

WATER POLLUTION CONTROL

A guide to the use of water quality
management principles

Edited by
Richard Helmer and Ivanildo Hespanhol

PUBLISHED ON BEHALF OF



WORLD HEALTH
ORGANIZATION

Water
Pollution
Control



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FOREWORD

Publication of this book is a milestone for the Water Supply and Sanitation Collaborative Council. It demonstrates the Council's unique capacity to bring together water and sanitation professionals from industrialised and developing countries to formulate practical guidance on a key issue of the day.

Industrialised countries have extensive experience of the problems caused by water pollution and the strategies and technologies available to control it. In the developing world, although pollution is increasing rapidly with urbanisation and industrialisation, most countries have very limited experience of pollution control measures or of the institutional and legislative frameworks needed to make such measures effective. On the other hand, the Collaborative Council's developing country members have the specialist knowledge and skills with which to adapt the practices of the industrialised nations to their own circumstances.

This synergy among members is at the heart of the Council's approach to sector issues. By mandating specialist working groups to seek out good practices, to analyse them and to reach agreement on the best way forward, the Council is able to give its members authoritative guidance and tools to help them face their own particular challenges.

Water pollution control is clearly one of the most critical of those challenges. Without urgent and properly directed action, developing countries face mounting problems of disease, environmental degradation and economic stagnation, as precious water resources become more and more contaminated. At the Earth Summit in Rio de Janeiro in June 1992, world leaders recognised the crucial importance of protecting freshwater resources. Chapter 18 of Agenda 21 sees "effective water pollution prevention and control programmes" as key elements of national sustainable development plans.

At its second Global Forum, in Rabat, Morocco, in 1993, the Collaborative Council responded to the Rio accord by mandating a Working Group on Water Pollution Control, convened jointly with the World Health Organization and the United Nations Environment Programme. We were fortunate that Richard Helmer from the World Health Organization agreed to co-ordinate the Working Group. Richard had been a prime mover in the preparation of the freshwater initiatives endorsed in Rio de Janeiro and so was particularly well placed to ensure that the Group's deliberations were well directed. Experts from developing countries, UN agencies, bilaterals, professional associations, and academic institutions have all contributed over the last three and a half

years. The Council is grateful to them, and I want to express my own personal appreciation for the voluntary time and effort they have devoted to the task.

The result is a comprehensive guidebook which I know will be a valuable tool for policy makers and environmental managers in developing and newly industrialised countries as they seek to combat the damaging health, environmental and economic impacts of water pollution. The council will play its part in advocacy and promotion. We all owe a duty to future generations to safeguard their water supplies and to protect their living environment.

A handwritten signature in black ink, appearing to read 'M. Catley-Carlson', with a long horizontal flourish extending to the right.

Margaret Catley-Carlson,
Chair, Water Supply and Sanitation Collaborative Council

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The work was directed by a core group of staff from the World Health Organization (WHO), the United Nations Environment Programme (UNEP), the United Nations Centre for Human Settlements (UNCHS), the Food and Agriculture Organization of the United Nations (FAO) and experts from bilateral agencies who are members of the Water Supply and Sanitation Collaborative Council, WHO collaborating centres and experts from developing and newly industrialising countries. The activities have been implemented together with UNEP, the Danish Water Quality Institute (VKI), the Institute for Inland Water Management and Wastewater Treatment in the Netherlands (RIZA), the International Institute for Infrastructural, Hydraulic and Environmental Engineering of the Netherlands (IHE), the World Bank, the WHO Collaborating Centre for Water Quality Control, and the WHO European Centre for Environment and Health/Nancy Project Office. Other international organisations, in particular the International Association for Water Quality (IAWQ) and the International Water Resources Association (IWRA) have provided support to the Working Group. Additional support has also been received from bilateral and other external support agencies, particularly the Ministry of Foreign Affairs/DGIS of the Netherlands. Financial support for the activities undertaken by the Working Group has been provided by UNEP and by the Government of the Netherlands.

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The draft text for this book was reviewed by the Working Group members through meetings and written comments and amendments. The broad range of issues and the wide geographical scope covered by the Working Group can best be demonstrated through complete listings of all members as given in the Appendix. In this way the co-sponsoring agencies and the editors would like to express their great appreciation for the dedication given by all participants to this project. The book would, however, not have been possible without the editorial assistance of Dr Deborah Chapman who undertook technical and language editing as well as layout and production management, in collaboration with the publisher. As the editor of the UNEP/WHO co-sponsored series of guidebooks dealing with various aspects of water quality management, she was responsible for ensuring compatibility with *Water Quality Assessments* and *Water Quality Monitoring*, two of the other books in the series.

Chapter 1*

POLICY AND PRINCIPLES

1.1 Introduction

During recent years there has been increasing awareness of, and concern about, water pollution all over the world, and new approaches towards achieving sustainable exploitation of water resources have been developed internationally. It is widely agreed that a properly developed policy framework is a key element in the sound management of water resources. A number of possible elements for such policies have been identified, especially during the preparation of Agenda 21 as well as during various follow up activities.

This chapter proposes some general principles for the policy making process and for policy document structure. Some examples of policy elements which support the overall sustainable management of water resources are also given.

1.2 Policy framework

Policy statements regarding water pollution control can be found within the legislative framework of most countries. However, the statements are often "hidden" in official documents, such as acts of government, regulations, action and master plans. Moreover, government statutes and constitutional documents often include paragraphs about environmental policies. Such statements are rarely coherent, and inconsistencies with other policies often exist because they have been developed separately with different purposes.

Water pollution control is usually specifically addressed in connection with the establishment of environmental legislation and action plans, but also within the framework of water resources management planning. Moreover, documents related to public health aspects may also consider water pollution. These three interacting areas are often administered in different line ministries — typically a Ministry of Environment, a Ministry of Water and a Ministry of Health. In addition, the policy making process, if it exists, may often take place independently.

* *This chapter was prepared by H. Larsen, N.H. Ipsen and L. Ulmgren*

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To reach a situation where the adopted political intentions can result in a real impact on the practical management of water resources, it is important to define policy statements clearly and in proper policy documents. It is recommended that the water pollution control policy statements either be placed within a water resources policy document or within an environment policy document, or the statements can form a document in themselves, referring to overall health–water and resources–environment policies. The approach selected will depend on the administrative organisation of water resources and environmental management in a particular country.

Some general principles that should be considered within the policy making process are as follows:

- A water pollution control policy, ideally, should be seen as part of a coherent policy framework ranging from overall statements such as can be found in government statutes, constitutions, etc., to specific policy statements defined for environment and water resources management as well as for particular sector developments.
- The policy making process should therefore incorporate consultations and seek consensus with all line ministries relevant for water resources management, including organisations responsible for overall economic development policies. In addition, when formulating new development policies for other sectors, water resources policy statements should be taken into account where appropriate.
- Policy statements must be realistic. Good intentions reflected in statements such as “No pollution of surface waters shall occur...” cannot be applied in practice and therefore become meaningless in the context of an operational policy.
- The statements in a policy document need to be relatively long-lived because they must pass a laborious political adaptation process. Thus, detailed guidelines, which may need regular adaptation to the country’s actual development level, should be avoided and placed into the more dynamic parts of the legislation system, such as the regulation framework, that can be amended at short notice.

1.2.1 The policy document

A policy document should be formulated clearly and concisely, but at the same time it must be operational. This means that the statements should be easily understood and the document should form a guide for administrators formulating laws and regulations as well as those enforcing, and thereby interpreting, such texts. To fulfil these requirements the policy document should include, in addition to very general statements, well explained guiding

principles for water pollution management as well as outlines for strategies for the implementation of the policy.

1.2.2 Overall policy statements

The overall policy statements, relevant for water pollution control, define a government's concept of the water resources as well as its long-term priorities for exploitation of the resource. These statements should, preferably, be derived from the country's general environment and water resources management policies. They should also document the government's willingness to let management instruments ensure the long-term protection and sustainable exploitation of water resources along with social and economic development.

Agenda 21 adopted some conceptual statements concerning water resources, but which apply to water pollution control as well as to other elements of water resources management. Two central statements were "*Fresh water should be seen as a finite and vulnerable resource, essential to sustain life, development and the environment*" and "*Water should be considered as a social and economic good with a value reflecting its most valuable potential use*". The latter statement suggests an overall concept for prioritising water-related development activities.

1.3 Guiding principles for water pollution control

The guiding principles of the policy document put the political intentions into more practical terms by setting a more detailed conceptual framework that supports the overall policy objectives. It is recommended that these principles should be clarified by a short narrative interpretation. The following guiding principles provide a suitable basis for sound management of water pollution.

Prevent pollution rather than treating symptoms of pollution. Past experience has shown that remedial actions to clean up polluted sites and water bodies are generally much more expensive than applying measures to prevent pollution from occurring. Although wastewater treatment facilities have been installed and improved over the years in many countries, water pollution remains a problem, including in industrialised countries. In some situations, the introduction of improved wastewater treatment has only led to increased pollution from other media, such as wastewater sludge. The most logical approach is to prevent the production of wastes that require treatment. Thus, approaches to water pollution control that focus on wastewater minimisation, in-plant refinement of raw materials and production processes, recycling of

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waste products, etc., should be given priority over traditional end-of-pipe treatments.

In many countries, however, an increasing proportion of water pollution originates from diffuse sources, such as agricultural use of fertilisers, which cannot be controlled by the approach mentioned above. Instead, the principle of “best environmental practice” should be applied to minimise non-point source pollution. As an example, codes of good agricultural practice that address the causes of water pollution from agriculture, such as type, amount and time of application of fertilisers, manure and pesticides, can give guidance to farmers on how to prevent or reduce pollution of water bodies. Good agricultural practice is recognised by the United Nations Economic Commission for Europe (UNECE) as a means of minimising the risk of water pollution and of promoting the continuation of economic agricultural activity (UNECE, 1993).

Use the precautionary principle. There are many examples of the application and discharge of hazardous substances into the aquatic environment, even when such substances are suspected of having detrimental effects on the environment. Until now the use of any substance and its release to the environment has been widely accepted, unless scientific research has proved unambiguously a causal link between the substance and a well-defined environmental impact. However, in most cases it takes a very long time to establish such causal links, even where early investigations suggest clear indications of such links. When, eventually, the necessary documentation is provided and action can be taken to abandon the use of the substance, substantial environmental damage may already have occurred. Examples of such situations include a number of pesticides which are now being abandoned because contamination of groundwater resources has been demonstrated.

The examples clearly show that action to avoid potential environmental damage by hazardous substances should not be postponed on the grounds that scientific research has not proved fully a causal link between the substance and the potential damage (UNECE, 1994).

Apply the polluter-pays-principle. The polluter-pays-principle, where the costs of pollution prevention, control and reduction measures are borne by the polluter, is not a new concept but has not yet been fully implemented, despite the fact that it is widely recognised that the perception of water as a free commodity can no longer be maintained. The principle is an economic instrument that is aimed at affecting behaviour, i.e. by encouraging and inducing behaviour that puts less strain on the environment. Examples of

attempts to apply this principle include financial charges for industrial wastewater discharges and special taxes on pesticides (Warford, 1994).

The difficulty or reluctance encountered in implementing the polluter-pays-principle is probably due to its social and economic implications (Enderlein, 1995). Full application of the principle would upset existing subsidised programmes (implemented for social reasons) for supply of water and removal of wastewater in many developing countries. Nevertheless, even if the full implementation of the polluter-pays-principle is not feasible in all countries at present, it should be maintained as the ultimate goal.

Apply realistic standards and regulations. An important element in a water pollution control strategy is the formulation of realistic standards and regulations. However, the standards must be achievable and the regulations enforceable. Unrealistic standards and non-enforceable regulations may do more harm than having no standards and regulations, because they create an attitude of indifference towards rules and regulations in general, both among polluters and administrators. Standards and regulations should be tailored to match the level of economic and administrative capacity and capability. Standards should be gradually tightened as progress is achieved in general development and in the economic capability of the private sector. Thus, the setting of standards and regulations should be an iterative and on-going process.

Balance economic and regulatory instruments. Until now, regulatory management instruments have been heavily relied upon by governments in most countries for controlling water pollution. Economic instruments, typically in the form of wastewater discharge fees and fines, have been introduced to a lesser extent and mainly by industrialised countries.

Compared with economic instruments, the advantages of the regulatory approach to water pollution control is that it offers a reasonable degree of predictability about the reduction of pollution, i.e. it offers control to authorities over what environmental goals can be achieved and when they can be achieved (Bartone *et al.*, 1994). A major disadvantage of the regulatory approach is its economic inefficiency (see also Chapter 5). Economic instruments have the advantages of providing incentives to polluters to modify their behaviour in support of pollution control and of providing revenue to finance pollution control activities. In addition, they are much better suited to combating non-point sources of pollution. The setting of prices and charges are crucial to the success of economic instruments. If charges are too low, polluters may opt to pollute and to pay, whereas if charges are too high they may inhibit economic development.

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Against this background it seems appropriate, therefore, for most countries to apply a mixture of regulatory and economic instruments for controlling water pollution. In developing countries, where financial resources and institutional capacity are very limited, the most important criteria for balancing economic and regulatory instruments should be cost-effectiveness (those that achieve the objectives at the least cost) and administrative feasibility.

Apply water pollution control at the lowest appropriate level. The appropriate level may be defined as the level at which significant impacts are experienced. If, for example, a specific water quality issue only has a possible impact within a local community, then the community level is the proper management level. If environmental impacts affect a neighbouring community, then the appropriate management level is one level higher than the community level, for example the river basin level.

On a wider scale, the appropriate management level may be the national level for major water bodies where no significant water pollution impacts are anticipated for neighbouring states. Where significant impacts occur in several nations, the appropriate management level is international (e.g. an international river basin commission). The important point is that decisions or actions concerning water pollution control should be taken as close as possible to those affected, and that higher administrative levels should enable lower levels to carry out decentralised management. However, in considering whether a given administrative level is appropriate for certain water pollution control functions, the actual capacity to achieve these functions (or the possibility of building it) at that level should also be taken into account. Thus, this guiding principle intends to initiate a process of decentralisation of water pollution control functions that is adapted to administrative and technical feasibility.

Establish mechanisms for cross-sectoral integration. In order to ensure the co-ordination of water pollution control efforts within water-related sectors, such as health and agriculture, formal mechanisms and means of co-operation and information exchange need to be established. Such mechanisms should:

- Allow decision makers from different sectors to influence water pollution policy.
 - Urge them to put forward ideas and plans from their own sector with impacts on water quality.
 - Allow them to comment on ideas and plans put forward by other sectors.
- For example, a permanent committee with representatives from the involved sectors could be established. The functions and responsibilities of the cross-sectoral body would typically include at least the following:

- Co-ordination of policy formulation on water pollution control.
- Setting of national water quality criteria and standards, and their supporting regulations.
- Review and co-ordination of development plans that affect water quality.
- Resolution of conflicts between government bodies regarding water pollution issues that cannot be resolved at a lower level.

Encourage participatory approach with involvement of all relevant stakeholders. The participatory approach involves raising awareness of the importance of water pollution control among policy-makers and the general public. Decisions should be taken with full public consultation and with the involvement of groups affected by the planning and implementation of water pollution control activities. This means, for example, that the public should be kept continuously informed, be given opportunities to express their views, knowledge and priorities, and it should be apparent that their views have been taken into account.

Various methods exist to implement public participation, such as interviews, public information sessions and hearings, expert panel hearings and site visits. The most appropriate method for each situation should take account of local social, political, historical, cultural and other factors. In many countries in transition, for example, only professional and scientific experts usually participate and other groups have mostly been excluded from the process. Public participation may take time but it increases public support for the final decision or result and, ideally, contributes to the convergence of the views of the public, governmental authorities and industry on environmental priorities and on water pollution control measures.

Give open access to information on water pollution. This principle is directly related to the principle of involvement of the general public in the decision-making process, because a precondition for participation is free access to information held by public authorities. Open access to information helps to stimulate understanding, discussions and suggestions for solutions of water quality problems. In many countries, notably the countries in economic transition and the developing countries, there is no tradition of open access to environmental information. Unfortunately, this attitude may seriously jeopardise the outcome of any international co-operation that is required.

Promote international co-operation on water pollution control. Trans-boundary water pollution, typically encountered in large rivers, requires international co-operation and co-ordination of efforts in order to be

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effective. Lack of recognition of this fact may lead to wasteful investments in pollution load reductions in one country if, due to lack of co-operation, measures are introduced upstream that have counteractive effects. In a number of cases (e.g. the Danube, Zambezi and Mekong rivers), permanent international bodies with representatives from riparian states have been successfully established, with the objective of strengthening international co-operation on the pollution control of the shared water resources.

A framework for international co-operation on water pollution control that has been widely agreed is the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (UNECE, 1994). Although some countries have already started international co-operation on water pollution control, there is still a huge need for concerted planning and action at the international level.

1.4 Strategy formulation

Strategy formulation for water pollution control should be undertaken with due consideration to the above mentioned guiding principles, as well as to other principles for water resources management laid down in various documents, e.g. Agenda 21, that have been widely agreed. When formulating a water pollution control strategy, it should be ensured that various complementary elements of an effective water pollution control system are developed and strengthened concurrently. For example, financial resources would not be used very effectively by spending them all on the formulation of policies and the drafting of legislation, standards and regulations, if there is no institutional capacity to fill the established framework and enforce the regulations.

The main components of a rational water pollution control system can be defined as:

- An enabling environment, which is a framework of national policies, legislation and regulations setting the scene for polluters and management authorities.
- An institutional framework that allows for close interaction between various administrative levels.
- Planning and prioritisation capabilities that will enable decision-makers to make choices between alternative actions based on agreed policies, available resources, environmental impacts and the social and economic consequences.

All three components are needed in order to achieve effective water pollution control and it is, therefore, advisable to develop all three components hand-in-hand.

At the policy level the strategy must provide general directions for water quality managers on how to realise the objectives of the water pollution control policies and on how to translate the guiding principles into practical management. The strategy should provide adequate detail to help identify and formulate concrete actions and projects that will contribute to achieving the defined policies.

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Chapter 2*

WATER QUALITY REQUIREMENTS

2.1 Introduction

Control of water pollution has reached primary importance in developed and a number of developing countries. The prevention of pollution at source, the precautionary principle and the prior licensing of wastewater discharges by competent authorities have become key elements of successful policies for preventing, controlling and reducing inputs of hazardous substances, nutrients and other water pollutants from point sources into aquatic ecosystems (see Chapter 1).

In a number of industrialised countries, as well as some countries in transition, it has become common practice to base limits for discharges of hazardous substances on the best available technology (see Chapters 3 and 5). Such hazardous water pollutants include substances that are toxic at low concentrations, carcinogenic, mutagenic, teratogenic and/or can be bioaccumulated, especially when they are persistent. In order to reduce inputs of phosphorus, nitrogen and pesticides from non-point sources (particularly agricultural sources) to water bodies, environmental and agricultural authorities in an increasing number of countries are stipulating the need to use best environmental practices (Enderlein, 1996).

In some situations, even stricter requirements are necessary. A partial ban on the use of some compounds or even the total prohibition of the import, production and use of certain substances, such as DDT and lead- or mercury-based pesticides, may constitute the only way to protect human health, the quality of waters and their aquatic flora and fauna (including fish for human consumption) and other specific water uses (ECLAC, 1989; UNECE, 1992; United Nations, 1994).

Some water pollutants which become extremely toxic in high concentrations are, however, needed in trace amounts. Copper, zinc, manganese, boron and phosphorus, for example, can be toxic or may otherwise adversely affect

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aquatic life when present above certain concentrations, although their presence in low amounts is essential to support and maintain functions in aquatic ecosystems. The same is true for certain elements with respect to drinking water. Selenium, for example, is essential for humans but becomes harmful or even toxic when its concentration exceeds a certain level.

The concentrations above which water pollutants adversely affect a particular water use may differ widely. Water quality requirements, expressed as water quality criteria and objectives, are use-specific or are targeted to the protection of the most sensitive water use among a number of existing or planned uses within a catchment.

Approaches to water pollution control initially focused on the fixed emissions approach (see Chapter 3) and the water quality criteria and objectives approach. Emphasis is now shifting to integrated approaches. The introduction of holistic concepts of water management, including the ecosystem approach, has led to the recognition that the use of water quality objectives, the setting of emission limits on the basis of best available technology and the use of best available practices, are integral instruments of prevention, control and reduction of water pollution (ICWE, 1992; UNCED, 1992; UNECE, 1993). These approaches should be applied in an action-orientated way (Enderlein, 1995). A further development in environmental management is the integrated approach to air, soil, food and water pollution control using multimedia assessments of human exposure pathways.

2.2. Why water quality criteria and objectives?

Water quality criteria are developed by scientists and provide basic scientific information about the effects of water pollutants on a specific water use (see Box 2.1). They also describe water quality requirements for protecting and maintaining an individual use. Water quality criteria are based on variables that characterise the quality of water and/or the quality of the suspended particulate matter, the bottom sediment and the biota. Many water quality criteria set a maximum level for the concentration of a substance in a particular medium (i.e. water, sediment or biota) which will not be harmful when the specific medium is used continuously for a single, specific purpose. For some other water quality variables, such as dissolved oxygen, water quality criteria are set at the minimum acceptable concentration to ensure the maintenance of biological functions.

Most industrial processes pose less demanding requirements on the quality of freshwater and therefore criteria are usually developed for raw water in relation to its use as a source of water for drinking-water supply, agriculture and recreation, or as a habitat for biological communities. Criteria may also

Box 2.1 Examples of the development of national water quality criteria and guidelines

Nigeria

In Nigeria, the Federal Environmental Protection Agency (FEPA) issued, in 1988, a specific decree to protect, to restore and to preserve the ecosystem of the Nigerian environment. The decree also empowered the agency to set water quality standards to protect public health and to enhance the quality of waters. In the absence of national comprehensive scientific data, FEPA approached this task by reviewing water quality guidelines and standards from developed and developing countries as well as from international organisations and, subsequently, by comparing them with data available on Nigeria's own water quality. The standards considered included those of Australia, Brazil, Canada, India, Tanzania, the United States and the World Health Organization (WHO). These sets of data were harmonised and used to generate the Interim National Water Quality Guidelines and Standards for Nigeria. These address drinking water, recreational use of water, freshwater aquatic life, agricultural (irrigation and livestock watering) and industrial water uses. The guidelines are expected to become the maximum allowable limits for inland surface waters and groundwaters, as well as for non-tidal coastal waters. They also apply to Nigeria's transboundary watercourses, the rivers Niger, Benue and Cross River, which are major sources of water supply in the country. The first set of guidelines was subject to revision by interested parties and the general public. A Technical Committee comprising experts from Federal ministries, State Governments, private sector organisations, higher educational institutions, non-governmental organisations and individuals is now expected to review the guidelines from time to time.

Papua New Guinea

In Papua New Guinea, the Water Resources Act outlines a set of water quality requirements for fisheries and recreational use of water, both fresh and marine. The Public Health Drinking Water Quality Regulation specifies water quality requirements and standards relating to raw water and drinking water. The standards were established in accordance with WHO guidelines and data from other tropical countries.

Viet Nam

In Viet Nam, the water management policy of the Government highlights the need for availability of water, adequate in quantity and quality for all beneficial uses, as well as for the control of point and non-point pollution sources. The Government is expected to draw up and to update a comprehensive long-term plan for the development and management of water resources. Moreover, an expected reduction in adverse impacts from pollution sources in upstream riparian countries on the water quality within the Mekong River delta will be based on joint studies and definitions of criteria for water use among riparian countries of the river.

A set of national water quality criteria for drinking-water use as well as criteria for fish and aquatic life, and irrigation have been established (ESCAP, 1990). Criteria for aquatic life include: pH (range 6.5–8), dissolved oxygen ($> 2 \text{ mg l}^{-1}$), $\text{NH}_4\text{-N}$ ($< 1 \text{ mg l}^{-1}$), copper ($< 0.02 \text{ mg l}^{-1}$), cadmium ($< 0.02 \text{ mg l}^{-1}$), lead ($< 0.01 \text{ mg l}^{-1}$) and dissolved solids ($1,000 \text{ mg l}^{-1}$). More recently, allowable concentrations of pesticides in the fresh-water of the Mekong delta have been established by the Hygiene Institute of Ho Chi Minh City as follows: DDT 0.042 mg l^{-1} , heptachlor 0.018 mg l^{-1} , lindane 0.056 mg l^{-1} and organophosphate 0.100 mg l^{-1} . According to Pham Thi Dung (1994), the actual concentrations of these pesticides during the period June 1992 to June 1993 were considerably below these criteria.

Sources: ESCAP, 1990; FEPA, 1991; Pham Thi Dung, 1994

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Table 2.1 Definitions related to water quality and pollution control

Term	Definition
Water quality criterion (synonym: water quality guideline)	Numerical concentration or narrative statement recommended to support and maintain a designated water use
Water quality objective (synonyms: water quality goal or target)	A numerical concentration or narrative statement which has been established to support and to protect the designated uses of water at a specific site, river basin or part(s) thereof
Water quality standard	An objective that is recognised in enforceable environmental control laws or regulations of a level of Government ¹
Precautionary principle	The principle, by virtue of which action to avoid the potential adverse impact of the release of hazardous substances shall not be postponed on the ground that scientific research has not fully proved a causal link between those substances, on the one hand, and the potential adverse impact, on the other

¹ Water quality standards are discussed in Chapter 3

Sources: Adapted from Dick, 1975; CCREM, 1987; Chiaudani and Premazzi, 1988; UNECE, 1992, 1993

be developed in relation to the functioning of aquatic ecosystems in general. The protection and maintenance of these water uses usually impose different requirements on water quality and, therefore, the associated water quality criteria are often different for each use.

Water quality criteria often serve as a baseline for establishing water quality objectives in conjunction with information on water uses and site-specific factors (see Table 2.1). Water quality objectives aim at supporting and protecting designated uses of freshwater, i.e. its use for drinking-water supply, livestock watering, irrigation, fisheries, recreation or other purposes, while supporting and maintaining aquatic life and/or the functioning of aquatic ecosystems. The establishment of water quality objectives is not a scientific task but rather a political process that requires a critical assessment of national priorities. Such an assessment is based on economic considerations, present and future water uses, forecasts for industrial progress and for the development of agriculture, and many other socio-economic factors (UNESCO/WHO, 1978; UNECE, 1993, 1995). Such analyses have been carried out in the catchment areas of national waters (such as the Ganga river

basin) and in the catchment areas of transboundary waters (such as the Rhine, Mekong and Niger rivers). General guidance for developing water quality objectives is given in the *Convention on the Protection and Use of Transboundary Watercourses and International Lakes* (UNECE, 1992) and other relevant documents.

Water quality objectives are being developed in many countries by water authorities in co-operation with other relevant institutions in order to set threshold values for water quality that should be maintained or achieved within a certain time period. Water quality objectives provide the basis for pollution control regulations and for carrying out specific measures for the prevention, control or reduction of water pollution and other adverse impacts on aquatic ecosystems.

In some countries, water quality objectives play the role of a regulatory instrument or even become legally binding. Their application may require, for example, the appropriate strengthening of emission standards and other measures for tightening control over point and diffuse pollution sources. In some cases, water quality objectives serve as planning instruments and/or as the basis for the establishment of priorities in reducing pollution levels by substances and/or by sources.

2.3 Water quality criteria for individual use categories

Water quality criteria have been widely established for a number of traditional water quality variables such as pH, dissolved oxygen, biochemical oxygen demand for periods of five or seven days (BOD_5 and BOD_7), chemical oxygen demand (COD) and nutrients. Such criteria guide decision makers, especially in countries with rivers affected by severe organic pollution, in the establishment of control strategies to decrease the potential for oxygen depletion and the resultant low BOD and COD levels.

Examples of the use of these criteria are given in the case studies on the Ganga, India (Case Study 1), the Huangpu, China (Case Study 2) and Pasig River, Philippines (Case Study 3). Criteria for traditional water quality variables also guide decision makers in the resolution of specific pollution problems, such as water pollution from coal mining as demonstrated in the case study on the Witbank Dam catchment, South Africa (Case Study 5).

2.3.1 Development of criteria

Numerous studies have confirmed that a pH range of 6.5 to 9 is most appropriate for the maintenance of fish communities. Low concentrations of dissolved oxygen, when combined with the presence of toxic substances may lead to stress responses in aquatic ecosystems because the toxicity of certain

elements, such as zinc, lead and copper, is increased by low concentrations of dissolved oxygen. High water temperature also increases the adverse effects on biota associated with low concentrations of dissolved oxygen. The water quality criterion for dissolved oxygen, therefore, takes these factors into account. Depending on the water temperature requirements for particular aquatic species at various life stages, the criteria values range from 5 to 9.5 mg l⁻¹, i.e. a minimum dissolved oxygen concentration of 5–6 mg l⁻¹ for warm-water biota and 6.5–9.5 mg l⁻¹ for cold-water biota. Higher oxygen concentrations are also relevant for early life stages. More details are given in Alabaster and Lloyd (1982) and the EPA (1976, 1986).

The European Union (EU) in its *Council Directive of 18 July 1978 on the Quality of Fresh Waters Needing Protection or Improvement in Order to Support Fish Life* (78/659/EEC) recommends that the BOD of salmonid waters should be $\leq 3 \text{ mg O}_2 \text{ l}^{-1}$, and $\leq 6 \text{ mg O}_2 \text{ l}^{-1}$ for cyprinid waters. In Nigeria, the interim water quality criterion for BOD for the protection of aquatic life is 4 mg O₂ l⁻¹ (water temperature 20–33 °C), for irrigation water it is 2 mg O₂ l⁻¹ (water temperature 20–25 °C), and for recreational waters it is 2 mg O₂ l⁻¹ (water temperature 20–33 °C) (FEPA, 1991). In India, for the River Ganga, BOD values are used to define water quality classes for designated uses and to establish water quality objectives that will be achieved over a period of time. For Class A waters, BOD should not exceed 2 mg O₂ l⁻¹ and for Class B and C waters it should not exceed 3 mg O₂ l⁻¹ (see section 2.4.1 and Box 2.3).

Water quality criteria for phosphorus compounds, such as phosphates, are set at a concentration that prevents excessive growth of algae. Criteria for total ammonia (NH₃) have been established, for example by the EPA, to reflect the varying toxicity of NH₃ with pH (EPA, 1985). Criteria have been set for a pH range from 6.5 to 9.0 and a water temperature range from 0 to 30 °C (Table 2.2). Ammonium (NH₄⁺) is less toxic than NH₃. Similar values form the basis for the control strategy in the Witbank Dam catchment, South Africa (Case Study 5).

In a number of industrialised countries, as well as some countries in transition and other countries of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) region, increasing attention is being paid to the development of water quality criteria for hazardous substances. These are substances that pose a threat to water use and the functioning of aquatic ecosystems as a result of their toxicity, persistence, potential for bioaccumulation and/or their carcinogenic, teratogenic or mutagenic effects. Genetic material, recombined *in vitro* by genetic engineering techniques, is also very often included in this category of substances. In

Table 2.2 Criteria for total ammonia (NH₃) for the protection of aquatic life at different water temperatures

pH	Ammonia concentration (mg l ⁻¹)						
	0 °C	5 °C	10 °C	15 °C	20 °C	25 °C	30 °C
6.50	2.50	2.40	2.20	2.20	1.49	1.04	0.73
6.75	2.50	2.40	2.20	2.20	1.49	1.04	0.73
7.00	2.50	2.40	2.20	2.20	1.49	1.04	0.74
7.25	2.50	2.40	2.20	2.20	1.50	1.04	0.74
7.50	2.50	2.40	2.20	2.20	1.50	1.05	0.74
7.75	2.30	2.20	2.10	2.00	1.40	0.99	0.71
8.00	1.53	1.44	1.37	1.33	0.93	0.66	0.47
8.25	0.87	0.82	0.78	0.76	0.54	0.39	0.28
8.50	0.49	0.47	0.45	0.44	0.32	0.23	0.17
8.75	0.28	0.27	0.26	0.27	0.19	0.16	0.11
9.00	0.16	0.16	0.16	0.16	0.13	0.10	0.08

Source: EPA, 1985

accordance with the precautionary principle, when developing water quality criteria, many countries are also taking into account substances (including genetically modified organisms) for which there is insufficient data and which are presently only suspected of belonging to the category of hazardous substances.

The elaboration of water quality criteria for hazardous substances is a lengthy and resource-expensive process. Comprehensive laboratory studies assessing the impact of hazardous substances on aquatic organisms often need to be carried out, in addition to a general search and analysis of published literature. In Canada, for example, the average cost of developing a criterion for a single substance by means of a literature search and analysis is in the order of Canadian \$ 50,000. In Germany, the average cost of laboratory studies for developing a criterion for a single hazardous substance amounts to about DM 200,000 (McGirr *et al.*, 1991).

Some countries have shared the costs and the workload for developing water quality criteria amongst their regional and national agencies. For example, the Canadian Council of Resource and Environment Ministers (CCREM) has established a task force, consisting of specialists from the federal, provincial and territorial governments, to develop a joint set of Canadian water quality criteria. This has enabled them to produce, at a modest cost, a much more comprehensive set of criteria than would have been possible by individual efforts. It has also ended the confusion caused by the use of different

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criteria by each provincial government. In Germany, a joint task force was established to develop water quality criteria and to establish water quality objectives. This task force consists of scientists and water managers appointed by the Federal Government and the *Länder* authorities responsible for water management.

In some countries attempts have been made to apply water quality criteria elaborated in other countries (see Box 2.1). In such cases, it is necessary to establish that the original criteria were developed for similar environmental conditions and that at least some of the species on which toxicity studies were carried out occur in relevant water bodies of the country considering adoption of other national criteria. On many occasions, the application of water quality criteria from other countries requires additional ecotoxicological testing. An example of the adaptation of a traditional water pollution indicator is the use of a 3-day BOD in the tropics rather than the customary 5-day BOD developed for temperate countries.

2.3.2 Raw water used for drinking-water supply

These criteria describe water quality requirements imposed on inland waters intended for abstraction of drinking water and apply only to water which is treated prior to use. In developing countries, large sections of the population may be dependent on raw water for drinking purposes without any treatment whatsoever. Microbiological requirements as well as inorganic and organic substances of significance to human health are included.

Quality criteria for raw water generally follow drinking-water criteria and even strive to attain them, particularly when raw water is abstracted directly to drinking-water treatment works without prior storage. Drinking-water criteria define a quality of water that can be safely consumed by humans throughout their lifetime. Such criteria have been developed by international organisations and include the WHO *Guidelines for Drinking-water Quality* (WHO, 1984, 1993) and the EU *Council Directive of 15 July 1980 Relating to the Quality of Water Intended for Human Consumption* (80/778/EEC), which covers some 60 quality variables. These guidelines and directives are used by countries, as appropriate, in establishing enforceable national drinking-water quality standards.

Water quality criteria for raw water used for drinking-water treatment and supply usually depend on the potential of different methods of raw water treatment to reduce the concentration of water contaminants to the level set by drinking-water criteria. Drinking-water treatment can range from simple physical treatment and disinfection, to chemical treatment and disinfection, to intensive physical and chemical treatment. Many countries strive to ensure

that the quality of raw water is such that it would only be necessary to use near-natural conditioning processes (such as bank filtration or low-speed sand filtration) and disinfection in order to meet drinking-water standards.

In member states of the European Union, national quality criteria for raw water used for drinking-water supply follow the *EU Council Directive of 16 June 1975 Concerning the Quality Required of Surface Water Intended for the Abstraction of Drinking Water in Member States (75/440/EEC)*. This directive covers 46 criteria for water quality variables directly related to public health (microbiological characteristics, toxic compounds and other substances with a deleterious effect on human health), variables affecting the taste and odour of the water (e.g. phenols), variables with an indirect effect on water quality (e.g. colour, ammonium) and variables with general relevance to water quality (e.g. temperature). A number of these variables are now being revised.

2.3.3 Irrigation

Poor quality water may affect irrigated crops by causing accumulation of salts in the root zone, by causing loss of permeability of the soil due to excess sodium or calcium leaching, or by containing pathogens or contaminants which are directly toxic to plants or to those consuming them. Contaminants in irrigation water may accumulate in the soil and, after a period of years, render the soil unfit for agriculture. Even when the presence of pesticides or pathogenic organisms in irrigation water does not directly affect plant growth, it may potentially affect the acceptability of the agricultural product for sale or consumption. Criteria have been published by a number of countries as well as by the Food and Agriculture Organization of the United Nations (FAO). Some examples are given in Table 2.3. Quality criteria may also differ considerably from one country to another, due to different annual application rates of irrigation water.

Water quality criteria for irrigation water generally take into account, amongst other factors, such characteristics as crop tolerance to salinity, sodium concentration and phytotoxic trace elements. The effect of salinity on the osmotic pressure in the unsaturated soil zone is one of the most important water quality considerations because this has an influence on the availability of water for plant consumption. Sodium in irrigation waters can adversely affect soil structure and reduce the rate at which water moves into and through soils. Sodium is also a specific source of damage to fruits. Phytotoxic trace elements such as boron, heavy metals and pesticides may stunt the growth of plants or render the crop unfit for human consumption or other intended uses.

Table 2.3 Selected water quality criteria for irrigational waters (mg l⁻¹)

Element	FAO	Canada	Nigeria
Aluminium	5.0	5.0	5.0
Arsenic	0.1	0.1	0.1
Cadmium	0.01	0.01	0.01
Chromium	0.1	0.1	0.1
Copper	0.2	0.2–1.0 ¹	0.2–1.0 ¹
Manganese	0.2	0.2	0.2
Nickel	0.2	0.2	0.2
Zinc	2.0	1.0–5.0 ²	0.0–5.0 ²

¹ Range for sensitive and tolerant crops, respectively.

Sources: FAO, 1985; CCREM, 1987; FEPA, 1991

² Range for soil pH > 6.5 and soil pH > 6.5, respectively.

As discussed in the chapters on wastewater as a resource (Chapter 4) and the case study on wastewater use in the Mezquital Valley, Mexico (Case Study 7), both treated and untreated wastewater is being used for the irrigation of crops. In these cases, the WHO *Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture* (WHO, 1989) should be consulted to prevent adverse impacts on human health and the environment (Hespanhol, 1994).

2.3.4 Livestock watering

Livestock may be affected by poor quality water causing death, sickness or impaired growth. Variables of concern include nitrates, sulphates, total dissolved solids (salinity), a number of metals and organic micropollutants such as pesticides. In addition, blue-green algae and pathogens in water can present problems. Some substances, or their degradation products, present in water used for livestock may occasionally be transmitted to humans. The purpose of quality criteria for water used for livestock watering is, therefore, to protect both the livestock and the consumer.

Criteria for livestock watering usually take into account the type of livestock, the daily water requirements of each species, the chemicals added to the feed of the livestock to enhance the growth and to reduce the risk of disease, as well as information on the toxicity of specific substances to the different species. Some examples of criteria for livestock watering are given in Table 2.4.

Table 2.4 Selected water quality criteria for livestock watering (mg l^{-1})

Water quality variable	Canadian criteria	Nigerian criteria
Nitrate plus nitrite	100	100
Sulphates	1,000	1,000
Total dissolved solids	3,000	3,000
Blue-green algae	Avoid heavy growth of blue-green algae	Avoid heavy growth of blue-green algae
Pathogens and parasites	Water of high quality should be used	Water of high quality should be used (chlorinate, if necessary, sanitation and manure management must be emphasised to prevent contamination of water supply sources)

Sources: CCREM, 1987; FEPA, 1991; ICPR, 1991

2.3.5 Recreational use

Recreational water quality criteria are used to assess the safety of water to be used for swimming and other water-sport activities. The primary concern is to protect human health by preventing water pollution from faecal material or from contamination by micro-organisms that could cause gastro-intestinal illness, ear, eye or skin infections. Criteria are therefore usually set for indicators of faecal pollution, such as faecal coliforms and pathogens. There has been a considerable amount of research in recent years into the development of other indicators of microbiological pollution including viruses that could affect swimmers. As a rule, recreational water quality criteria are established by government health agencies.

The EU Council Directive of 8 December 1975 Concerning the Quality of Bathing Water (76/160/EEC) for example, established quality criteria containing both guideline values and maximum allowable values for microbiological parameters (total coliforms, faecal coliforms, faecal, streptococci, salmonella, enteroviruses) together with some physico-chemical parameters such as pH, mineral oils and phenols. This Directive also prescribes that member states should individually establish criteria for eutrophication-related parameters, toxic heavy metals and organic micropollutants.

Recreational use of water is often given inadequate consideration. For example, in the United Nations Economic Commission for Latin America and the Caribbean (ECLAC) region, several tourist areas are effected to various degrees by water pollution, including such popular resorts as Guanabara Bay in Brazil, Vina del Mar in Chile and Cartagena in Colombia. Offensive

smells, floating materials (particularly sewage solids) and certain other pollutants can create aesthetically repellent conditions for recreational uses of water and reduce its visual appeal. Even more important, elevated levels of bacteriological contamination and, to a lesser extent, other types of pollution can render water bodies unsuitable for recreational use. This is of particular concern in those countries of the region where tourism is an important source of foreign exchange and employment. In general, recreation is a much neglected use of water within the ECLAC region and is hardly considered in the process of water management despite the available information that suggests that pollution in recreational areas is a serious problem. This is of particular concern as the recreational use of water is very popular in the region and is also concentrated in water bodies closest to the large metropolitan areas. Many of these are increasingly contaminated by domestic sewage and industrial effluents (ECLAC, 1989).

2.3.6 Amenity use

Criteria have been established in some countries aimed at the protection of the aesthetic properties of water. These criteria are primarily orientated towards visual aspects. They are usually narrative in nature and may specify, for example, that waters must be free of floating oil or other immiscible liquids, floating debris, excessive turbidity, and objectionable odours. The criteria are mostly non-quantifiable because of the different sensory perception of individuals and because of the variability of local conditions.

2.3.7 Protection of aquatic life

Within aquatic ecosystems a complex interaction of physical and biochemical cycles exists. Anthropogenic stresses, particularly the introduction of chemicals into water, may adversely affect many species of aquatic flora and fauna that are dependent on both abiotic and biotic conditions. Water quality criteria for the protection of aquatic life may take into account only physico-chemical parameters which tend to define a water quality that protects and maintains aquatic life, ideally in all its forms and life stages, or they may consider the whole aquatic ecosystem.

Water quality parameters of concern are traditionally dissolved oxygen (because it may cause fish kills at low concentrations) as well as phosphates, ammonium and nitrate (because they may cause significant changes in community structure if released into aquatic ecosystems in excessive amounts). Heavy metals and many synthetic chemicals can also be ingested and absorbed by organisms and, if they are not metabolised or excreted, they may bioaccumulate in the tissues of the organisms. Some pollutants can also cause carcinogenic, reproductive and developmental effects.

When developing criteria for the protection of aquatic life, ideally there should be complete information on the fate of chemicals within organisms and their exposure-effect relationships. In Canada, criteria for aquatic life are based on the lowest concentration of a substance that affects the test organisms (lowest observable effect level). Different fish, invertebrates and plant species resident in North America are used for testing. A number of other countries use a similar approach with some differences in data requirements. In Germany, for example, toxicity studies are carried out for primary producers (e.g. green alga *Scenedesmus subspicatus*), primary consumers (e.g. crustacean *Daphnia magna*), secondary consumers (e.g. fish) and reducers (e.g. bacterium *Pseudomonas putida*). Other information is also used, including the organoleptic properties (e.g. fish tainting) of the substance, its mobility and distribution through different environmental media and its biodegradation behaviour (persistence).

More recently within the concept of the ecosystem approach to water management, attempts have been made to address criteria that indicate healthy aquatic ecosystem conditions. In addition to traditional criteria, new criteria try to describe the state of resident species and the structure and/or function of ecosystems as a whole. In developing these criteria, the assumption has been made that they should be biological in nature. In some countries, research is under way on the development of biocriteria that express water quality criteria quantitatively in terms of the resident aquatic community structure and function.

Biocriteria are defined as measures of "biological integrity" that can be used to assess cumulative ecological impact from multiple sources and stress agents. In the UK, quality criteria for the protection of aquatic ecosystems are now being based on an ecological quality index. In other countries, considerable efforts have been made to identify key species which may serve as useful integrative indicators of the functional integrity of aquatic ecosystems. Ongoing research suggests that such criteria and indicators should include both sensitive, short-lived species and information about changes in community structure resulting from the elimination of key predators.

Amongst other features, candidate organisms to serve as indicators of ecosystem quality should (UNECE, 1993):

- Have a broad distribution in the ecosystem.
- Be easily collected and measured in terms of biomass.
- Be indigenous and maintain themselves through natural reproduction.
- Interact directly with many components of its ecosystem.
- Have historical, preferably quantified, information available about their abundance and other critical factors relevant to the state of the organisms.

24 Water Pollution Control

- Exhibit a graded response to a variety of human-induced stresses.
- Serve as diagnostic tools for specific stresses of many sorts.
- Respond to stresses in a manner that is both identifiable and quantifiable.
- Be suitable species for laboratory investigations.
- Serve to indicate aspects of ecosystem quality other than those represented by currently accepted variables.

Biomarkers are becoming an increasingly useful approach for identifying the impact of deteriorating water quality at an early stage. A biomarker is a variation in cell structure or in a biochemical process or function that is induced by a pollutant and that can be measured, for example, by changes in the activity of enzymes. Ideally, a biomarker should respond to a pollutant with a dose-response quantitative change which is sensitive to concentrations found in the environment and which is specific to a particular class or classes of pollutants. Thus for toxic metals, delta-aminolevulinic acid dehydratase (ALAD) inhibition provides a signal of a potential problem and is a definite indicator of metal pollution. It is also a predictive indicator of long-term adverse effects.

2.3.8 Commercial and sports fishing

Water quality criteria for commercial and sports fishing take into account, in particular, the bioaccumulation of contaminants through successive levels of the food chain and their possible biomagnification in higher trophic levels, which can make fish unsuitable for human consumption. They are established at such a concentration that bioaccumulation and biomagnification of any given substance cannot lead to concentrations exceeding fish consumption criteria, i.e. criteria indicating the maximum content of a substance in fish for human consumption that will not be harmful. The FAO European Inland Fisheries Advisory Commission (EIFAC), for example, has been investigating these issues and has published relevant guidance (Alabaster and Lloyd, 1982).

2.3.9 Suspended particulate matter and sediment

The attempts in some countries to develop quality criteria for suspended particulate matter and sediment aim at achieving a water quality, such that any sediment dredged from the water body could be used for soil improvement and for application to farmland. Another goal of these quality criteria is to protect organisms living on, or in, sediment, and the related food chain. Persistent pollutants in sediments have been shown to be accumulated and biomagnified through aquatic food chains leading to unacceptable concentrations in fish and fish-eating birds.

Development of criteria for sediment has not yet reached an advanced stage and only a few criteria are available at present. Under the auspices of the

Table 2.5 Water quality objectives for the River Rhine related to metals in suspended matter

Water quality variable	Quality objective (mg kg ⁻¹)
Cadmium	1.0
Chromium	100.0
Copper	50.0
Lead	100.0
Mercury	0.5
Nickel	50.0
Zinc	50.0

Source: ICPR, 1991

International Commission for the Protection of the Rhine against Pollution, for example, criteria related to metals in suspended matter have been converted into water quality objectives (Table 2.5). At present the quality objectives are mainly based on limit values developed for the spreading of sewage sludge on agricultural areas and taking into account, if available, information related to the adverse impacts of sewage sludge on soil organisms. At a later stage, the quality objectives will be revised in order to protect organisms living in or on sediment, as well as to protect the marine ecosystem (for situations where dredged sediment is disposed of at sea).

Recent experience in Germany and the Netherlands suggests that a far greater number of substances than previously considered are a potential threat to aquatic and terrestrial life. Consequently, present water quality criteria for sediment are now under revision.

2.4 Water quality objectives

A major advantage of the water quality objectives approach to water resources management is that it focuses on solving problems caused by conflicts between the various demands placed on water resources, particularly in relation to their ability to assimilate pollution. The water quality objectives approach is sensitive not just to the effects of an individual discharge, but to the combined effects of the whole range of different discharges into a water body. It enables an overall limit on levels of contaminants within a water body to be set according to the required uses of the water.

The advantage of the fixed emission approach (see Chapter 5) is that it treats industry equitably requiring the use of best available technology for treating hazardous, as well as a number of conventional, water pollutants

wherever the industry is located. This is seen to be a major advantage for transboundary catchment areas where all riparian countries are required to meet the same standards and no country has an unfair trade advantage.

It is generally recognised that water quality objectives, the setting of emission limits on the basis of best available technology, and the use of best environmental practice should all form part of an integrated approach to the prevention, control and reduction of pollution in inland surface waters. In most cases, water quality objectives serve as a means of assessing pollution reduction measures. For example, if emission limits are set for a given water body on the basis of best available technology, toxic effects may, nevertheless, be experienced by aquatic communities under certain conditions. In addition, other sensitive water uses, such as drinking-water supplies, may be adversely affected. The water quality objectives help to evaluate, therefore, whether additional efforts are needed when water resources protection is based on using emission limits for point sources according to the best available technology or on best environmental practice for non-point sources.

Experience gained in some countries suggests that catchment planning plays an essential role in setting water quality objectives (see Box 2.2). It provides the context in which the demands of all water users can be balanced against water quality requirements. Catchment planning also provides the mechanism for assessing and controlling the overall loading of pollutants within whole river catchments and, ultimately, into the sea, irrespective of the uses to which those waters are put. The need for "catchment accountability" is becoming increasingly important in order to ensure that both national and international requirements to reduce pollutant loadings are properly planned and achieved.

The elaboration of water quality objectives and the selection of the final strategy for their achievement necessarily involves an analysis of the technical, financial and other implications associated with the desired improvements in water quality. The technical means available to reduce inputs of pollutants into waters have a direct bearing on the elaboration of water quality objectives by indicating the technical feasibility of attaining the threshold values set in the objectives. Economic factors are also taken into account because the attainment of a certain objective may require the allocation of considerable financial resources and may also have an impact on investment, employment and, inevitably, on prices paid by consumers.

The establishment of a time schedule for attaining water quality objectives is mainly influenced by the existing water quality, the urgency of control measures and the prevailing economic and social conditions. In some countries, a step-by-step approach to establish water quality objectives is applied.

Box 2.2 Examples of the setting of water quality objectives**Canada and the United States of America**

Water quality objectives for watercourses may also take into account quality requirements of downstream lakes and reservoirs. For example, water quality objectives for nutrient concentrations in tributaries of the Great Lakes consider the quality requirements of the given watercourse, as well as of the lake system. Similarly, requirements for the protection of the marine environment, in particular of relatively small enclosed seas, need to be taken into consideration when setting water quality objectives for watercourses (as has been done, for example, in the setting of water quality objectives for the Canadian rivers flowing into the sea).

Germany

A methodology to establish water quality objectives for aquatic communities, fisheries, suspended particulate matter/sediment, drinking-water supply, irrigation, and recreation has been drawn up by a German task force (see section 2.3.1). This task force will further develop its methodology, for example, by comparing numerical values established according to its methodology with the results of the monitoring of 18 toxic and carcinogenic substances in surface waters. Once water quality objectives are established, they will be used by regional authorities as a basis for water resources planning. However, such water quality objectives will not be considered as generally obligatory but regional authorities will have to decide, case by case, which water uses are to be protected in a given water body and which water quality objectives are to be applied. Obligatory limit values will only be established in the course of the implementation of water management plans by competent water management authorities. The authorities will decide on the specific uses of a given water body that should be protected and the relevant water quality objective that should be used, taking into account the water uses that have been licensed for that water body.

Sources: McGirr *et al.*, 1991; UNECE, 1993

This gradual introduction is probably also the best approach for developing countries. For example, in order to establish a baseline for water pollution control measures, priority should be given to setting objectives for variables related to the oxygen regime and nutrients (e.g. dissolved oxygen, BOD, $\text{NH}_3\text{-N}$) because many rivers in the world suffer from pollution by organic matter (Meybeck *et al.*, 1989). Experience also suggests that establishing water quality objectives initially only for a limited number of variables can focus attention on key water quality attributes and lead to marked improvements in water quality in a cost-effective manner. It is of the utmost

importance that the objectives are understandable to all parties involved in pollution control and are convertible into operational and cost-effective measures which can be addressed through targets to reduce pollution. It should also be possible to monitor, with existing networks and equipment, compliance with such objectives. Objectives that are either vague or too sophisticated should be avoided. The objectives should also have realistic time schedules.

Targets to improve water quality are usually set at two levels. The first represents the ultimate goal at which no adverse effects on the considered human uses of the water would occur and at which the functions of the aquatic ecosystems would be maintained and/or protected. This level corresponds, in most countries, with the most stringent water quality criterion among all of the considered water uses, with some modifications made to account for specific site conditions. A second level is also being defined that should be reached within a fixed period of time. This level is a result of a balance between what is desirable from an environmental point of view and what is feasible from an economic and technical point of view. This second level allows for a step-by-step approach that finally leads to the first level. Additionally, some countries recommend a phased approach, which starts with rivers and catchments of sensitive waters and is progressively extended to other water bodies during a second phase.

In many countries, water quality objectives are subject to regular revisions in order to adjust them, among other things, to the potential of pollution reduction offered by new technologies, to new scientific knowledge on water quality criteria, and to changes in water use.

Current approaches to the elaboration and setting of water quality objectives differ between countries. These approaches may be broadly grouped as follows:

- Establishment of water quality objectives for individual water bodies (including transboundary waters) or general water quality objectives applicable to all waters within a country.
- Establishment of water quality objectives on the basis of water quality classification schemes.

The first approach takes into account the site-specific characteristics of a given water body and its application requires the identification of all current and reasonable potential water uses. Designated uses of waters or "assets" to be protected may include: direct extraction for drinking-water supply, extraction into an impoundment prior to drinking-water supply, irrigation of crops, watering of livestock, bathing and water sports, amenities, fish and other aquatic organisms.

In adopting water quality objectives for a given water body, site-specific physical, chemical, hydrological and biological conditions are taken into consideration. Such conditions may be related to the overall chemical composition (hardness, pH, dissolved oxygen), physical characteristics (turbidity, temperature, mixing regime), type of aquatic species and biological community structure, and natural concentrations of certain substances (e.g. metals or nutrients). These site-specific factors may affect the exposure of aquatic organisms to some substances or the usability of water for human consumption, livestock watering, irrigation and recreation.

In some countries general water quality objectives are set for all surface waters in a country, irrespective of site-specific conditions. They may represent a compromise after balancing water quality requirements posed by individual water uses and economic, technological and other means available to meet these requirements at a national level. Another approach is to select water quality criteria established for the most sensitive uses (e.g. drinking-water supply or aquatic life) as general water quality objectives.

2.4.1 Water quality classification schemes

Many countries in the ECE and ESCAP regions have established water quality objectives for surface waters based on classification schemes (see Box 2.3). A number of these countries require, as a policy goal, the attainment of water quality classes I or II (which characterise out of a system of four or five quality classes, excellent or good water quality) over a period of time. In the UK, this approach has even led to statutory water quality objectives for England and Wales under the 1989 Water Act (NRA, 1991). Generally, before establishing quality objectives on the basis of classification systems, comprehensive water quality surveys have to be carried out.

The ECE has recently adopted a *Standard Statistical Classification of Surface Freshwater Quality for the Maintenance of Aquatic Life* (UNECE, 1994). The class limits are primarily derived from ecotoxicological considerations and based on the research work of the US EPA. As a general rule, the orientation of the classification system towards aquatic life implies that the class limits are more conservative than they would be if targeted at other water uses. In addition to variables that characterise the oxygen regime, eutrophication and acidification of waters, the system includes hazardous substances such as aluminium, arsenic, heavy metals, dieldrin, dichlorodiphenyltrichloroethane (DDT) and its metabolites, endrin, heptachlor, lindane, pentachlorophenol, polychlorinated biphenyls (PCBs) and free ammonia. It also includes gross α - and β -activity. Concentrations of

Box 2.3 Examples of water quality classification schemes**India**

In India, five water quality classes have been designated (A–E) on the basis of the water quality requirements for a particular use:

Class A waters for use as drinking water source without conventional treatment but after disinfection.

Class B waters for use for organised outdoor bathing.

Class C waters for use as drinking water source with conventional treatment followed by disinfection.

Class D waters to maintain aquatic life (i.e. propagation of wildlife and fisheries).

Class E waters for use for irrigation, industrial cooling and controlled waste disposal.

The five classes have been used to set quality objectives for stretches of the Yamuna and Ganga rivers, and surveys have been carried out to compare the actual river-quality classification with that required to sustain the designated best use. Where a river has multiple uses, the quality objectives are set for the most stringent (best) use requirements. After comparing ambient water quality with the designated water quality objective, any deficiencies will require appropriate pollution control measures on the discharges, including discharges in upstream stretches. This system is also helpful for the planning and siting of industry. No industries are permitted to discharge any effluent in stretches of rivers classified in Class A.

A pollution control action plan was drawn up for the Ganga in 1984 and the Ganga Project Directorate was established under the Central Ganga Authority in 1985. This Directorate oversees pollution control and abatement (ESCAP, 1990). The table below shows the improvements in water quality classification that were achieved by 1987. The classification and zoning of 12 other major rivers has also been recently accomplished.

A comparison between water quality objectives for the Ganga and results of classifications in 1982 and 1987

Zone	River length (km)	Water quality objective class	Results of water quality classification		Critical primary water quality characteristics
			1982	1987	
Source to Rishikesh	250	A	B	B	Total coliform
Rishikesh to Kannauj	420	B	C	B	Total coliform, BOD
Kannauj to Trighat	730	B	D	B	Total coliform, BOD
Trighat to Kalyani	950	B	C	B	Total coliform
Kalyani to Diamond Harbour	100	B	D	B	Total coliform

Thailand

There are many forms of legislation on water quality control and management in Thailand including laws, acts, regulations and ministerial notifications established by various agencies, depending on their relative areas of responsibility. The objectives of setting water quality requirements and standards in Thailand are: to control and maintain water quality at a level that suits the activities of all concerned, to protect public health, and to conserve natural resources and the natural environment.

The Ministry of Agriculture and Cooperatives has established, for example, regulations concerning water quality for irrigation, wildlife and fisheries. The Office of the

Box 2.3 Continued

National Environmental Board (ONEB) is responsible for defining the water quality requirements of receiving waters, as well as for setting quality standards for freshwaters, domestic effluents and effluents from agricultural point sources (e.g. pig farms and aquaculture). These standards are based on sets of water quality criteria. For example, in order to protect commercial fishing, ONEB has set the following allowable concentrations of pesticides in aquatic organisms: DDT 5.0 mg kg⁻¹, endrin 0.5 mg kg⁻¹, lindane 0.5 mg kg⁻¹, heptachlor 0.3 mg kg⁻¹ and parathion 0.2 mg kg⁻¹ (ESCAP, 1990).

The system of surface water resources classification and standards in Thailand is based on the idea that the concentrations of water quality parameters in Class I shall correspond to the natural concentrations. Variables characterising the oxygen and nutrient regimes, the status of coliform bacteria, phenols, heavy metals, pesticides and radioactivity are being considered.

Sources: ESCAP, 1990; Venugopal, 1994

United Kingdom

The Water Resources Act of 1991 enabled the UK Government to prescribe a system for classifying the quality of controlled waters according to specified requirements. These requirements (for any classification) consist of one or more of the following:

- General requirements as to the purposes for which the waters to which the classification is applied are to be suitable.
- Specific requirements as to the substances that are to be present, in or absent from, the water and as to the concentrations of substances which are, or are required to be, present in the water.
- Specific requirements as to other characteristics of those waters.

Future regulations will describe whether such requirements should be satisfied by reference to particular sampling procedures. Then, for the purpose of maintaining or improving the quality of controlled waters the Government may, by serving a notice on the National Rivers Authority (NRA), establish with reference to one or more of the classifications to be described as above, the water quality objectives for any waters and the date by which the objectives shall apply.

The purpose of the new system is to provide a firmer framework for deciding the policy that governs the determination of consent for discharges into each stretch of controlled waters and the means by which pollution from diffuse sources can be dealt with. The system will be extended to coastal waters, lakes and groundwater. It will provide a basis for a requirement for steady improvement in quality in polluted waters.

The 1994 Surface Waters (River Ecosystem) (Classification) Regulations introduced a component of the scheme designed to make water quality targets statutory. The NRA has set water quality targets for all rivers and these are known as river quality objectives (RQO) and they establish a defined level of protection for aquatic life. They are used for planning the maintenance and improvement of river quality and to provide a basis for setting consent to discharge effluent into rivers, and guide decisions on the NRA's other actions to control and prevent pollution. Achieving the required RQO will help to sustain the use of rivers for recreation, fisheries and wildlife, and to protect the interest of abstractors. The water quality classification scheme used to set RQO planning targets is known as the river ecosystem scheme. It provides a nationally consistent basis for setting RQO. The scheme comprises five classes which reflect the chemical quality requirements of communities of plants and animals occurring in the rivers. The standards defining these classes reflect differing degrees of pollution by organic matter and other common pollutants.

Sources: NRA, 1991, 1994; UNECE, 1993

hazardous substances in Class I and Class II should be below current detection limits. In Class III, their presence can be detected but the concentrations should be below chronic and acute values. For Class IV, concentrations may exceed the chronic values occasionally but should not lead to chronically toxic conditions, either with respect to concentration, duration or frequency (Table 2.6).

The system has been applied to a number of internal and transboundary waters within the region, and is expected to constitute a basis for setting water quality objectives at border sections of transboundary waters under the *Convention on the Protection and Use of Transboundary Watercourses and International Lakes* (UNECE, 1992). The system is expected to be supplemented by water quality objectives for specific hazardous substances as well as by a system of biologically-based water quality objectives.

2.4.2 Transboundary waters

To date, there are only a few examples of transboundary waters for which water quality objectives have been established. Examples include the Great Lakes and some transboundary rivers in North America (St Croix, St John, St Lawrence, River Poplar, River Rainy, Red River of the North) and the River Rhine in Europe (Tables 2.5 and 2.7 and Box 2.4). Following the provisions of the *Convention on the Protection and Use of Transboundary Watercourses and International Lakes* (UNECE, 1992), water quality objectives are being developed for some other transboundary surface waters in Europe, including the rivers Danube, Elbe and Oder and their tributaries. In the ESCAP region, countries riparian to the Mekong river are jointly developing water quality objectives for the main river and other watercourses in the catchment area.

2.4.3 The ecosystem approach

The application of the ecosystem approach in water management has led to the development of objectives for safeguarding the functional integrity of aquatic ecosystems. The functional integrity of aquatic ecosystems is characterised by a number of physical, chemical, hydrological, and biological factors and their interaction.

Ecosystem objectives attempt to describe a desired condition for a given ecosystem through a set of variables, taking into account the ecological characteristics and uses of the water. Ecosystem objectives may specify the level or condition of certain biological properties that could serve as indicators of the overall condition or "health" of the aquatic ecosystem. Ecosystem objectives are used in combination with water quality objectives, and objectives relating to hydrological conditions.

Table 2.6 ECE standard statistical classification of surface freshwater quality for the maintenance of aquatic life

Variables	Class I	Class II	Class III	Class IV	Class V
<i>Oxygen regime</i>					
DO (%)					
epilimnion (stratified waters)	90–110	70–90 or 110–120	50–70 or 120–130	30–50 or 130–150	< 30 or > 150
hypolimnion (stratified waters)	90–70	70–50	50–30	30–10	< 10
unstratified waters	90–70	70–50 or 110–120	50–30 or 120–130	30–10 or 130–150	< 10 or > 150
DO (mg l ⁻¹)	> 7	7–6	6–4	4–3	< 3
COD-Mn (mg O ₂ l ⁻¹)	< 3	3–10	10–20	20–30	> 30
COD-Cr (mg O ₂ l ⁻¹)	–	–	–	–	–
<i>Eutrophication</i>					
Total P (µg l ⁻¹) ¹	< 10 (< 15)	10–25 (15–40)	25–50 (40–75)	50–125 (75–190)	> 125 (> 190)
Total N (µg l ⁻¹) ¹	< 300	300–750	750–1,500	1,500–2,500	> 2,500
Chlorophyll a (µg l ⁻¹) ¹	< 2.5 (< 4)	2.5–10 (4–15)	10–30 (15–45)	30–110 (45–165)	> 110 (> 165)
<i>Acidification</i>					
pH ²	9.0–6.5	6.5–6.3	6.3–6.0	6.0–5.3	< 5.3
Alkalinity (mg CaCO ₃ l ⁻¹)	> 200	200–100	100–20	20–10	< 10
<i>Metals</i>					
Aluminium (µg l ⁻¹ ; pH 6.5)	< 1.6	1.6–3.2	3.2–5	5–75	> 75
Arsenic (µg l ⁻¹) ³	< 10	10–100	100–190	190–360	> 360
Cadmium (µg l ⁻¹) ⁴	< 0.07	0.07–0.53	0.53–1.1	1.1–3.9	> 3.9
Chromium (µg l ⁻¹) ³	< 1	1–6	6–11	11–16	> 16

Continued

Table 2.6 Continued

Variables	Class I	Class II	Class III	Class IV	Class V
<i>Metals</i>					
Copper ($\mu\text{g l}^{-1}$) ⁴	< 2	2-7	7-12	12-18	> 18
Lead ($\mu\text{g l}^{-1}$) ⁴	< 0.1	0.1-1.6	1.6-3.2	3.2-82	> 82
Mercury ($\mu\text{g l}^{-1}$) ⁴	< 0.003	0.003-0.007	0.007-0.012	0.012-2.4	> 2.4
Nickel ($\mu\text{g l}^{-1}$) ⁴	< 15	15-87	87-160	160-1,400	> 1,400
Zinc ($\mu\text{g l}^{-1}$) ⁴	< 45	45-77	77-110	110-120	> 120
<i>Chlorinated micropollutants and other hazardous substances</i>					
Dieldrin ($\mu\text{g l}^{-1}$)	na	na	< 0.0019	0.0019-2.5	> 2.5
DDT and metabolites ($\mu\text{g l}^{-1}$)	na	na	< 0.001	0.001-1.1	> 1.1
Endrin ($\mu\text{g l}^{-1}$)	na	na	< 0.0023	0.0023-0.18	> 0.18
Heptachlor ($\mu\text{g l}^{-1}$)	na	na	< 0.0038	0.0038-0.52	> 0.52
Lindane ($\mu\text{g l}^{-1}$)	na	na	< 0.08	0.08-2.0	> 2.0
Pentachlorophenol ($\mu\text{g l}^{-1}$)	na	na	< 13	13-20	> 20
PCBs ($\mu\text{g l}^{-1}$)	na	na	< 0.014	0.014-2.0	> 2.0
Free ammonia (NH_3)	na	na	-	-	-
<i>Radioactivity</i>					
Gross-alpha activity (mBq l^{-1})	< 50	50-100	100-500	500-2,500	> 2,500
Gross-beta activity (mBq l^{-1})	< 200	200-500	500-1,000	1,000-2,500	> 2,500

Measures falling on the boundary between two classes are to be classified in the lower class.
na Not applicable
- No value set at present

¹ Data in brackets refer to flowing waters.
² Values > 9.0 are disregarded in the classification of acidification.
³ Applicable for hardness from about 0.5 to 8 meq l^{-1} . Arsenic V and chromium III to be

converted to arsenic III and chromium VI, respectively.
⁴ Applicable for hardness from about 0.5 to 8 meq l^{-1} .
Source: UNECE, 1994

Table 2.7 Water quality objectives for the River Rhine related to organic substances

Water quality variable	Water quality objective ($\mu\text{g l}^{-1}$)	Basis for elaboration ¹
Tetrachloromethane	1.0	Drw+aqL
Trichloromethane	0.6	aqL
Aldrin, Dieldrin, Endrin, Isodrin	0.0001 (per substance)	aq+terrL
Endosulfan	0.003	aqL
Hexachlorobenzene	0.0005	aqL
Hexachlorobutadien	0.001	aqL
PCB 28, 52, 101, 180, 138, 153	0.001 (per substance)	aqL
1-Chloro-4-nitro-Benzen	1.0	Drw
1-Chloro-2-nitro-Benzen	1.0	Drw+aqL
Trichlorobenzene	0.1	aqL
Pentachlorophenol	0.001	aq+terrL
Trichloroethen	1.0	Drw
Tetrachloroethen	1.0	Drw
3,4-Dichloroanilin	0.1	aqL
2-Chloroanilin	0.1	Drw+aqL
3-Chloroanilin	0.1	Drw
4-Chloroanilin	0.01	aqL
Parathion(-ethyl)	0.0002	aqL
Parathion(-methyl)	0.01	aqL
Benzene	0.1	aqL
1, 1, 1-Trichloroethane	1.0	Drw
1, 2-Dichloroethane	1.0	aqL
Azinphos-methyl	0.001	aqL
Bentazon	0.1	Drw
Simazine	0.1	Drw+aqL
Atrazine	0.1	Drw+aqL
Dichlorvos	0.001	aqL
2-Chlorotoluol	1.0	Drw
4-Chlorotoluol	1.0	Drw
Tributyl tin-substances	0.001	aqL
Triphenyl tin-substances	0.001	aqL
Trifluralin	0.1	aqL
Fenthion	0.01	aqL

¹ Water quality objectives have been set on the basis of water quality criteria for drinking-water supply (Drw), drinking-water supply and aquatic life (Drw+aqL) and/or aquatic life (aqL), as well as on the basis of toxicity testing on selected species of aquatic and terrestrial life (aq+terrL).
Source: ICPR, 1991

Box 2.4 An example of water quality objectives for transboundary rivers: the Rhine

Water quality objectives established for the River Rhine are based on the four major elements of the Rhine Action Programme aimed at:

- Improving the ecosystem of the river in such a way that sensitive species which were once indigenous in the Rhine will return.
- Guaranteeing the future production of drinking water from the Rhine.
- Reducing the pollution of the water by hazardous substances to such a level that sediment can be used on land or dumped at sea without causing harm.
- Protecting the North Sea against the negative effects of the Rhine water.

At present, water quality objectives for the River Rhine cover 50 priority substances, such as heavy metals, organic micropollutants as well as ammonium and phosphorus discharged from industries, municipalities or agriculture. The list of these substances was established on the basis of catchment inventories of point and diffuse sources of discharges of substances into the Rhine. The established water quality objectives should be complied with by the year 2000.

Source: ICPR, 1994

Ecosystem objectives are expressed by a set of species, referred to as the target variables. The target variables as a whole are usually a cross-section of the aquatic ecosystem that provides a fairly representative picture of ecosystem conditions and include, for example:

- Species from all types of aquatic habitats.
- Species from the benthos, water column, water surface and shores.
- Species from high and low parts of the food web.
- Plants and animals.
- Sessile, migratory and non-migratory species.

In order to ensure, for example, the functional integrity of Lake Ontario, specific ecosystem objectives were developed that enabled the waters of the lake to support diverse, healthy, reproducing and self-sustaining communities in a dynamic equilibrium. Human health considerations were also taken into account in this process, because the lake should be usable for drinking water and recreation, as well as for the safe human consumption of fish and wildlife.

Determining whether the functioning integrity of the ecosystem is achieved requires a set of measurable and quantitative indicators. Extensive studies were undertaken to select appropriate biological indicators that would supplement conventional physical and chemical measurements of water