Chapter 2* - Water Quality Requirements

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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 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 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.

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, nongovernmental 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 mg l^{-1}), NH_4-N (< 1 mg l^{-1}), copper (< 0.02 mg l^{-1}), cadmium (< 0.02 mg l^{-1}), lead (< 0.01 mg l^{-1}) and dissolved solids (1,000 mg l^{-1}). More recently, allowable concentrations of pesticides in the freshwater 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

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

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 mg O_2 l^{-1}, and $\leq$ 6 mg O_2 l^{-1} for cyprinid waters. In Nigeria, the interim water quality criterion for BOD for the protection of aquatic life is 4 mg O_2 l^{-1} (water temperature 20-33 °C), for irrigation water it is 2 mg O_2 l^{-1} (water temperature 20-25 °C), and for recreational waters it is 2 mg O_2 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 O_2 l^{-1} and for Class B and C waters it should not exceed 3 mg O_2 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 (NH_3) have been established, for example by the EPA, to reflect the varying toxicity of NH_3 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 (NH_4^+) is less toxic than NH_3. 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 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.

Table 2.2 Criteria for total ammonia (NH_3) for the protection of aquatic life at different water temperatures

	Ammonia concentration (mg l^{-1})						
pH	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

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

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

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 Waste-water 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, entero viruses) 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.

- 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 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).

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

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. 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, NH_3-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.

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

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, dichloro-diphenyltrichloroethane (DDT) and its metabolites, endrin, heptachlor, lindane, pentachlorophenol, polychlorinated biphenyls (PCBs) and free ammonia. It also includes gross α- and β-activity. Concentrations of 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).

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 National Environmental Board (ONEB) is responsible for defining the water quality requirements of receiving waters, as well as for setting quality standards for fresh-waters, 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; Venugupal, 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

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
Oxygen regime					
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})	-	-	-	-	-
Eutrophication					
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)
Acidification					
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
Metals					
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
Copper (µg l^{-1})[4]	<2	2-7	7-12	12-18	>18

Leader ($\mu g\ l^{-1}$)[4]	<0.1	0.1-1.6	1.6-3.2	3.2-82	>82
Mercury ($\mu g\ l^{-1}$)[4]	<0.003	0.003-0.007	0.007-0.012	0.012-2.4	>2.4
Nickel ($\mu g\ l^{-1}$)[4]	<15	15-87	87-160	160-1,400	>1,400
Zinc ($\mu g\ l^{-1}$)[4]	<45	45-77	77-110	110-120	>120
Chlorinated micropollutants and other hazardous substances					
Dieldrin ($\mu g\ l^{-1}$)	na	na	<0.0019	0.0019-2.5	>2.5
DDT and metabolites ($\mu g\ l^{-1}$)	na	na	<0.001	0.001-1.1	>1.1
Endrin ($\mu g\ l^{-1}$)	na	na	<0.0023	0.0023-0.18	>0.18
Heptachlor ($\mu g\ l^{-1}$)	na	na	<0.0038	0.0038-0.52	>0.52
Lindane ($\mu g\ l^{-1}$)	na	na	<0.08	0.08-2.0	>2.0
Pentachlorophenol ($\mu g\ l^{-1}$)	na	na	<13	13-20	>20
PCBs ($\mu g\ l^{-1}$)	na	na	<0.014	0.014-2.0	>2.0
Free ammonia (NH_3)	na	na	-	-	-
Radioactivity					
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 (µg 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 quality. Comprehensive criteria were elaborated by the Aquatic Ecosystems Objectives Committee (established within the framework of the 1978 Great Lakes Water Quality Agreement) to judge the suitability of candidate organisms to serve as indicators of the quality of the ecosystem.

Based on these criteria, a number of organisms were considered suitable indicators for the Great Lakes. For oligotrophic systems of Lake Superior, the lake trout *Salvelinus namaycush* (the top aquatic predator) and the amphipod *Pontoporeia hoyi* (the major benthic macro-invertebrate of a cold-water community) were selected. For mesotrophic systems, the walleye *Stizostedion vitreum*, which has many characteristics in common with the lake trout, has recently been chosen, together with the mayfly *Hexagenia limbata* which was considered as representative of a diverse benthic community because of its requirements for clean, well-oxygenated sediment. Work is under way to select mammalian, avian and reptilian species.

The absence or presence of Atlantic salmon is used as an indicator of the functional integrity of the Rhine riverine ecosystem and of the quality of its water. Other indicator species and groups of species are also being observed. A method of ecological and biological assessment known as AMOEBA, the Dutch acronym for "a general method of ecosystem description and assessment", was developed in the Netherlands (ten Brink *et al.,* 1990). As indicators for the Rhine ecosystems, for example, some 30 species have been selected. For each species, the abundance for the period 1900-30 (a pragmatic selection to represent an unaffected situation) was estimated and compared with that of the present day, thus showing the deviation from the quasi-natural situation. Other aquatic ecosystems have also been characterised by choosing about 30 species which can be regarded as representative for their specific ecosystem.

2.4.4 Implementation and monitoring compliance

Usually, a two-step approach is applied for achieving compliance with water quality objectives. The urgency of control measures, for example, has a direct bearing on the time schedule for attaining water quality objectives for specific hazardous substances. For examples, the immediate and substantial reduction of emissions of three organic substances (carbon tetrachloride, DDT and pentachlorophenol) was stipulated by the EU *Council Directive 86/280/EEC of 12 June 1986 on Limit Values and Quality Objectives for Discharges of Certain Dangerous Substances Included in List I of the Annex to Directive 76/464/EEC.* Water quality objectives for these substances had to be complied with after a period of one and a half years (as of 1 January 1988). In some countries and for other hazardous substances, a time period of 5-10 years has been set to attain water quality objectives by the substantial reduction of emissions from point sources. Some countries, notably those participating in the Rhine Action Programme, have chosen the year 2000 as the deadline for attaining water quality objectives. Phasing out the use of certain substances, reducing nutrient discharges and changing agricultural practices usually requires a longer time period and the need to comply with relevant water quality objectives should take this fact into consideration.

Water quality objectives may be subject to revision and to adjustment in order to take account of potential reductions in pollution offered by new technology, of new scientific knowledge on water quality criteria and of changes in water use. Practical experience suggests, however, that dischargers should not be asked to review their practices on the basis of newly elaborated water quality objectives too often, or too soon after establishing practices designed to comply with earlier water quality objectives. In the UK, for example, the 1991 Water Act allows for the revision of water quality objectives although such a review can only take place at intervals of at least five years, or if the NRA requests such a review following consultation with water users and other appropriate bodies.

Adaptation of monitoring programmes, surveillance systems and laboratory practices are necessary in the implementation of water quality objectives. Two problems deserve special mention in this respect: the detection limit of laboratory equipment, and agreement on a criterion for the attainment of water quality objectives. Experience in many countries shows that laboratory techniques should have a detection limit that is preferably, one order of magnitude lower than the water quality objective for the substance in question. In the case of hazardous substances, this may require sophisticated laboratory equipment and specially trained personnel and may lead to high costs for laboratory analyses.

Usually, water quality criteria used as a basis for elaborating water quality objectives already have a built-in margin of safety so that, for the most part, a certain number of monitoring data may exceed the established water quality objective and forewarn of a certain risk, without requiring immediate action. In most cases, this advance warning ensures that action can be taken before real damage occurs. For hazardous substances some countries consider that the water quality objective has been attained if at least 90 per cent of all measurements (within a period of three years) comply with the water quality objective, or if the mean value of the concentration of the substance is less than, or equal to, half the concentration value of the water quality objective. Another approach requires the use of the mean concentration of a substance as an evaluation criterion. This approach is followed, for example, by the EU Council Directive 86/280/EEC. In some countries, the median value for phosphorus is taken as a criterion for assessing the attainment of its water quality objective.

2.5 Conclusions and recommendations

Many chemical substances emitted into the environment from anthropogenic sources pose a threat to the functioning of aquatic ecosystems and to the use of water for various purposes. The need for strengthened measures to prevent and to control the release of these substances into the aquatic environment has led many countries to develop and to implement water management policies and strategies based on, amongst others, water quality criteria and objectives. To provide further guidance for the elaboration of water quality criteria and water quality objectives for inland surface waters, and to strengthen international co-operation the following recommendations have been put forward (UNECE, 1993):

- The precautionary principle should be applied when selecting water quality parameters and establishing water quality criteria to protect and maintain individual uses of waters.

- In setting water quality criteria, particular attention should be paid to safeguarding sources of drinking-water supply. In addition, the aim should be to protect the integrity of aquatic ecosystems and to incorporate specific requirements for sensitive and specially protected waters and their associated environment, such as wetland areas and the surrounding areas of surface waters which serve as sources of food and as habitats for various species of flora and fauna.

- Water-management authorities in consultation with industries, municipalities, farmers' associations, the general public and others should agree on the water uses in a catchment area that are to be protected. Use categories, such as drinking-water supply, irrigation, livestock watering, fisheries, leisure activities, amenities, maintenance of aquatic life and the protection of the integrity of aquatic ecosystems, should be considered wherever applicable.

- Water-management authorities should be required to take appropriate advice from health authorities in order to ensure that water quality objectives are appropriate for protecting human health.

- In setting water quality objectives for a given water body, both the water quality requirements for uses of the relevant water body, as well as downstream uses, should be taken into account. In transboundary waters, water quality objectives should take into account water quality requirements in the relevant catchment area. As far as possible, water quality requirements for water uses in the whole catchment area should be considered.

- Under no circumstances should the setting of water quality objectives (or modification thereof to account for site-specific factors) lead to the deterioration of existing water quality.

- Water quality objectives for multipurpose uses of water should be set at a level that provides for the protection of the most sensitive use of a water body. Among all identified water uses, the most stringent water quality criterion for a given water quality variables should be adopted as a water quality objective.

- Established water quality objectives should be considered as the ultimate goal or target value indicating a negligible risk of adverse effects on use of the water and on the ecological functions of waters.

- The setting of water quality objectives should be accompanied by the development of a time schedule for compliance with the objectives that takes into account action which is technically and financially feasible and legally implementable. Where necessary, a step-by-step approach should be taken to attain water quality objectives, making allowance for the available technical and financial means for pollution prevention, control and reduction, as well as the urgency of control measures.

- The setting of emission limits on the basis of best available technology, the use of best environmental practices and the use of water quality objectives as integrated instruments of prevention, control and reduction of water pollution, should be applied in an action-oriented way. Action plans covering point and diffuse pollution sources should be designed, that permit a step-by-step approach to water pollution control which are both technically and financially feasible.

• Both the water quality objectives and the timetable for compliance should be subject to revision at appropriate time intervals in order to adjust them to new scientific knowledge on water quality criteria, to changes in water use in the catchment area, and to achievements in pollution control from point and non-point sources.

• The public should be kept informed about water quality objectives that have been established and about measures taken to attain these objectives.

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