Part Two

WATER-QUALITY CRITERIA AND OBJECTIVES

INTRODUCTION

National strategies have been developed in the UN/ECE region to prevent, control and reduce the emission of hazardous substances and the excessive release of nutrients and other conventional water pollutants into aquatic ecosystems. This applies in particular to substances that are toxic, even at relatively low concentrations, carcinogenic, mutagenic, teratogenic and/or bio-accumulative, especially when they are persistent. The accumulation of substances in aquatic organisms may additionally provoke a series of adverse effects on the food web and, for example, render fish unfit for human consumption. Water-quality criteria and objectives have been increasingly used at the national and international levels for the protection of human health, water resources and aquatic ecosystems.

The development and application of water-quality objectives and criteria is an objective of the UN/ECE *Convention on the Protection and Use of Transhoundary Watercourses and International Lakes* (Helsinki, 1992). The Parties to the Convention shall define, where appropriate, water-quality objectives and adopt water-quality criteria for the purpose of preventing, controlling and reducing transboundary impact (article 3). The Parties bordering the same transboundary waters shall elaborate joint water-quality criteria and water-quality objectives (article9); undertake specific research and development activities in support of achieving and maintaining the water-quality objectives and water-quality criteria (article 12); and also make available to the public the information on water-quality objectives and the results of checking compliance therewith (article 16, paragraph 1 (c)). General guidance for developing water-quality criteria and objectives is given in annex III to the Convention.

This part of the publication examines existing methods for assessing the status of surface waters in member countries and for defining water-quality criteria and objectives with the aim of maintaining and, where necessary, improving the existing water quality, in particular of trans-boundary waters. Cooperative arrangements on the subject made by riparian countries in the UN/ECE region are also reviewed.

The recommendations contained therein may assist UN/ECE countries in defining water-quality objectives and in adopting water-quality criteria, and help riparian countries bordering the same transboundary waters, to resolve extant problems in the elaboration of joint water-quality objectives and criteria. It may additionally assist member Governments in defining levels of significant transboundary water pollution, resolving problems related to responsibility and liability in regard to transboundary water pollution, and selecting technology for waste-water treatment.

RECOMMENDATIONS TO UNIECE GOVERNMENTS ON WATER-QUALITY CRITERIA AND OBJECTIVES

Many chemical substances emitted into the environment from anthropogenic sources pose a threat to the functioning of aquatic ecosystems and the utilization of water for various purposes. The need for strengthened measures to prevent and control the release of hazardous substances into the aquatic environment, and to abate the deterioration of water quality owing to these substances as well as to an excessive release of nutrients and other conventional water pollutants, has led many countries to develop and implement water management strategies on the basis of, *inter alia,* water-quality criteria and objectives, taking into account water-quality requirements for water uses in the relevant catchment area.

Guidelines for developing water-quality objectives and criteria are given in annex III to the UN/ECE *Convention on the Protection and Use of Transhoundary Watercourses and International Lakes* (Helsinki, 1992). With a view to providing further guidance in the elaboration of water-quality criteria and the formulation and setting-up of water-quality objectives for inland surface waters, and in order to strengthen international cooperation,

it is recommended that:

Water-quality requirements for different water uses, such as drinking-water, irrigation, livestock watering, fisheries, leisure activities, amenities, and maintenance of riverine flora and fauna should be clearly defined, taking into account in particular the adverse impact of the use of substances that are toxic, persistent, bio-accumulative, carcinogenic, mutagenic and teratogenic, or which cause eutrophication and acidification of aquatic ecosystems.

Special attention should be given to acquiring more information on the substance's behaviour in water as well as to the fate and interaction of different substances and their mixtures (for example, synergistic effects) both on the biotic and abiotic components of aquatic ecosystems.

A methodology for the selection of water-quality parameters, including physical properties, chemical constituents and microbiological parameters of water, which are of relevance to water uses for various purposes, should be developed and harmonized, if possible, at an international level. Particular attention should be given to the development and harmonization, at the international level, of methodological approaches for the selection of biological indicators relating to the conservation of flora and fauna and to other parameters suitable for characterizing the structural and/or functional integrity of aquatic ecosystems.

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

(a) Raw-water quality criteria for drinking-water supply should strive for attainment as appropriate of drinking-water criteria;

(h) Water-quality criteria for aquatic life should be aimed at the protection and maintenance of riverine flora and fauna in all its forms and life stages, taking into account, in particular, the protection of the functional integrity of aquatic ecosystems;

(c) Water-quality criteria for surface waters used for irrigation should not lead to any significant adverse effects on soil properties, salinization or accumulation of toxic substances or to the subsequent transfer of pollution from soil to surface water and groundwater;

(d) Quality criteria for sediment and suspended particulate matter should be aimed at the protection of aquatic organisms living in or on sediment, at the protection of aquatic ecosystems, and at the protection of soils and terrestrial ecosystems, if dredged sediment is to be disposed of.

Particular attention should be paid to the protection of the integrity of aquatic ecosystems and to specific requirements regarding sensitive and specially protected waters and their environment, such as wetland areas, and the surrounding areas of surface waters which serve as source of food and habitats for various species of flora and fauna. Special-use categories should be defined for that purpose. Quality criteria for these categories should be established on the basis of indicators relating to the conservation of flora and fauna and other information that characterizes the structural and/or functional integrity of aquatic ecosystems.

In setting water-quality criteria, particular attention should be paid to substances that cause acute and chronic toxic effects at low concentrations, as well as to substances that cause (or are suspected of causing) carcinogenic, mutagenic and teratogenic effects.

Water-quality criteria should be used as a reference base for the assessment of the current water quality in water bodies and its suitability for different purposes.

In order to improve knowledge about the adverse impact of pollution on aquatic ecosystems, research should be continued on sensitive indicators and/or criteria that are capable of diagnosing early stages of stress to aquatic ecosystems. Particular attention should be paid to the further development and improvement of systems for water-quality assessment and classification that rely on biological information, as well as the combination of physico-chemical and biological assessment and classification systems. Efforts should be made by riparian countries to jointly develop and agree on water-quality assessment and classification systems for transboundary waters.

Water-management authorities in consultation, *inter alia,* with industries, municipalities, farmers' associations and the general public 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 protection of the integrity of aquatic ecosystems, should be considered, if applicable.

In setting water-quality objectives for a given water body, both the water-quality requirements for water uses of the relevant water body as well as downstream uses should be taken into account. In transboundary waters, water-quality objectives should be set taking 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.

Water-quality objectives should be set, taking into account specific physico-chemical, biological and other characteristics of water bodies and their catchment area. Expert judgement should be sought for adjusting water-quality objectives to site-specific natural conditions, particularly natural excessive occurrence of some substances, such as heavy metals. 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 parameter should be adopted as a water-quality objective.

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

Water-quality objectives established should be considered as the ultimate goal, that is, as a target value which indicates a negligible risk of adverse effects on water uses and 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, taking into account action which is technically and financially feasible and legally implementable.

Where necessary, there should be a step-by-step approach to attain water-quality objectives, taking into account, *inter alia,* the current water quality, current and potential new water uses in the catchment area, available technical and financial means for pollution prevention. control and reduction, as well as the urgency of control measures. These objectives, which represent the result of a balance between what is desirable from an environmental point of view and what is feasible from a technical and economic point of view. should be regarded as a policy goal to be attained within a certain period of time.

The setting of emission limits on the basis of best available technology, the use of best environmental practices and water-quality objectives as integral instruments of prevention, control and reduction of water pollution, should be applied in an action-oriented way. Action plans covering both point and diffuse pollution sources should be designed, which permit a step-by-step approach and are both technically and financially feasible. In addition to action plans and measures implementing strategies and standards for emission limits, measures based on water-quality criteria and objectives should also be considered, where appropriate; the relative priorities of all these measures should also be considered. Preparatory and complementary administrative measures to these action plans should include, *inter alia:*

(a) Taking steps, such as emission inventories and catchment inventories, in order to ascertain where substances that are hazardous or otherwise likely to adversely affect water uses and aquatic ecosystems are manufactured, used, stored, disposed of or discharged into inland waters;

(h) Phasing out or prohibiting the use of hazardous substances when those pose a particular risk to sensitive or specially protected waters.

Monitoring programmes, including programmes for laboratory analyses, should be adapted to the water-quality objectives, particularly with regard to measurement parameters, range of concentrations and frequency of measurement, and should provide reliable information on whether water-quality objectives are met and what further reduction in emissions from both point and non-point sources in the catchment area is required to meet the objectives.

Both the water-quality objectives and the timetable for compliance should be subject to revision at appropriate time intervals in order to adjust them, *inter alia,* to new scientific knowledge on water-quality criteria, changes in water use in the catchment area, best available technology for point-source control, the establishment and implementation of rules of good agricultural practice for the control of agricultural sources as well as environmentally sound practices for the control of other non-point sources, which are technical and financially feasible, in addition to other factors that may have a bearing on the implementation of measures to prevent, control or reduce water pollution. The public should be kept informed about water-quality objectives that have been established, and about measures taken to attain these objectives.

I. WATER-QUALITY CRITERIA

Water-quality criteria generally describe the quality of water needed to protect and maintain individual water uses. They are based on parameters that describe the quality of water as such and/or the quality of suspended particulate matter, bottom sediment and biota.

Many water-quality criteria set a maximum level for the concentration of a substance (in water, sediment and/or biota, respectively) which is not harmful under the conditions of a continuous water use for a single, specific purpose, such as water for drinking-water supply, agriculture and recreation, and requirements of biological communities and the functioning of aquatic ecosystems in general. The protection and maintenance of the above-mentioned water uses usually impose different requirements on water quality and, therefore, water-quality criteria may be different for these uses. For some water-quality parameters, such as dissolved oxygen, water-quality criteria are set at the minimum acceptable level for the concentration of a substance to ensure the maintenance of biological functions.

Some countries introduce different risk levels when developing water-quality criteria. In the Netherlands, for example, discussion between policy makers and scientists has led to the definition of two different risk levels for the setting of water-quality criteria as described in section B of this chapter. In other countries, for example in the United States, criteria may have three components, the first serving as the risk assessment endpoint and the other two being applied in assessing the exposure, as follows:

(a) Magnitude, i.e., the concentration of a pollution allowable;

(b) Duration, i.e., the period of time over which the predicted in-stream concentration is to be averaged forcomparison with the criteria concentration (this specification limits the duration of concentrations above the criteria);

(c) Frequency, i.e., how often criteria can be exceeded without unacceptably affecting the designated use.

Water-quality criteria have been developed for a number of traditional water-quality parameters such as pH, dissolved oxygen and nutrients.

Numerous studies have confirmed, for example, that a pH-range of 6.5 to 9 is appropriate for the maintenance of fish communities. Consequently, water-quality criteria for pH usually follow this range. As concerns dissolved oxygen, the combination of low concentrations of dissolved oxygen and the presence of toxic substances may lead to stress responses in aquatic ecosystems because the toxicity of, for example, zinc, lead and copper, is increased by low concentrations of dissolved oxygen. High water temperature also increases the adverse effects of a low concentration of dissolved oxygen on biota. The water-quality criterion for dissolved oxygen takes these factors into account: it is in the order of 5 to 9.5 mg/I depending on water temperature requirements for particular species during various life stages, i.e., a minimum dissolved-oxygen concentration of 5 to 6 mg/I for warm-water biota and 6.5 to 9.5 mg/1 for cold-water biota.

Water-quality criteria for nutrients, such as phosphates and ammonium. are usually established as follows: criteria for phosphates are set at a level at which an excessive growth of algae would not occur, and criteria for ammonium are based on no-effect concentration levels of ammonia.

Increasing attention is now being paid to the development of water-quality criteria for hazardous substances that, due to their toxicity, persistence, bio-accumuiation capability and/or their carcinogenic. teratogenic or mutagenic effects, pose a threat to water use-and the functioning of aquatic ecosystems. 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, substances including genetically modified organisms that due to insufficient data are for the time being merely suspected of belonging to the category of hazardous substances are also taken into account in many countries in the development of water-quality criteria.

Discussion continues on the issue of which fraction of a hazardous substance should be taken for developing water-quality criteria: the total recoverable and/or the dissolved form of a substance. Criteria for these fractions may be quite different. This may also have a bearing on water-quality objectives, established on the basis of criteria for different fractions of hazardous substances. Section A of chapter III provides some examples on this issue.

The elaboration of water-quality criteria for hazardous substances appears to be a lengthy and resource-expensive process. Comprehensive laboratory studies assessing the impact of hazardous substances on water-borne organisms often need to be carried out, supplementing the general literature search and analysis. In Canada, for example, the average cost of developing a criterion for a single substance through a literature search and analysis is of the order of Can$ 50,000. In Germany, the average cost of laboratory studies for developing a criterion for a single substance amounts to some DM 200,000.

The costs and the workload for developing water-quality criteria have been shared in some countries. For example, the Canadian Council of Ministers of the Environment (CCME) 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 mote comprehensive set of criteria than would have been possible by individual efforts, as well as to end the confusion caused by the use of different criteria by different provincial governments. Examples of water-quality criteria developed in Canada are given in tables 1 to 3.

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

In some countries attempts were made to apply water-quality criteria elaborated in other countries. In such cases, it was 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 occurred in relevant water bodies of the "borrowing" country. On many occasions, the application of "foreign" water-quality criteria required additional aqua-toxicological testing.

In the Netherlands. for example, a risk-assessment method has been developed, enabling the determination of water-quality criteria using toxicity data from national and international literature. This method decreases thenumber of toxicity studies to be made and allows for a significant decrease in costs.

In some countries procedures are being established for a priority selection of water-quality parameters, notably hazardous substances for which water-quality criteria are being developed in the first instance.

A. Assessment of hazardous characteristics of water pollutants

There are currently approximately 100,000 chemical substances available on the market. Many of these substances cause or are likely to cause an adverse impact on water quality and conditions in aquatic ecosystems. Some substances, notably mercury, cadmium and pesticides, have long been recognized as being hazardous in this respect. Other substances have only recently been recognized as having such characteristics.

The problem faced by water pollution control authorities is one of selecting from the existing huge number of substances those that warrant priority action in order to prevent, control and reduce their emission into the aquatic environment. For example, the Council of the European Communities in its *Directive of 4 May 1976 on Pollution Caused by Certain Dangerous Substances Discharged into the Aquatic Environment of the Community* (76/464/EEC)[1] identified substances whose discharge into the aquatic environment is subject to prohibition, and those substances and categories of substances whose discharge is subject to control or reduction. In Canada, a list of priority substances was developed by an independent panel composed of representatives from the provincial governments, industry, the academic community and environmental organizations, with technical support from the Federal Government. This list is now being used as a guide in drafting water-quality criteria, among other purposes.

The selection of priority substances is based upon the consideration of relevant characteristics of these substances. Long discussions were held, however, on the issue of which characteristics should constitute the minimum necessary to describe a hazard, i.e., whether a substance should be classified as hazardous because of its toxicity only, because of its toxicity combined with either persistence or bio-accumulation, or because it possesses all three characteristics.

Among toxicity parameters used in assessment schemes, acute aquatic toxicity and chronic aquatic toxicity are widespread. In defining acute aquatic toxicity two indicators are generally used: the concentration of a substance at which 50 per cent of test organisms (commonly fish or *Daphnia)* die within 96 hours, or the concentration that causes immobilization of 50 per cent of test organisms (usually *Daphnia)* within 48 hours. In defining chronic aquatic toxicity, test organisms are usually exposed over their entire lifetime to different concentrations of a substance with the aim of establishing the concentration level which produces "no-adverse effects" on the test organism. These laboratory studies

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Directives of the Council of the European Communities are hereafter referred to as EC Council Directives.

TABLE 1

Water-quality criteria for inorganic water-quality parameters established in Canada[a]

	Use-related water-quality criteria in mg/l		
Water-quality parameter	*Aquatic life*	*Irrigation*	*Livestock watering*
Aluminium (total)	0.005-0.1[h]	5.0	5.0
Ammonia (total)	1.37-2.2[e]		
Arsenic (total)	0.05	0.1	0.5-5.0
Beryllium		0.1	0.1[e]
Boron (total)		0.5-6.0	5.0
Cadmium (total)	0.0002-0.0018[d]	0.01	0.02
Calcium			1000
Chloride (total)		100-700	
Chlorine (total, residual)	0.002		
Chromium (total)	0.002-0.02	0.1	1.0
Cobalt (total)		0.05	1.0
Copper (total)	0.002-0.004[d]	0.2-1.0[f]	0.5-5.0
Cyanide (as free CN)	0.005		
Fluoride (total)		1.0	1.0-2.0
Iron (total)	0.3	5.0	
Lead (total)	0.001-0.007[d]	0.2[e]	0.1
Lithium (total)		2.5	
Manganese (total)		0.2	
Mercury (total)	0.0001		0.003
Molybdenum (total)		0.01-0.05	0.5
Nickel (total)	0.025-0.15[d]	0.2	1.0
Nitrate	Avoid prolific weed growth		
Nitrate and nitrite			100
Nitrite	0.06		10.0
Oxygen, dissolved	5.0-9.5		
pH	6.5-9.0		
Selenium (total)	0.001	0.02-0.05	0.05
Silver (total)	0.0001		
Sodium			
Sulphate			1000
Total dissolved solids		500-3500	3000
Uranium (total)		0.01[e]	0.2
Vanadium (total)		0.1	0.1
Zinc (total)	0.03[e]	1.0-5.0[h]	50.0

[a] As of March 1990, published by the Canadian Council of Ministers of the Environment.
[b] Criteria vary with pH, calcium and dissolved organic carbon concentrations.
[c] Criteria change with temperature and pH.
[d] Criteria change with hardness.
[e] Tentative criteria because of insufficient evidence.
[f] Criteria vary depending on crops.
Setting of criteria requires special analysis of the level at which sodium is absorbed.
[h] Criteria change with pH.

TABLE 2

Water-quality criteria for pesticides established in Canada [a]

	Use-related water-quality criteria in mil					
		Irrigation				
Pesticide	Aquatic life	Hay and cereals	Legumes	Others	Livestock watering	Amenities
Aldicarb			1.0b	67.5	[illegible]	0.5
Atrazine		2.0	10b	10b	[illegible]	60b
Bromoxynil		5.0	7.4	0.35	[illegible]	19b
Captan					[illegible]	20b
Carbofuran					[illegible]	45
Chlorothalonil		c	c	c	c	c
Cyanazin		2.0b	0.5b	0.5b	[illegible]	10b
Dicamba		10b	0.6	0.06	[illegible]	69
Diclofop-methyl		6.1	0.18		[illegible]	9.0b
Dinoseb		0.05	16	16	[illegible]	150
Dimethoate					[illegible]	4b
Endosulfan	0.02					
Glyphosate					[illegible]	280
Lindane					[illegible]	4.0
Linuron				c	c	c
MCPA	c	c	c	c	c	
Metolachlor		8.0	28	28	[illegible]	50b
Metribuzin		1.0b	0.5b	0.5b	[illegible]	80b
Picloram					[illegible]	190b
Simazine		10	[illegible]	0.5b 0.5b	10b	
Tebuthiuron		c	c	c	c	c
Triallate					[illegible]	230b
Trifluralin					[illegible]	45b
2,4-D					[illegible]	100b

[a] As of September 1992.
[b] Interim criterion.
[c] Criteria under development.

TABLE 3

Water-quality criteria for selected organic water-quality parameters established in Canada for the protection of aquatic lifea

Water-quality parameter	*Water-quality criteria for aquatic life n mgll*	*Notes*
Aldrin/dieldrin	0.000004	
Atrazine	0.002	
Benzene	0.3	Tentative criterion
Carbofuran	0.00175	
Chlordane	0.000006	
Monochlorobenzene	0.015	Tentative criteria because of insufficient evidence for all chloro-benzenes
Dichlorobenzene, 1,2-	0.0025	
Dichlorobenzene, 1,3-	0.0025	
Dichlorobenzene, 1,4-	0.004	
Trichlorobenzene, 1,2,3-	0.0009	
Trichlorobenzene, 1,2,4-	0.0005	
Trichlorobenzene, 1,3,5,-	0.00065	
Tetrachlorobenzene, 1,2,3,4-	0.0001	
Tetrachlorobenzene, 1,2,3,5-	0.0001	
Tetrachlorobenzene, 1,2,4,5-	0.00015	
Pentachlorobenzene	0.00003	
Hexachlorobenzene	0.0000065	
Monochlorophenol	0.007	
Dichlorophenols	0.0002	
Trichlorophenols	0.018	
Tetrachlorophenols	0.001	
Pentachlorophenol	0.0005	
Cyanazin	0.002	Tentative criterion
2,4-D	0.004	
DDT	0.000001	
Dichloroethane, 1,2-	0.1	
Endosulfan	0.00002	
Endrin	0.0000023	
Ethylbenzene	0.7	Tentative criterion
Glyphosate	0.065	
Heptachlor + heptachlor epoxide	0.00001	
Hexachlorobutadiene	0.0001	
Hexachlorocyclohexane isomers	0.000001	
Metribuzin	0.001	
Phenols (total)	0.001	
Dibutyl phthalate	0.004	
Di-(2-ethylhexyl)phthalate	0.0006	
Other phthalate esters	0.0002	
Picloram	0.029	Tentative criterion
Polychlorinated biphenyls (total)	0.000001	Criteria for inland water
	0.00001	Criteria for marine water
Tetrachloroethvlene	0.26	Tentative criterion
Toluene	0.3	
Toxaphene	0.000008	
Trichloroethvlene	0.02	

[a] As of March 1990. published by the Canadian Council of Ministers of the Environment.

may, however, produce different results, mainly because of the absence of uniform test methods for chronic toxicity.

The persistence of a substance in the aquatic environment often relates to the risk that a substance may constitute: the longer the substance is present, the greater the probability of its effects on targets of interest. Usually, the aquatic half-life of a substance is used for quantifying persistence. This is not, however, a simple parameter, as the persistence of a substance is generally influenced by a range of physical, chemical and biological processes. Expert judgement is made, when necessary, to provide the best estimate of this parameter.

Bio-accumulation describes effects of uptake of a substance from the environment upon a target organism. As with persistence, bio-accumulation may constitute a risk only in combination with effects parameters such as toxicity. Methods have been elaborated in some UN/ECE countries which also make it possible to include the bio-accumulation potential of a substance in the assessment of the risk this substance poses to the whole aquatic ecosystem.

Carcinogenicity, mutagenicity and teratogenicity have also been applied in some schemes as selection criteria. The wider application of these characteristics is however limited mainly because of problems related to the availability and comparability of information, as well as to the classification and ranking of carcinogenic, reproductive and developmental effects.

Usually, compensation factors are applied to extrapolate laboratory test data to the actual situation of the water body and to compensate for any missing data. The lower the level of knowledge of the harmful effects, particularly with respect to the long-term effects of low concentrations, the wider the safety margin to be established between the effects data and the quality criteria based thereon. Most UN/ECE countries use a safety factor of 10 with data on chronic toxicity for sensitive aquatic species. If data on acute toxicity only are available, a larger factor, most commonly 100, is used unless information on the ratio between acute/chronic toxicity is available.

Experience in some UN/ECE countries pointed to the need to verify toxicity data derived from laboratory tests by comparison with the available field toxicity data, taking care to distinguish between the effects of the particular compound and those of other potentially toxic compounds present. Any discrepancies between the field data and the tentative water-quality criteria require the reassessment of the available field and laboratory data and. if necessary. the application of a different safety factor.

Concern for extrapolation of data from standard laboratory species to complex aquatic ecosystems has led to multiple species testing and, more recently, the attempts to develop integrated field, laboratory and mesocosm approaches. Current methods for toxicity testing may also fail to deal with ecosystem complexity resulting from multiple causality and synergy of multiple stresses acting simultaneously within the ecosystem.

As large aquatic ecosystems, including transboundary waters, are frequently subject to a great number of human interaction, mathematical modelling of chemicalfate is at present the preferred approach to overcoming this difficulty. In the Great Lakes. for example, the modelling approach integrates data on physico-chemical properties of toxic substances with hydrodynamic and aerodynamic transport models, first applied to the prediction of the concentration of polychlorinated biphenyls (PCBs) in fish. An alternative approach to obtaining information on toxicity at the levels of biological communities and ecosystems is the potential use of individual-based, organism models. These models, subject to further research, are intended to reflect the outcome of interaction between individuals in a population or between species in a community.

In general, comprehensive data on the harmful properties of substances or their concentrations in inland waters, biota and sediment are scarce and expert judgement is often required in assessing the reliability of data and providing default values. In some countries, computerized systems have been recently developed in order to facilitate the selection of priority substances. In the United Kingdom, for example, a computerized system based on four scenarios is applied, as follows:

(a) The short-term scenario considers whether the concentration of a substance in water, owing to the emission of that substance from point and non-point sources, will approach the level at which acute toxic effects occur;

(b) The long-term scenario looks at whether the concentration of the substance from a variety of emission sources may approach the level at which chronic toxic effects occur, due to the substance's persistence;

(c) The food-chain scenario assesses whether the concentration of the substance will reach a level at which toxicity problems occur in higher organisms due to bio-accumulation through the food chain;

(d) The carcinogenicity scenario studies whether the substance's properties suggest that it may cause cancer following exposure in or through the aquatic environment.

B. Water-quality criteria for individual use categories

1. *Criteria for raw water used for drinking-water supply*

These criteria describe water-quality requirements imposed on inland waters intended for abstraction of drinking water. Water-quality criteria for raw water generally follow drinking-water criteria that define a quality of water that can be safely consumed by humans throughout their lifetime. They address microbiological and biological requirements as well as inorganic and organic substances of significance to human health. Drinking water should, for example, not contain any micro-organisms known to be pathogenic and should be free from bacteria indicative of pollution with excreta (faecal coliforms and coliform organisms). It should also not contain any pathogenic intestinal protozoa, that is organisms possibly introduced into water through human or, in some cases, animal faecal contamination.

In order to arrive at drinking-water criteria for inorganic and organic substances of health significance, toxicological studies with laboratory animals are conducted in order to predict the toxic effects of substances on humans. One major problem is the extrapolation of toxicological data from animals to man, owing in particular to the relatively high doses used in experiments and the low concentrations found in drinking water. Uncertainties are also related to the assessment of the total intake of a substance from air, water and food. Furthermore, there is the potential of additive, synergistic and antagonistic effects of substances that may be present in water. These uncertainties are currently taken into account by the use of safety factors as high as 100 or 1,000.

Criteria for drinking water have been developed by some international organizations and include the 1984 World Health Organization's *Guidelines for Drinking-water Quality* and the EC *Council Directive of 15 July 1980 Relating to the Quality of Water Intended for Human Consumption* (80/778/EEC), covering some 60 quality parameters. These documents are used by UN/ECE countries, as appropriate, in establishing enforceable national drinking-water quality standards.

Water-quality criteria for raw water used for drinking-water supply differ depending on the potential of different methods of raw-water treatment (e.g., simple physical treatment and disinfection, chemical treatment and disinfection, intensive physical and chemical treatment) to reduce the concentration of water contaminants to the level set by drinking-water criteria. In revising the existing criteria, many countries strive to ensure such quality of raw water as would require only the use of near-natural conditioning processes (e.g., bank filtration or low-speed sand filtration) and disinfection in order to meet drinking-water standards.

In member States of the European Community, national quality criteria for raw water used for drinking-water supply also follow prescriptions of the EC *Council Directive of 16 June 1975 Concerning the Quality Required of Sui face Water Intended for the Abstraction of Drinking Water in Member States* (75/440/EEC), which covers 45 criteria for parameters directly related to public health (microbiological characteristics, toxic compounds and other substances with a deleterious effect on human health), parameters affecting the taste and odour of water (e.g., phenols), parameters with an indirect effect on water quality (e.g., colour, ammonium) and parameters with general relevance to water quality (e.g., temperature).

Increasing knowledge on organic pollutants, hazardous in water at low concentrations, has led some countries to narrow the gap between drinking-water criteria and raw-water criteria. In the Netherlands, for example. the raw-water criteria for pesticides and related products (insecticides, herbicides, fungicides) have been set at a concentration of 0.1 1.tg/1, in accordance with the EC Council Directive (80/778/EEC) for drinking-water criteria. In Germany, similar action is under consideration.

2. *Criteria for irrigation*

Irrigation is one of the main agricultural consumers of water in the UN/ECE region. 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. Contaminants in irrigation water may accumulate in the soil and render the soil unfit for agriculture after a period of years. When the presence of pesticides or pathogenic organisms in irrigation water does not directly affect plant growth, it may, however, potentially affect the acceptability of the agricultural product.

Water-quality criteria for irrigation water generally take into account 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 as 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 injury 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.

A number of other factors have a bearing on water-quality criteria for irrigation. The effect of water on irrigated crops depends for example on the texture of the soil, as well as the physical properties of the specific contaminants in the water. In some countries, two different sets of water-quality criteria are developed for sandy soils and clay-based soils in order to account for different rates of water percolation and accumulation of substances in the root zone. Additionally, the type of crop may be taken into account.

Quality criteria may differ considerably from one country to another, due to different annual application rates of irrigation water. In Canada, for example, water-quality criteria for irrigation are being set so that the land can be irrigated for at least 100 years with an annual application rate of 1,000 mm irrigation water before concentrations of contaminants in the soil reach the threshold of phytotoxicity.

3. *Criteria for livestock watering*

Poor quality water may affect livestock by causing death, sickness or less than optimum growth of the animals. Parameters of concern include in particular nitrates, sulphates, total dissolved solids (salinity), a number of metals, and organic micropollutants such as pesticides in addition to blue-green algae and pathogens in water. Some of these 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 livestock to speed up the growth process and reduce the risk of disease, as well as information on the toxicity of specific substances to the different species. If water for livestock contains high concentrations of elements, the diets of animals may require adjustment to ensure that the elements in question will not produce any toxic effects.

The setting of water-quality criteria for livestock watering is complicated by factors similar to those encountered when criteria are developed for other water uses. Problems include the lack of conclusive research results on cause-effect relationships between contaminants and animals, the unknown effects of combinations of toxicants or interaction of toxicants with certain non-toxic substances (which may give rise, for instance, to synergetic effects), and analytical problems associated with measurements of low concentrations of toxic substances.

4. *Criteria for recreation and amenities*

Recreational water-quality criteria are used to assess the safety of water to be used for swimming and other water-sport activities such as windsurfing and water-skiing. 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 or skin infections. As a rule, recreational water-quality criteria are established by government health agencies.

Recreational criteria are often set for indicators of faecal pollution, such as faecal coliforms and pathogens. There has been a considerable amount of research recently in the development of other indicators of microbiological pollution including viruses that would affect swimmers.

Criteria are also being developed for pH, since extremes of pH may cause eye irritation, and for some other parameters, such as turbidity and salinity. Usually, recreational water-quality criteria do not take into account hazardous substances such as heavy metals and organic micropollutants. Due to the short exposure of swimmers, recreational water-quality criteria for these substances would be less stringent than similar criteria established for other water uses.

The EC *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 (ammonium, nitrogen and phosphates), toxic heavy metals and organic micropollutants. No quality criteria were established for these parameters in the Directive itself.

Some criteria have been established in UN/ECE countries aimed at the protection of the aesthetic properties of water. These criteria are primarily oriented towards the visual aspect. They are usually narrative in nature, and may specify, for example, that waters must be free of floatin[g], oil or other immiscible liquids, floating debris, excessive turbidity, and objectionable odours. The criteria are mostly non-quantifiable because of the varying acuteness of sensory perception and because of the variability of local conditions.

5. *Criteria for commercial and sports fishing*

Water-quality criteria for commercial and sports fishing take into account, in particular, the bio-accumulation of contaminants through successive levels of the food web, which can make fish unsuitable for human consumption. In some countries, the approach described hereunder is applied in developing these criteria.

First, the tolerable daily intake (TDI) is determined. This is the quantity of a chemical that can be consumed daily by man over his lifetime, with reasonable assurance that his health will not be affected. The TDI is based on all available animal and human toxicology data for the substance in question and the application of safety factors because of uncertainties about the relationship between exposure and effect.

Second, the probable daily intake (PDI) of the chemical contaminant is determined, based on a person's exposure to the chemical from all sources. The PDI values take into account the average and high rates of consumption of fish and other food; they also consider the potential exposure of more sensitive subgroups of the population (such as children or the elderly).

Third, when the PDI is greater than the TDI, the maximum allowable concentration of a substance in fish is determined (fish consumption criteria). Finally, water-quality criteria are established at such a concentration that bio-accumulation and biomagnification (the successive increase in the concentration of a substance in the food web) of the substance cannot lead to concentrations in fish exceeding the fish consumption criteria.

6. *Criteria for protection of aquatic life*

Aquatic ecosystems are composed of the biological community (producers, consumers, decomposers) and the physical and chemical (abiotic) components. Within the aquatic ecosystem 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, which are dependent on both abiotic conditions (e.g., temperature, flow conditions, pH, concentration of dissolved oxygen, concentration of heavy metals and organic micropollutants) and biotic conditions (e.g., species composition).

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 (causing fish kills at low concentrations) as well as phosphates, ammonium and nitrate (causing significant changes in community structure if released in excessive amounts into aquatic ecosystems).

Heavy metals and many synthetic chemicals can gain entry into organisms, resist being metabolized or excreted, and thus bio-accumulate. If the organism continues to be exposed to chemicals that it cannot adequately excrete or detoxify, concentrations can increase to toxic levels. 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 exposure-effect relationships. The mechanisms of both the uptake of contaminants from water bodies by aquatic organisms and the bio-accumulation therein are to be studied. Fish, for example, absorb toxic chemicals directly from the water flowing across their gills as part of their normal respiration. Contaminants are also absorbed from the sediment by bottom-dwelling animals such as tubificid worms, insect larvae, molluscs or crayfish and accumulate in ducks, turtles and bottom-feeding fish such as white suckers, brown bullheads and carp. Heavy metals and many organic micropollutants, such as PCBs, dioxines and organo-chlorinated pesticides. may be absorbed from the water by phytoplankton and then pass through the food web to fish and eventually to the aquatic birds and mammals. As many aquatic animals excrete these chemicals very slowly (or not at all), these contaminants build up to higher concentrations at each step in the food web because of the biomagnification effect, and can reach toxic concentrations.

In Canada, criteria for aquatic life are based on the lowest concentration of a substance that affects the test organisms (lowest observable effect level). The water-quality criteria established refer to the most sensitive species in different species groups. The minimum data-set requirements applied in Canada for development of these criteria are:

(a) *Fish:* at least three studies of the toxicity of the substance on three or more freshwater species resident in North America, including at least one cold-water species (e.g., trout) and one warm-water species (e.g., fathead minnow); of the above studies, at least two must be studies of chronic toxicity (partial or full life cycle);

(b) *Invertebrates:* at least two chronic toxicity studies (partial or full life cycle) on two or more invertebrate species from different classes, one of which includes a planktonic species resident in North America (e.g., daphnid species);

(c) *Plants:* at least one study on a freshwater vascular plant or freshwater algal species resident in North America. For highly phytotoxic parameters, the requirements increase to include four acute and/or chronic toxicity studies on algal or higher freshwater plant species.

In cases where these requirements for criteria derivation are not met, interim criteria are being developed in Canada. as follows:

(a) *Fish:* at least two studies of acute and/or chronic toxicity of the substance on two or more fish species, one of which includes a cold-water species resident in North America (e.g., rainbow trout);

(b) *Invertebrates:* at least two studies of acute and/or chronic toxicity on two or more invertebrate species from different classes, one of which includes a planktonic species resident in North America (e.g., daphnid species).

If a toxicity study indicates that a plant species is the most sensitive species in the data-set, then this plant species is used in Canada for drawing up the interim criteria.

A number of other UN/ECE 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 algal *Scenedesmus subspicatus),* primary consumers (e.g., water flea *Daphnia magna),* secondary consumers (e.g., fish) and reducers (e.g., bacterium *Pseudomonas putida).* Other information is also used, including that on organoleptic properties (e.g., fish tainting) of the substance, its mobility and distribution through different environmental media and biodegradation behaviour (persistence).

In the Netherlands water-quality criteria are established as follows: first a maximum permissible risk level (MRL) is established which agrees with the concentration of a substance at which full protection is provided to 95% of the species in a given aquatic ecosystem. As organisms in the field are always exposed to several substances at once, a factor of 100 is applied to the MRL to reach the concentration values that correspond to the negligible risk level (NRL). The MRL of a substance is estimated using a practical extrapolation method for the natural variance in sensitivity between organisms with regard to toxic substances. On the basis of chronic toxicity data for a number of test organisms which are considered representative of an aquatic ecosystem, the 95% protection level can be estimated. If insufficient toxicity data (less than four) are available, general safety factors of 10, 100 or 1,000 are used.

Although in the Netherlands the MRL- and NRL-values are primarily intended to protect aquatic life, already at this stage water-quality requirements for other uses are taken into account if these are stricter than requirements for aquatic life. In doing so, it is intended to fully protect functions in aquatic ecosystems and the human uses of water. If, for example, the drinking-water supply requires lower concentrations of a substance, the NRL is lowered to a concentration at which this use is fully protected. This particularity of setting water-quality criteria should be taken into account when comparing water-quality criteria and/or water-quality objectives established in the Netherlands with those of other countries (see chapter III).

More recently within the concept of the ecosystem approach in water management, attempts have been made to address criteria that indicate healthy aquatic ecosystem conditions. In addition to traditional criteria dealing, for instance, with contaminant concentrations and oxygen levels, 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 UN/ECE countries, research is under way on the development of biocriteria that quantitatively express water-quality criteria in terms of the resident aquatic community's structure and function. Biocriteria are understood as measures of "biological integrity" that can be used to assess cumulative ecological impact from multiple sources and stress agents.

In the United Kingdom, quality criteria for the protection of aquatic ecosystems are now being based on an ecological quality index. This approach is discussed below under section II.

Considerable efforts have been made to identify key species which may serve as useful integrative indicators of the functional integrity of aquatic ecosystems. This issue has been extensively covered in the *Guidelines on the Ecosystem Approach in Water Management,* contained in Part One of the present publication.

It appears, for instance, that by the time a substance produces adverse effects on key species, ecosystems integrity may already have been adversely affected. This calls for more research on sensitive indicators and/or criteria that are capable of diagnosing early phases of stress to aquatic ecosystems. Ongoing research suggests that such criteria and indicators should include both sensitive, short-lived species and information about changes in community resulting from the elimination of key predators.

7. Criteria for suspended particulate matter and sediment

Sediment in lakes and rivers is composed of inorganic (mineral) and organic matter. Due to their physicochemical properties, some substances such as PCBs, organochlorine pesticides and metals adsorb to the suspended particulate matter and sediment. The suspended particulate matter is also partially composed of plankton, which can accumulate metals and toxic organic chemicals. As a result, concentrations of, for example, PCBs in suspended particulate matter and sediment can be 1,000 times higher than in water.

The development of quality criteria for suspended particulate matter and sediment has not yet reached an advanced stage in the UN/ECE region, and few criteria are available so far. The attempts in some UN/ECE countries to develop quality criteria for suspended particulate matter and sediment aim at achieving such a water quality that the sediment (dredged material) 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. It relates to bottom-feeding fish, sediment-dwelling invertebrates and other organisms likely to be affected by contaminated sediment.

The application of quality criteria for sediment in water pollution control is considered to be complicated, however, as sediment quality reflects the accumulation process of pollutants over a long period of time. On the other hand, quality criteria for suspended particulate matter are being effectively used in some UN/ECE countries, as these criteria address pollutants recently introduced into the water body.

Recent experience in 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.

II. WATER-QUALITY ASSESSMENT AND CLASSIFICATION

Water-quality assessments and classifications are generally based on a reference system against which the cur-rent water quality is compared. The purpose of a reference base is to describe, as far as possible, the natural conditions of a water body or basic requirements posed on water quality by different water uses. There are numerous difficulties in setting up such a reference base, in particular relating to catchment areas subject to anthropogenic stress over decades and to the use category "aquatic life". Many UN/ECE countries now use water-quality criteria for that purpose. Other countries carry out specific hydrochemical investigations of the catchment area concerned in order to establish an appropriate reference base.

It is, however, practically impossible to establish the reference base for all water-quality parameters. Assessments of water quality and subsequent classification have been often confined therefore to a study of a selected number of criteria taking into account in particular the most important water pollution problems in a given country. Expert judgement is often used to ascertain appropriate water-quality determinants relevant to given water-quality problems.

In Norway, for example, eutrophication, acidification and toxicity of surface waters as well as suspended solids and the presence of faecal organisms constitute the most important water pollution-related problems. The choice of water-quality parameters for the assessment and classification scheme was based in that country on the following concept:

(a) The parameter (or a number of parameters) should adequately describe the pollution problem in question;

(h) Both the emission values and the immission's situation should be known for the parameter(s) in question;

(c) Information should be available on the response of a water body to changes in loading in order both to calculate necessary reductions of pollution loading (in order to attain a given water-quality class) and to estimate the costs of pollution reduction measures.

Based on this concept, 23 quality parameters have been selected in Norway (table 4). Threshold values for these parameters (i.e., criteria), taken as reference level to characterize "excellent" water quality, represent water quality required for maintenance of aquatic life or natural water quality, i.e., water quality in catchment areas without any significant anthropogenic influence.

Similarly, in the Swedish system for reporting and assessing water quality, water-quality parameters were chosen that appropriately describe the nutrient status; the oxygen status, including levels of oxygen-demanding substances; light conditions; acidity status and acidification; and toxicity of waters caused by metals. Background concentration levels, estimated on the basis of hydrochemical analyses of unperturbed "reference" lakes or flowing waters in the region concerned, constitute the reference basis for surface water. In order to establish background concentrations of substances in sediment, pre-industrial levels in sediment profiles from the area concerned are used in many instances. If specific local background values are not available, default values are used, established on the basis of expert judgement.

TABLE 4

Parameters and quality classes in the Norwegian system for classification of polluted waters

Problem	*Water body*	*Water-quality determinants*	*Unit of measurement*	*Water-quality classes*
Eutrophication	Lakes	Total phosphorus[a]	fig P/1	
		Total nitrogen'	i_tg N/1	
		Chlorophyll 2	1.1g/1	
		Primary production	jig C/rri[z]/a	
		Secchi depth'	m	
	Rivers	Total phosphorus [b]	jig P/1	
		Total nitrogen[b]	N/1	
Organic material	Rivers and lakes	Colour		
		COD'	mg 0/1	
		TOG'	mg C/I	
		Hypolimnion 02	% 02	
Acidification '	Rivers and lakes	pHd		
		Alkalinity"	mmo1/1	
		Aluminium (labil)`	i..tg A1/1	
Heavy metals	Rivers and lakes	Copper'	jig Cu/1	
		Tin`	jag Zn/I	
		Cadmium'	tig Cd/1	
		Lead'	jig Pb/1	
		Nickel`	1.tg NO	
		Chromium'	jag Cr/1	
		Iron`	mg Fe/1	
		Manganese'	mg Mn/1	
Suspended particulate matter	Rivers and lakes	Turbidity	FTU	
		Suspended matter	mg/I	
Microbial pollution	Rivers and lakes	Thermotolerant coliform bacteria	Number per 100 ml	

[a] Mean value during summer.
[b] Mean annual values.
[c] The highest value of the year.
[d] The lowest value of the year.

The above-mentioned water-quality assessment and classification systems describe only a partial set of conditions to be met to maintain the functioning of aquatic ecosystems. In order to assess the integrated, long-term effects of pollution on aquatic ecosystems, biologically-based assessment and classification systems are increasingly used.

Most biological methods for water-quality assessment and classification are modifications of the saprobity system, developed many years ago. That system recognizes distinct saprobity levels (from the xeno- and oligosaprobity for unpolluted and slightly polluted water, to polysaprobity for heavily polluted waters). characterized by different communities of organisms. Sampling and identifying indicator organisms belonging to various groups of aquatic life, including bacteria, algae, fungi, macrophytes, invertebrates and fish, provide a means of assessing long-term pollution changes in a water body. The saprobity system may provide a picture of the long-term impact of pollution on aquatic ecosystems. The saprobity system is difficult to use, however, as expertise of highly specialized hydrobiologists is required for the sampling and identification of all components of the biocenosis at the species level.

Biotic indicators, including the use of diatoms and macroinvertebrates, and indices of diversity, which are relevant only to certain groups of aquatic life but require less input information, are also being used in a number of countries.

In the United Kingdom, for example, biologically-based scoring systems, such as the biological monitoring working party (BMWP) score and the average score per taxon (ASPT), have been applied in assessing river quality. These systems are relevant only to the benthic macroinvertebrates which live on or in the bottom sediment. The scoring systems reflect the status of communities of those animals with respect to the degree to which they are affected by pollution.

A major drawback of a number of these systems is, however, that they do not always take into account the natural physical and chemical properties of waters which have a fundamental influence on aquatic communities. This makes it sometimes difficult to make meaningful areal comparisons between scores because of the influence of the geology and topography of catchments, and physiographic properties of rivers which will differ around the country.

Computerized models have recently become available which enable predictions to be made about the nature and composition of biological communities based on certain natural physical and chemical properties at a given river stretch. These approaches show potential for the development of criteria, applicable both nationally and for transboundary waters, because they take into account the natural properties of catchments which determine the nature of biological communities. Using these systems provides a means to separate the influence of the natural factors from those which are pollution-related. This allows direct comparisons to be made of the status of aquatic communities between catchments and river stretches.

One such model, the river invertebrate prediction and classification system (RIVPACS), developed in the United Kingdom. has recently been applied extensively in biological surveys of rivers in that country. It allows a prediction to be made of the composition of the invertebrate community that would be expected for an unpolluted site according to its geographic location, and certain natural physical and chemical properties of the river, including the river bed and the water. It is then possible to compare the status of the invertebrate community which is actually present in the river with that which would be expected were that site to be unpolluted. The ratio of the observed to predicted status can be expressed as an ecological quality index (see below in this section).

At present, workable systems for applying ecological classification schemes are only available for invertebrate communities in rivers. Research is currently in progress to examine the feasibility of developing and introducing comparable systems for other categories of waters and other groups of aquatic flora and fauna.

Assessments of the biological quality provide an indication of the "living" state of the river whilst a chemical assessment provides a link to the discharges and pollution control requirements. Both kinds of information are important for water-quality management.

In some instances, it was proposed to have separate chemical and biological classification schemes which would be applied independently. A stretch of a surface water body, for example, would then be assigned both a chemical and biological class. However, such a scheme would probably be complicated to apply and might lead to confusion, particularly in cases where wide discrepancies would occur between chemical and biological classes assigned to a given stretch.

Ways of combining these two different measures of water quality into a single classification scheme are the subject of research and field investigations in some UN/ECE countries.

In the United Kingdom, for example, a preliminary analysis of data of the 1990 water-quality survey suggests that the most effective way of combining both chemical and biological criteria in a single classification scheme would be to apply a "biological over-ride" to the chemical classification. This would operate by assessing the biological quality of sites which fall into each of the chemical classes. Criteria would then be applied to decide whether a change of class is warranted, depending on whether the biological quality was better or worse than expected for that particular chemical class.

In most of the water-quality classification schemes. there is a risk of subjectivity in the definition of concentration values that apply to a given water-quality class. Quality classes also span a relatively broad range of concentrations that may in some cases not allow detection of variations of water quality in time and space (in particular the "in-class" variations). Furthermore, it is recognized that there is an inherent risk of misclassifying a water body from the result of routine chemical sampling programmes because of the effect of sampling error.

Attempts have been made, in a number of countries, to develop mathematically derived water-quality indices based on water-quality criteria for physico-chemical and microbiological parameters. These systems are used both for assessing surface water quality as such and for assessing the usability of water for a given use category.

Research in the Russian Federation, for example, has resulted in the development of a water-pollution index that relates the concentration of six water-quality parameters to the respective water-quality criteria. The choice of these six water-quality parameters largely depends on local conditions. Dissolved oxygen and the biochemical oxygen demand have always been considered. A number of modifications of this index have been studied with a view to selectin[g], appropriate parameter sets and elaborating aggregation functions appropriate to the local or subre[g]ional conditions.

In the United Kingdom, water-quality indices are used in combination with water-quality classification systems in order to get information on "in-class" quality variations. In order to arrive at the respective water-quality index, current' water quality is related (with the help of rating curves) to the "ideal" water-quality expressed by the water-quality criteria for the use in question. Four indices are used: a general water quality index containing nine quality parameters, a potable water supply index reflecting water quality in terms of its suitability for drinking-water supply, an aquatic toxicity index and a potable sapidity index both based on toxic contaminants harmful to human and aquatic life. Expert opinion has been gathered and evaluated in order to assign a set of water-quality parameters to each index. The parameters included in the four indices are presented in table 5.

TABLE 5

Water-quality indices in the United Kingdom

General water quality index	*Potable water supply index*	*Aquatic toxicity index*	*Potable sapidity index*
Dissolved oxygen	Dissolved oxygen	Dissolved copper	Total copper
Ammoniacal nitrogen	Ammoniacal nitrogen	Total zinc	Total zinc
Biochemical oxygen demand	Biochemical oxygen demand	Dissolved cadmium	Total cadmium
Suspended solids	Suspended solids	Dissolved lead	Total lead
Nitrates	Nitrates	Dissolved chromium	Total chromium
pH	pH	Total arsenic	Total arsenic
Temperature	Temperature	Total mercury	Total mercury
Chlorides	Chlorides	Total cyanide	Total cyanide
Total coliforms	Total coliforms	Phenols	Phenols
	Sulphates		Total hydrocarbons
	Fluorides Colour		Polycyclic aromatic hydrocarbons
	Dissolved iron		Total pesticides

Various systems have been developed in the UN/ECE region to assess the usability of water for a number of designated uses, such as drinking-water supply, recreation, fishery and irrigation. For example, in Finland and Norway water-quality classification systems should:

(a) Be applicable to all types of surface waters;

(13) Allow assessments of the usability of surface water resources for multi-purpose use;

(c) Take into account water-quality criteria for different modes of water use and be based upon physical, chemical. biological, and aesthetic parameters;

(d) Be flexible so as to be easily revised when new information becomes available.

The selection of an appropriate reference base for assessments of the usability of water for use categories does not usually constitute a problem, as long as water-quality criteria for these uses are available.

A particular problem is. however, the selection of the reference base of the use category "aquatic life". Water-quality criteria for aquatic life, i.e., the information about no-effect concentrations of individual chemical substances on aquatic flora and fauna, are usually applied in this respect. However, such an approach has a number of weaknesses. Firstly, it relies on the results of laboratory tests, which may not be representative of field conditions, to set no-effect levels for "real-life" biological communities. Secondly, it may not be practicable to set and monitor performance against requirements for more than a few chemical parameters; yet biological communities respond to the sum total of their chemical environment, which may be a complex mixture of different substances. Thirdly, it may not be practicable to monitor all waters at a frequency which will guarantee the detection of all polluting events. However, many waters are affected by episodic pollution and biological communities will respond to these events.

Taking all these factors into account, attempts have been made to develop and apply requirements which relate directly to the nature and composition of biological communities themselves rather than to any surrogate chemical criteria. Proposals to this effect have been developed recently.

For example, in the United Kingdom the ecological quality index (EQI), derived from RIVPACS, has been elaborated. It serves as a basis for classifying water bodies according to their capacity to maintain and protect the integrity of aquatic ecosystems. The EQI directly reflects the influence of water quality on biological communities, and presents an opportunity for setting -standards" which would be relevant across the whole country. The data collected during the 1990 national biological survey of rivers is currently being evaluated to assess the extent to which this system is capable of providing reliable and robust ecological "standards" within a general ecosystem classification scheme.

Under this scheme, the highest class would apply to those waters where essentially natural ecological conditions prevail and which have not been fundamentally affected by human activities. The lower classes would reflect the effects of differing degrees of pollution on biological communities. It is recognized, however, that in some cases the establishment of natural biological communities will be affected by factors other than water quality, such as water engineering carried out (e.g., concrete-lined, canalized rivers). Work is under way to improve the scheme_in this respect. It was also recognized that a separate use category was needed to take into account specific requirements of water bodies or parts thereof which were given a special protection status for nature conservation reasons.

III. WATER-QUALITY OBJECTIVES

Water-quality objectives aim at ensuring the multipurpose use of fresh water, 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. They are being developed in UN/ECE countries by water authorities in cooperation with other relevant institutions to set threshold values in water quality to be maintained or achieved within a certain time period. Water-quality objectives provide the basis for pollution control regulations and for undertaking specific measures for the prevention, control or reduction of water pollution and other adverse impacts on aquatic ecosystems.

A major advantage of the water-quality objectives approach is that it focuses on solving problems caused by conflicts between the various demands placed on waters, 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 to be set according to the required uses of the water body.

It is generally recognized that water-quality objectives, the setting of emission limits on the basis of best available technology, and the use of best environmental practice are integral instruments of prevention, control and reduction of pollution in inland surface waters. Priority is given to the reduction of pollution and the conservation of waters in their natural state and the restoration of water quality taking into account the necessary water uses. In addition to an improvement of water quality, water bodies, their banks and related terrestrial ecosystems have to be restored or maintained in a state which allows the development of a sound diversity of species in ecosystems that are as undisturbed as possible.

In most cases, water-quality objectives serve as a supplementary means of pollution prevention, control and reduction as well as a supplementary means for assessing whether or not a sound diversity of species may develop in aquatic ecosystems.

For example, if emission limits are set in a given water body on the basis of best available technology, toxic effects on aquatic communities may neverthelessoccur under certain conditions and/or other sensitive water uses, such as drinking-water use, may be adversely affected. Water pollution is also caused by inputs of substances from diffuse sources, such as agricultural areas.

Water-quality objectives may therefore be used as an instrument to evaluate whether additional efforts are needed in water protection exceeding the requirement of using emission limits for point sources on the basis of best available technology and 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. 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, consequently, 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.

A. Approaches to the elaboration and setting of water-quality objectives

Water-quality criteria serve as a baseline in establishing water-quality objectives in conjunction with information on water uses and site-specific factors.

In order to arrive at water-quality objectives, information is gathered, *inter alia,* on the basis of:

(a) Inventories of current and potential new water uses;

(h) Inventories of emission sources including point and non-point sources, and of sites of production, use, storage and disposal of hazardous substances which could accidentally be emitted into aquatic ecosystems;

(c) Results of water-quality monitoring and/or water-quality assessments and classifications;

(d) Surveys of specially protected waters such as drinking-water reservoirs and groundwater, and specially protected areas such as wetlands;

(e) Results of hydrological measurements and related information (e.g., run-off, hydraulic characteristics of water bodies).

Comprehensive catchment inventories have been carried out in a number of UN/ECE countries in order to ascertain where hazardous substances and/or products containing them are manufactured, used, stored or disposed of. Surveys have also covered direct discharges into water bodies from industrial sites, direct discharges into sewer systems, sea outfalls and tidal waters, as well as emission sources of nutrients and air-borne pollutants. In some UN/ECE countries, such surveys have been conducted in response to significant pollution accidents and in designing water protection zones. Such inventories and surveys constitute an important part of the development of water-quality objectives and of setting time schedules for attaining them.

The elaboration of water-quality objectives necessarily involves an analysis of the technical, financial and other implications associated with the desired improvements in water quality to determine the final strategy. Available technical means to prevent, control and reduce the emission of substances into the aquatic environment (e.g.. best available technology for pollution control) have a direct bearing on the elaboration of water-quality objectives indicating the technical feasibility of attaining the threshold values set in the objectives. Economic factors are also taken into account as the attainment of a certain objective may require the allocation of considerable financial resources. The attainment of a certain objective may also have an impact on investment, employment and, inevitably, on prices paid by consumers.

The existing water quality, urgency of control measures and prevailing economic and social conditions largely influence the establishment of a time schedule for attaining water-quality objectives. In some countries, a step-by-step approach is applied. Today, targets to improve water quality are usually set at two levels. One level represents the ultimate goal at which no adverse effects on the considered human water uses would occur and 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 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 fits in 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 in a second phase.

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

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

(a) Establishment of water-quality objectives for individual water bodies;

(h) Establishment of general water-quality objectives for all water bodies in a country;

(c) Establishment of water-quality objectives on the basis of water-quality classification schemes;

(d) Setting water-quality objectives for transboundary waters.

1. *Water-quality objectives for individual waters*

This approach of establishing water-quality objectives takes into account site-specific characteristics of a given water body. It is being applied for instance in North America in the Great Lakes and in some river basins in Europe.

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 impoundment prior to drinking-water supply, irrigation of crops, watering of livestock, bathing and water-sports, amenities, fish and other aquatic organisms.

Generally a limited number of existing water-quality criteria are selected as water-quality objectives for a given water body. The water-quality objectives frequently follow the most stringent criterion among water-quality criteria for individual water uses.

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 waterin[g], irrigation and recreation. For instance, many metals have lower toxicity in hard water or in water containing other complexing agents. The toxicity of many substances is increased under conditions of low concentrations of dissolved oxygen or other conditions producing stress on organisms. The nature of a discharge, for example whether it is continuous or intennittent, may also have an effect on the mixing regime and sedimentation processes. The complexity of interaction of these factors requires a case-by-case study of individual water bodies and vast experience, among others, in the field of aquatoxicology. Inventories of pollution sources and the results of water-quality monitoring in the water body concerned are also taken fully into consideration.

Water-quality objectives for watercourses may also take into account quality requirements of downstream lakes and reservoirs. For example, water-quality objectives for nutrient concentration in tributaries of the Great Lakes consider the quality requirements both 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 account in setting water-quality objectives for watercourses. This is the case, for instance, of water-quality objectives set for the Canadian rivers flowing into the sea.

Basic principles of this approach are also used in Germany. A concept was developed to establish water-quality objectives for aquatic communities, fishery, suspended particulate matter/sediment, drinking-water supply, irri[g]ation, and recreation. A working group in Germany is currently reviewing its work by comparing numerical values established according to that theoretical concept with the results of the monitoring of 18 toxic and carcino[g]enic substances in surface waters. Once water-quality objectives are established, they will be used by authorities as a basis for water resources planning. However, such water-quality objectives will not be considered as generall[y] binding limit values. 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. Binding limit values on water quality will only be established in the course of the implementation of water management plans by competent water management authorities. They will decide upon the specific uses of a given water body which are to be protected and the relevant water-quality objective to be used, taking into account the water uses licensed for that water body.

2. *General water-quality objectives*

In some European countries general water-quality objectives are set for all surface waters in a country, irrespective of site-specific conditions. There are several approaches to setting this type of objective. 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 that water-quality criteria established for the most sensitive uses (e.g., drinking-water supply or aquatic life) are selected as general water-quality objectives. In both cases, a limited set of parameters is reviewed for the eventual setting of water-quality objectives.

In certain circumstances the general water-quality objectives may, however, be adapted to particular conditions in water bodies. For instance, when the concentration of a substance in a given water body is lower than the concentration required by the general water-quality objective, the current concentration of the substance in question is taken as a water-quality objective for that water body. A general water-quality objective may also need to be adapted in cases where natural concentrations of substances (for example, heavy metals) exceed the relevant water-quality objectives. Expert judgement is required in those cases in order to decide what kind of adjustment to the water-quality objectives, if any, would be needed.

This approach is used, for example, in the Netherlands. Two sets of general quality objectives are defined for a large number of toxic substances: target and limit values. These are established as follows:

(a) The target values represent the environmental quality level at which risk is considered negligible. This may be risk to ecosystems, functional properties of the aquatic compartment and other compartments. Target values indicate the ultimate goal (for environmental quality) to be achieved. They steer source-oriented policy and provide an impetus for the reduction of environmental pollution from point and diffuse sources. Target values for "man-made" substances are based on a negligible risk level, by taking for the respective substance the most stringent water-quality criterion among all water uses (i.e., the NRL value). They can also be used to judge whether new "man-made" substances should be allowed on the market. Target values for naturally occurring metals are set at the level of background levels in relatively uncontaminated areas. If target values do not provide sufficient protection, especially in sensitive areas, a particular environmental quality objective for that area is defined.

(h) The limit values are the result of a balance between what is desirable from an environmental point of view and what is feasible from a technical or economic point of view. Limit values are set at concentration levels which are equal to, or higher than, the target values of substances derived on the basis of the risk-assessment method. Limit values should be reached within a certain period of time. Limit values defined in this way have a policy-based component. In the Netherlands, these limit values should be reached by the year 2000.

Examples of target and limit values established in the Netherlands are presented in table 6.

3. *Establishment of water-quality objectives on the basis of water-quality classification schemes*

Some UN/ECE countries have established water-quality objectives for surface waters based on classification schemes. Generally, before establishing those quality objectives, comprehensive water-quality surveys are carried out.

In Norway, for example, the newly elaborated water-quality classification system forms the basis for establishing water-quality objectives for its rivers, lakes and fjords. The national strategy plan sets these objectives first for water bodies where emissions from point sources are the major concern. The long-term goal is to ensure that all water bodies attain class I water quality, i.e., the highest water-quality class.

In Sweden, the long-term national water-quality objective suggested by the Environment Protection Agency also foresees the attainment of class I of the national water classification system for all Swedish inland waters. According to this objective the phosphorus concentration in water bodies should not exceed the natural background phosphorus load by a factor of two. Similarly, maximum concentrations of heavy metals in water and sediment should not exceed the natural background load by a factor of three and six, respectively. Water-quality objectives for individual water bodies are now being elaborated, taking into account the specific conditions of each water body.

In the United Kingdom, the Water Resources Act of 1991 enables the Government to prescribe a system for classifying the quality of controlled waters according to specified requirements. These requirements specified in relation to any classification consist of one or more of the following:

(a) General requirements as to the purposes for which the waters to which the classification is applied are to be suitable;

(b) 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;

(c) 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, establish with reference to one or more of the

TABLE 6

Target and limit values of substances established in the Netherlands on the basis of risk-assessment methods

Water quality parameter	*Target and limit values for sit/face beaters*				*Groundwater*		
	Total fraction		*Dissolved fraction*		*Dissolved fraction*	*Soil and sediment('*	*Newly formed sedimentsa*
	Target value in pg/ι	*Limit value in ggll*	*Target value in pgll*	*Limit value n itgll*	*Target value in [tgll*	*Target value in Aglkg dry matter*	*Limit value n pg/kg dry matter*
Metals:							
Cadmium	0.05	0.2	0.01	0.06	0.4	800	2000
Mercury	0.02	0.03	0.003	0.005	0.05	300	500
Copper.......................................	3	3	1	1.3	15	36000	36000
Nickel	9	10	7	7	15	35000	35000
Lead...	4	25	0.2	1.3	15	85000	530000
Zinc	9	30	2	7	65	140000	150000
Chromium.................................	5	20	0.5	2.0	1	100000	380000
Arsenic	5	10	4	8.6	10	29000	55000
PAH:							
Naphthalene	0.1	0.1	0.1	0.1	0.1	15	15
Anthracene................................	0.02	0.02	0.02	0.02	0.02	50	50
Fenanthrene	0.02	0.02	0.02	0.02	0.02	45	50
Fluoranthene	0.006	0.07	0.005	0.06	0.005	15	300
Benzo(a)anthracene	0.003	0.008	0.002	0.005	0.002	20	50
Chrysene	0.003	0.008	0.002	0.005	0.002	20	50
Benzo(k)fluoranthene	0.003	0.02	0.001	0.008	0.001	25	200
Benzo(a)pyrene........................	0.003	0.005	0.001	0.002	0.001	25	50
Benzo(ghi)perylene	0.001	0.004	0.0002	0.0005	0.0002	20	50
Irideno(123cd)-pyrene	0.002	0.004	0.0004	0.0008	0.0004	25	50
Chlorophenols:							
Monochlorophenols.................	0.25	9	0.25	9	0.25	2.5	70
Dichlorophenols	0.08	0.08	0.08	0.08	0.08	3	3
Trichlorophenols	0.025	2.5	0.025	2.5	0.025	1	100
Tetrachlorophenols	0.01	1	0.01	1	0.01	1	90
Pentachlorophenol	0.02	0.05	0.02	0.05	0.02	2	20
Organochlorine pesticides:			0.00002				
Dieldrin	0.00007	0.002	0.0002	0.0005	0.00002	0.5	- 20
y-HCII (lindane)	0.0002	0.010		0.010	0.0002	0.05	1
Organophosphorus pesticides:			0.0007				
Azinphos-methyl	0.0007	0.02	0.00005	0.020	0.0007	0.06	0.3
Parathion-ethyl	0.00005	0.005	0.0009	0.005	0.00005	0.04	4
Diazinon	0.0009	0.030	0.00004	0.030	0.0009	0.07	2
Malathion..............................	0.00004	0.004		0.004	0.00004	0.02	2
Organotin compounds:			0.0001				
TBTO	0.0001	10		0.010	0.0001	0.1	1.5
Triazines:			0.0075				
Atrazine	0.0075	0.100		0.100	0.0075	0.05	2

[a] Values for standard soil (10 per cent organic matter and 25 per cent clay).

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 those waters that are polluted.

The water-quality objectives to be established in legal statute will:

(a) Define the stretches of water to which they apply;

(h) Identify one or more appropriate use categories, and the corresponding quality standards;

(c) Incorporate the standards required by EC Council Directives that are relevant to the stretch of water;

(d) Apply the quality standards relevant to one of the general classes of the classification scheme;

(e) Set dates by which each of the relevant sets of standards is to be met.

4. *Water-quality objectives for transboundary waters*

There are only a few examples of transboundary waters in the region for which water-quality objectives have been established so far. 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). In Europe, water-quality objectives have been established for the River Rhine. Water-quality objectives are being developed for some other transboundary surface waters in Europe.

Tables 7 and 8 provide examples of water-quality objectives for the Great Lakes. Concentration levels are set to protect the most sensitive user: i.e., the most stringent criterion of all the water-quality criteria for individual uses within the Great Lakes system has been chosen. These water-quality objectives have been established under the responsibility of the International Joint Commission according to the provisions of the 1978 Great Lakes Water Quality Agreement. To undertake this task, a Binational Objectives Development Committee was established.

The International Joint Commission has also been involved, directly or through consultations, in the development of water-quality objectives for the above-mentioned transboundary rivers in North America. The procedure for developing water-quality objectives follows those adopted for national water bodies, as described earlier in this section.

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

(a) Improving the ecosystem of the river in such a way that higher species which were once indigenous in the Rhine will return;

(b) Guaranteeing the future production of drinking water from the Rhine;

TABLE 7

Water-quality objectives for the Great Lakes related to persistent organic substances

Water-quality parameter	*Water-quality objective in parts per billion*
Aldrine/dieldrin	0.001
Benzo(a)pyrene	0.01
Chlordane	0.06
DDT (total)	0.003
Endrin	0.002
Heptachlor (total)	0.001
Lindane	0.01
Methoxychlor	0.04
PCP (pentachlorophenol)	0.4
DEHP (Di-2-ethylhexylphthalate)	0.6
PCBs (polychlorinated biphenyls)[a]	0.001
Toxaphene	0.008
2,3,7,8-TCDD (a dioxine congener)b	0.00001

[a] Proposed value.

[b] Current detection limit.

TABLE 8

Water-quality objectives for the Great Lakes related to metals

Water-quality parameter	*Water-quality objective in parts per billion*
Arsenic	50
Cadmium	0.2
Chromium	50
Copper	5
Lead[a]	10.0-25.0
Mercury	0.2
Selenium	10
Zinc	30

[a] Lower objectives were set for Lake Superior and Lake Huron.

(c) 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;

(d) Protecting the North Sea against the negative effects of the Rhine water.

At present, water-quality objectives for the River Rhine cover some 50 priority substances, such as heavy metals, organic micro-pollutants as well as ammonium and phosphorus (tables 9 to 12) 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.

B. Water-quality objectives in the context of the ecosystem approach in water management

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 characterized by a number of physical, chemical, hydrological, and biological factors and their interaction. Among them, water quality plays a decisive role.

Ecosystem objectives attempt to describe a desired condition for a given ecosystem through a set of parame-

T A B L E 9

Water-quality objectives for the River Rhine related to organic substances

Water-quality parameter	*Water-quality objective in pa*	*Basis for elaboration's*
Tetrachloromethane	1.0	Drw+aqL
Trichloromethane	0.6	aqL
Aldrin, Dieldrin, Endrin, Isodrin	[illegible]	aq+terrL
Endosulfan	0.003	aqL
Hexachlorobenzene	0.005	aqL
Hexachlorobutadien	0.001	aqL
PCB 28, 52, 101, 180, 138, 153	[illegible]	aqL
1-Chioro-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)	0.002	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
Simazin	0.1	Drw+aqL
Atrazin	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

[a] 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).

T A B L E 1 0

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

Water-quality parameter	*Quality objective° in mg, kg*
Cadmium	1.0
Chromium	1000
Copper	500
Lead	1000
Mercury	0.5
Nickel	500
Zinc	500

Quality objectives are mainly based on limit values developed for spreading of sewage sludge on agricultural areas. taking into account. if available, information related to adverse impacts of sewage sludge on soil organisms. At a later stage. quality objectives will be revised in order to protect also organisms living in/on sediment as well as to protect the marine ecosystem, it' sediment is to be disposed of therein.

TABLE 11

Water-quality objectives for the River Rhine related to adsorbable organic halogen (AOX)

Water-quality parameter	*Water-quality objective in gell*	*Basis for elaborations*
Adsorbable organic halogen (AOX)	50	Drw

[a] Water-quality objectives have been set on the basis of water-quality criteria for drinking-water supply (Drw).

TABLE 12

Water-quality objectives for the River Rhine related to nutrients

Water-quality parameter	*Water-qualit[y] objective in p.gli*	*Basis for elaboration's*
Total phosphorus...	150	aqL
Ammonium-nitrogen	200	aqL

[a] Water-quality objectives have been set on the basis of water-quality criteria for aquatic life (aqL).

ters, 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 indicator 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.

Ecosystem objectives are expressed by a set of various species, called the target variables. The target variables as a whole are usually a cross-section of the aquatic ecosystem in order to provide a fairly representative picture of ecosystem conditions, and include, for instance:

(a) Species from all types of aquatic habitats;

(h) Species from the benthos, water column, water surface and shores;

(c) Species from high and low parts of the food web;

(d) Plants and animals;

(e) Sessile, migratory and non-migratory species.

Water-quality criteria for the maintenance of aquatic life, drinking water and other uses provide an important set of conditions necessary to attain and maintain a water quality that supports the functional integrity of aquatic ecosystems. Consequently, the approach of using the most stringent water-quality criteria as water-quality objectives generally covers water-quality requirements for the health of the ecosystem.

In order to ensure, for example, the functional integrity of Lake Ontario, specific ecosystems objectives were developed to ensure that the waters of the lake support diverse, healthy, reproducing and self-sustaining communities in dynamic equilibrium. Human health considerations were also taken into account in this process, as 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 andquantitative indicators. Extensive studies were undertaken to select appropriate biological indicators that would supplement conventional physical and chemical parameters 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 indicator organisms have been selected for the Great Lakes. For oligotrophic systems 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 Lake Superior. For mesotrophic systems the walleye *(Sti:ostedion vitreum),* having many characteristics in common with the lake trout, has recently been chosen. The mayfly *Hexagenia limbata,* with its requirements for clean, well-oxygenated sediment, was considered as representing a diverse benthic community in those waters and was an ideal complementary indicator to the walleye. Work is under way to select mammalian, avian and reptilian species as complementary indicators of the health of the ecosystem.

The absence or presence of Atlantic salmon is used as an indicator of the functional integrity of the Rhine riverine ecosystem, including the quality of its water. Other indicator species and groups of species are also being observed. A method of ecological and biological assessment (AMOEBA) was developed in the Netherlands where some 30 species were chosen as indicators for the Rhine ecosystems. For each species the abundance for the period 1900-1930 (a pragmatic selection of 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 were characterized by choosing about 30 species regarded as representative for that specific ecosystem.

The approach followed by the United Kingdom for setting water-quality objectives on the basis of classification schemes also contains important elements for defining and evaluating requirements on the protection and maintenance of functions in aquatic ecosystems. Quality objectives to attain this goal are incorporated in the system as described above.

The *Guidelines on the Ecosystem Approach in Water Management,* contained in Part One of the present publication, summarize the current status of developing ecosystem objectives and give, *inter alia,* practical guidance for the application of such objectives.

C. Implementation of, and monitoring compliance with, water-quality objectives

Water-quality objectives are increasingly being used in UN/ECE countries for the prevention, control and reduction of water pollution in addition to the protection of different water uses identified for a given catchment area. In some countries, water-quality objectives play the role of a regulatory instrument. Their application may require, for instance, the appropriate strengthening of emission standards and other measures for tightening control over point and diffuse pollution sources. In other countries, 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. In all cases, the implementation of water-quality objectives, in particular those set for hazardous substances, requires both the use of the best available technology and measures to substantially reduce or phase out the use of hazardous substances in industry, commerce and agriculture.

TABLE 13

Reduction of phosphorus emissions in the catchment area of River Lagen upstream Lake Mjosa (Norway)

Present discharge /tonnes total Plyearl	Necessary reductions to reach quality class: [tonnes total Plyead			
	Class I	Class II	Class III	Class IV
15.7	8.6	4.5	1.4	no reduction

The objectives are accompanied by a time schedule for compliance, taking into account the time necessary to implement control and reduction measures. Usually, in UN/ECE countries, 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 reaching water-quality objectives of specific hazardous substances. For instance, the immediate substantial reduction of emissions of three organic substances (carbon tetrachloride, DDT and pentachlorophenol) was prescribed by the EC *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 from 1 January 1988.

As regards other hazardous substances, a time period of five to ten years has been set in some countries (e.g., Norway, Sweden) to attain water-quality objectives by substantially reducing 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 nutrients discharge and changing agricultural practices accordingly usually require a longer time period: and compliance with relevant water-quality objectives takes this fact into consideration.

Pending the adoption of water-quality objectives, the riparian countries that border the River Rhine agreed, in any event, at the very beginning of the Rhine Action Programme on a preliminary 50 per cent reduction of emissions from 1985 to 1995. In the catchment area of River Lagen upstream Lake Mjosa (Norway), for example, reductions of phosphorus emissions according to table 13 should be implemented in order to subsequently improve water quality therein from classes IV to I.

In some countries, water-quality objectives are subject to revision in order to adjust them, *inter alia,* to the potential of pollution reduction offered by new technology, new scientific knowledge on water-quality criteria and changes in water use. Practical experience suggests, however, that dischargers are entitled to at least some period of stability before being requested to review their practices on the basis of newly elaborated water-quality objectives.

In the United Kingdom, for example, the 1991 Water Act allows for the revision of water-quality objectives. However, such a review can only take place at intervals of at least five years or if the National Rivers Authority requests such a review after consultation with water users and other bodies that it considers appropriate.

Based on water-quality objectives, water-management strategies and action plans which are both technically and economically feasible and cover both point and non-point pollution sources are being developed in a number of countries and for transboundary waters, an example being the Rhine Action Programme. In some cases, it was necessary to combine management strategies based on water-quality criteria and objectives with strategies based on the emission approach. Measures taken according to these action plans include, *inter alia:*

(a) Making emission inventories and catchment inventories in order to ascertain where substances that are hazardous or otherwise likely to adversely affect water uses and aquatic ecosystems are manufactured, used, stored. disposed of or discharged into inland waters:

(h) Phasing out or prohibiting the use of hazardous substances which pose a particular risk to sensitive or specially protected waters.

Adaptation of monitoring programmes and surveillance systems as well as laboratory practices are necessary in the implementation of water-quality objectives. Two problems deserve special mention: 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 of 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 in laboratory analyses.

Usually, regular laboratory analyses are carried out for hazardous substances included in the national lists of priority substances. For a number of other substances, screening is carried out in order to decide on relevant measures to be taken on a case-by-case basis. Activities are under way to study these implications of the water-quality objectives approach for monitoring and laboratory practices and to develop, for example, proposals for the selection of substances subject to regular and sporadic laboratory analyses and/or screening.

Several measures for assessing whether a water-quality objective is attained are used in UN/ECE countries. 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 that exceed the established water-quality objective do forewarn of a certain risk, but need not require immediate action. In most cases, this advance warning ensures that action can be taken before real damage occurs.

As regards hazardous substances, for example. some countries consider that the water-quality objective is attained if at least 90% of all data measured (within a period of three years, for instance) 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 above-mentioned EC Council Directive 86/280/EEC. For nutrients (nitrogen and phosphorus), the median is taken in some countries as a criterion for assessing the attainment of water-quality objectives.