
USA	USEPA 2002. ***Draft strategy for Water Quality Standards and Criteria : Strengthening the Foundation of Programs to Protect and Restore and Nation's Waters.*** EPA-823-R-02-001, May 2002. USEPA Office of Water.	Yes
	USEPA 2003a. ***Ambient Water Quality Criteria for Dissolved Oxygen, Water clarity and Chlorophyll-a for the Chesapeake Bay and its Tidal Tributaries.*** EPA 903-R-03-002, April 2003. USEPA Region III Chesapeake Bay Program Office, Annapolis, Maryland.	Yes
	USEPA 2003b. ***Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability.*** EPA 903-R-03-004, August 2003. USEPA Region III Chesapeake Bay Program Office, Annapolis, Maryland. Washington.	Yes