Part One

GUIDELINES ON THE ECOSYSTEM APPROACH IN WATER MANAGEMENT

INTRODUCTION

These Guidelines are intended to assist UN/ECE Governments in developing and implementing national policies, action plans, programmes and practices for the practical application of the ecosystem approach to day-to-day water management. The measures proposed would ensure a holistic approach to environmentally sound management of inland water resources and riparian vegetation, wetlands, riverine floodplains and associated wildlife and habitats. This approach entails a new level of national and international awareness and responsibility in solving complex and interrelated problems of the environment.

These Guidelines are not intended, however, to cover comprehensively all the aspects of natural resource management, environmental protection and nature conservation. They deal primarily with the promotion of the ecosystem approach to water management within a catchment area.

These Guidelines build upon the documents prepared for, and the outcome of, the Seminar on Ecosystems Approach to Water Management, held in Oslo (Norway) in May 1991, including the *Recommendations to ECE Governments on Ecosystems-based Water Management* as adopted by the Senior Advisers to ECE Governments on Environmental and Water Problems at their fifth session in March 1992.

Although these Guidelines are primarily addressed to relevant public authorities in UN/ECE member countries responsible for water management, they should be brought to the attention of all those whose activities have impacts on aquatic ecosystems, so that Governments might comprehensively address their shared responsibility, individually and jointly, to ensure that the objectives of these Guidelines are met.

I. GENERAL RECOMMENDATIONS

Integrated policies and strategies should be developed and implemented in order to resolve the complex and interrelated conservation and management problems of aquatic ecosystems, and to overcome the management of water resources in isolation from other ecosystem components, namely land, air and living resources, and humans as part of the environment. Such policies and strategies should aim, *inter alia*, at:

(*a*) Furthering all measures and behaviours to maintain and improve conditions and functions of aquatic ecosystems including the conservation of aquatic biotic communities and the rehabilitation of damaged ecosystem components;

(*b*) Providing for the sustainable use of water resources and other ecosystem components in ways that meet the requirements of aquatic ecosystems and various human needs, individually or collectively, without compromising the ability of future generations to meet their needs;

(*c*) Fostering protective measures based on the precautionary principle: where there are threats to aquatic ecosystems, lack of full scientific knowledge should not delay the implementation of the best available measures to sustain the ecosystem resource; policies should be anticipatory rather than reactive and should address the causes rather than strive to measure the symptoms alone;

(*d*) Fostering cooperation and responsibility sharing for environmental protection among managers, planners, policy makers and users of water within the catchment area; the polluter-pays principle should be promoted;

(*e*) Promoting cooperation between countries bordering the same transboundary watercourses and international lakes.

The whole catchment area should be considered as the natural unit for integrated ecosystems-based water management, bearing in mind, however, that many catchment areas, particularly those of long rivers, represent a geographic/hydrographic mosaic of various ecosystems. A large variety and range of ecosystem types require specific approaches and actions tailored as far as possible to individual characteristics of ecosystem conditions.

The multi-media approach is important in ecosystems-based water management. The transfer of pollutants from one environmental medium to others should be assessed and controlled.

Aquatic ecosystems are not closed ecological systems, they exchange materials and energy with their surroundings. There is a need therefore to substantially broaden the scope of management to the exploration of the linkages and interactions within the ecosystem. A challenge lies in discovering abiotic and biotic factors, as well as the key linkages that provide for the ecosystem integrity, and to maintain energy, chemical, physical and biological balance in the interlocking ecosystems.

The ecosystem approach should be considered as a departure from the earlier focus on localized pollution and management of separate components of the ecosystem in isolation, and from planning provisions which often ignore the profound influences of land use on water quality. This approach should form a framework for decision-making that compels managers and planners to cooperate in devising integrated strategies for action.

The ecosystem approach includes humans as a central element in the well-being of the system. This implies recognition of social, economic, technical and political factors that affect the ways in which human beings use nature. These factors should be considered because of their ultimate effect on the integrity of the ecosystem.

II. ECOLOGICALLY-BASED CLASSIFICATIONS OF WATER BODIES

One of the major goals of water-management policy should be conservation and, where possible, restoration of aquatic ecosystems to a target state of high ecological quality. For many water bodies the original natural state of their ecosystems may not be reached, as floodgate systems, bank fortification, artificial substrate, the flow of effluents may remain in these water bodies. Depending on these factors and the selection of the functional uses of water, maintenance and restoration, to the extent possible, of ecological functions and natural properties of aquatic ecosystems should be strived for. For this purpose it is important for the policy makers to have a common understanding of basic ecological quality and high ecological quality of aquatic ecosystems.

Basic ecological quality could be defined as the quality in which, on the one hand, organisms that demand little of their environment survive and in which, on the other, the migration of rare species is not hindered. It implies that, apart from the physico-chemical characteristics of the water, a suitable habitat should be ensured for organisms to be able to complete their life cycle and that there should be no barriers to prevent fish species migrating.

Ecological quality of the aquatic ecosystem could be recognized as high, provided the following requirements are met, *inter alia*:

(*a*) Dissolved oxygen is suitable for the normal respiration of aquatic organisms;

(*b*) Concentrations of toxic or other harmful substances in water, sediment and biota are below established no-effect levels and do not prevent the beneficial uses of the water body;

(*c*) There is no evidence of elevated levels of disease in animal life, including fish and plant populations, due to anthropogenic impact;

(*d*) The status of the benthic/planktonic/macro-invertebrate communities is representative of the undisturbed state, and key species/taxa normally associated with the natural conditions in the ecosystem are present;

(*e*) The status of aquatic plant communities is representative of the undisturbed state, and key species/taxa normally associated with the natural conditions in the ecosystem are present; there is no evidence of excessive macrophytic or algal growth due to elevated nutrient levels of anthropogenic origin;

(*f*) The fish population is sustainable, and key species/taxa normally associated with the natural conditions of the ecosystem are present; there is no hindrance to the passage of migratory fish caused by human activity;

(*g*) The open water environment permits a higher vertebrate community representative of the undisturbed state of the ecosystem.

Ecologically founded systems to classify water bodies should be recognized as important for ecosystems-based water management. These classification systems should include rivers, lakes and estuaries as well as man-made reservoirs, large canals and watercourses. Not only should the open water be considered in these classifications, but also strips of riparian vegetation (important for wildlife habitat, nutrient interception, bank stabilization, temperature control, allochthonous food supply, etc.), and any adjacent semi-natural wet habitat intimately linked with the river and hydrologically dependent on it (e.g., marshland, fens or wet woodland such as willow and alder carr, coastal zones in estuaries).

Classification systems should help to identify, in particular, water bodies and their parts which are most sensitive to uses of water resources and hence of prime importance for conservation or restoration. Criteria for selecting water bodies or parts thereof of prime importance may include, *inter alia*, size, diversity (of habitats and species), naturalness, representativeness, rarity, fragility, potential value and intrinsic appeal. For rivers the most important criteria may be diversity (of habitats and species), naturalness (of river corridor) and representativeness (of rivers of a certain type).

Countries should undertake to harmonize their approaches to the elaboration of such classifications, in particular with regard to transboundary waters.

III. ECOSYSTEM OBJECTIVES

Ecosystem objectives that aim at safeguarding the functional integrity of an aquatic ecosystem should be developed. Such objectives should attempt to describe a desired condition for a given ecosystem through a set of parameters, taking into account the ecological characteristics and uses of the water. Ecosystem objectives may specify the level or condition of certain biological properties that could serve as indicators of the overall condition or "health" of the aquatic ecosystem. Ecosystem objectives could be used in combination with water-quality objectives, and objectives relating to hydrological conditions.

Ecosystem objectives could be expressed by a set of various species, called the target variables. The target variables as a whole have to be a cross-section of the aquatic ecosystem if they are to provide a reasonably representative picture of ecosystem conditions, and to include, for instance:

(*a*) Species from all types of aquatic habitats;

(*b*) 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.

A relevant reference system should be determined for the formulation of ecosystem objectives. The elaboration of ecosystem objectives of that type should be considered a pragmatic, indeed unifying concept to be adopted as basic policy and, where appropriate, prescribed in national legislation and transboundary water agreements. Objectives should be attained through the combination and integration of water management measures, prevention of pollution and of water resources misuse, as well as nature-conservation measures, including restoration of degraded habitats.

IV. ECOSYSTEM ASSESSMENTS

Ecosystem assessments should be based on integrated criteria in terms of water quality and quantity as well as flora and fauna. Systematic analysis of water quality, flow regimes and water levels, assessments of habitats, biological communities, sources and fate of pollutants as well as mass-balance derivations should be undertaken in order to provide reliable information.

A. Monitoring and surveillance

The first and foremost purpose of monitoring programmes should be to provide an ongoing assessment of environmental conditions in order to determine if ecosystem objectives are being achieved and complied with. A second purpose of monitoring should be to assist in identifying corrective action in the event that objectives are not being met. It is particularly important to identify and diagnose a problem as early as possible so that remedial action can be taken before damage has occurred. Since no single indicator can fulfil all these purposes, a comprehensive and organized approach is needed to develop a series of indicators, based on three general types: compliance, diagnostic and early-warning indicators. The additional cost of monitoring early-warning indicators may be a cost-effective alternative to sole reliance on the other two.

Every effort should be made to coordinate physical, chemical and biological measurements to improve understanding of the effect each variable has on the ecosystem. The ecosystem approach has to rely more than usual on continuous liaison between the disciplines involved in monitoring. Continuity of liaison should be ensured between those responsible for ecosystem monitoring and management at all levels of responsibility, whether local, catchment, or national/international.

Abiotic and biotic data should be collected as near as possible to the same sites and at the same time, in order that the interrelationships within ecosystems can be fully analysed and then conceptual and even dynamic models synthesized for ongoing guidance of water managers. Long-term monitoring programmes of this multi-media, multi-disciplinary nature are important for the ecosystem approach as they often provide the key to understanding cycles which may follow patterns of several years' duration.

Data for ecosystems-based water management should be taken or developed from existing observation networks and supplemented, where necessary, by integrated monitoring programmes to provide for comprehensive assessments of ecosystem conditions, including interlinkages between abiotic and biotic factors operating within the same catchment area. Chemical variables and the movements of elements into and out of the catchment area, as well as internal dynamics within the catchment area, should be studied. Furthermore, encroachments and changes in human activities and the corresponding habitat changes along water bodies, which may affect the aquatic ecosystem, should be monitored. Such monitoring programmes allow for an integrated evaluation more capable of determining cause-effect relations than other less comprehensive monitoring programmes currently under way.

Remote sensing and space imagery are promising tools in this regard. They can be used for rapidly updating catchment-related information on rates of change. They are particularly important for gauging the effects of agricultural practices, forestry activity and urbanization, and monitoring the type of prediction which can be made in simulation models of the type described in these Guidelines.

A greater effort should be directed towards biological assessments. Indicator species should be identified for such monitoring purposes. Candidate organisms that are to serve as indicators of ecosystem quality should, *inter alia*:

(*a*) Have a broad distribution in the ecosystem;

(*b*) Be easily collected and measured in terms of biomass;

(*c*) Be indigenous and maintain themselves through natural reproduction;

(*d*) Interact directly with many components of their ecosystem;

(*e*) Have historical, preferably quantified, information available pertaining to their abundance and other critical factors relevant to the state of the organisms;

(*f*) Exhibit a graded response to a variety of human-induced stresses;

(*g*) Serve as diagnostic tools for specific stresses of many sorts;

(*h*) Respond to stresses in a manner that is both identifiable and quantifiable;

(*i*) Be suitable species for laboratory investigations;

(*j*) Serve to indicate aspects of ecosystem quality other than those represented by currently accepted parameters.

Monitoring studies should include residue analysis in those organisms which apparently have been adversely affected by high concentrations of contaminants. Tissue banks could be established for the long-term preservation and storage of samples for future analysis, should new concerns be identified or methodologies refined.

Biomonitoring for chronic toxicity can use zooplankton and phytoplankton to measure the effects on growth and reproduction of long-term exposure to low levels of a toxic chemical. New measures for the more rapid assessment of toxicity in various components of the ecosystem should be explored. Bio-assays utilizing appropriate test organisms and responses, reproduction and growth, or tests which measure bacterial florescence allow researchers to quantify toxicity along spatial and temporal gradients: both the water and the underlying sediment should be assessed. Measures based on disease, deformities, viability of early life history stages, and molecular responses should continue to be assessed to determine whether or not they can provide early warning of environmental stresses at the organism level.

Given the large number of samples required to obtain statistically valid results and the high cost of chemical testing, it is best to limit assays to a low number of species, thereby ensuring satisfactory monitoring of temporal trends in the bio-accumulation of some priority contaminants over time. Development and application of new bio-assessment methods, including rapid bio-tests as well as sampling and processing analysis using advanced technology, should also be promoted, as should the systematic application of these methods.

The determination of certain ecological indices makes it possible to measure the state of health of communities and populations, something that could potentially be linked to the degree of contamination and/or degradation of aquatic ecosystems. Such parameters as abundance, diversity, regularity, biomass, growth rate, age and sex structure and fertility rate also make it possible to determine the state of health of biological communities. In any case, the application of biotic indices requiring minimal sampling effort should be strived for.

Particular attention should be given to the harmonization of sampling and data-processing methodologies, and *in situ* and laboratory analyses aimed at verifying and validating data. The harmonization of national monitoring programmes operated by riparian countries in their respective parts of catchment areas of transboundary waters or the implementation of joint monitoring programmes should be promoted.

B. Data management and presentation

The promotion of ecosystems-based water management requires better integration of, and access to, available data and information collected by various institutions. A variety of methods can be used to combine data from different projects. The creation and operation of reference databases is an indispensable tool for resolving information requirement problems.

Standard protocols should be developed and utilized in order to allow for more effective data comparisons across time and location, and between investigators. Where necessary, intercalibrations should be performed. Catchment-wide systems of data storage and analysis could be developed to make the exchange of information more effective and optimize the use of collected data.

Map atlases should be compiled to highlight the ecosystem aspects of water management. Such atlases could include, *inter alia*, maps of water supply, flows and levels; water and sewage works; land use; and fish and game habitats. Integrated ecological cartography acquires special significance when enlarged to encompass transboundary water issues.

Satellite multi-spectral scanning data of the entire catchment could be acquired and digitally classified for production of a series of land-cover type maps. These maps could then be field-checked, when necessary. These digital maps could be used as the base layer in a geographic information system (GIS) for storage, management and analysis of the large volumes of spatial data to be acquired during the catchment study programme.

In order to identify economic activities affecting ecosystems in the catchment area and predict likely effects of any change in these activities, data on land and water uses should be collected, analysed and coordinated so as to facilitate their integration with data on aquatic ecosystems. Features such as geology and topography should be taken into account. Hydrogeological data on aquifers that may be at risk should similarly be linked into these catchment studies. Catchment integration methods should allow examination, in particular, of changes in demand, fiscal support, prices and technical advances, and the assessment of the potential effects of these changes on both land use and aquatic ecosystems. The development of ''options'' or scenarios presenting the implications of single or multiple changes when combined with all factors at work in a given catchment area, should better help define ecosystem objectives and determine the priority for action at both the policy and programme levels.

Efforts should be made to improve the presentation of catchment data to those taking decisions on the use of water resources and other ecosystem components, as well as to the general public. Integrated state-of-ecosystems reports can be a very effective tool to this effect. This is in contrast with the ongoing practice of preparing sectoral reports and analyses and afterwards trying to establish the links between human activities and the pressures on the environment in general, and aquatic ecosystems in particular. Collaboration between the private and public sectors, the academic world, non-governmental organizations and the general public should be fostered by such reports.

C. Modelling and forecasting

The use of simulation models should be considered as an important tool in ecosystems-based water management and decision-making. Complex ecological models have been developed and used in research and development. In daily management and decision-making, however, there is a need for simple overview models which capture the essence of complex systems. These models should be easy to operate.

Hydrological models are well-developed and have a long tradition of application in water management. Nevertheless, in order to apply the ecosystems approach, water-quality and biological aspects should be integrated into hydrological models. The simulation of processes defining the conditions of habitats and living organisms in aquatic ecosystems, including hydrophysical, hydrochemical and hydrobiological factors, is required.

Modelling should be used as a tool to investigate various aspects of aquatic ecosystem perturbation and management. Process-oriented models assist in determining the relative importance of the various processes which control the behaviour of the simulated aquatic ecosystem. Mass-balance models have played and should continue to play an important role in investigating sources, losses, and trends in contaminant distribution. Fate and exposure models allow the study of effects at a number of levels and the investigation of multiple interactions (e.g., two or more toxicants, nutrients). Modelling also assists in the evaluation of management strategies, risk analysis, and cost-effectiveness.

Modelling and monitoring studies should be linked. Monitoring and surveillance studies provide data for model development and verification, while modellers can assist in the identification of key parameters to be measured in monitoring and surveillance studies.

Water management often takes account of only the closest, most direct consequences; however, alterations in ecosystems do not usually occur suddenly but are the result of long-term evolution. Ecological forecasting should be viewed in this context as an important part of water management activities at each stage. It should precede the implementation of water project design and planning studies and should be based on data from regular, systematic and highly reliable observation of ecosystem components.

A great deal of uncertainty exists, however, in long-term ecological developments. Cause-effect relationships are often poorly known. Information on the projected water use in terms of quantity and quality might not be readily available but needs to be collected and analysed in order to predict environmental impact. It should be borne in mind, however, that a full understanding of ecosystem dynamics and exposure at any given time is unrealistic. Where appropriate, analogues of ecosystems and their functions should be applied to avoid reliance on costly and tedious ecosystem audits. When the applications of any comprehensive ecosystem models are not considered to be feasible, ecological prediction should be based mainly on expert judgement.

D. Economic assessments

Economic assessment plays an important role in decision-making. It is used either directly as a means of ranking and giving priority to measures, or indirectly as a factor in the budgeting process. Multifaceted values of water, flora, fauna and their habitats, including their economic and non-economic values, are rarely taken into account in decision-making on the use of water and other ecosystem resources. Undervaluation of these resources in economic terms sometimes leads to conflicts between the goals of the ecosystem approach and those of socio-economic development. The ecosystem approach reinforces the need to place an economic value on components of the ecosystem. Pricing of water, as a first step, takes on great importance.

Natural-resource accounting systems should be further developed, aimed at ensuring that the value of healthy ecosystems is brought into the realms of cost-benefit and cost-effectiveness calculations. The development of economic assessment methods that provide for interdisciplinary and intersectoral analysis of long-term costs and benefits of measures taken within the framework of an ecosystems-based management plan should be promoted. Such assessments are admittedly difficult. Nevertheless, an important consideration in this regard is that of how much the public is prepared to pay to safeguard ecosystems *per se*, as the very well-being of man and future economic development depend on the quality of aquatic ecosystems. Surveys of the public's valuation of aquatic ecosystems and their appreciation of amenity considerations can be indicative in the valuation process.

Systems should be set up to appropriately distribute costs and benefits to the relevant sections of water-management and land-management activities so that ecosystem requirements are properly taken into account. The economic modelling and data management system used for assessing the effects of water management and land-management operations, such as agriculture and forestry, should be investigated to cost the implications of maintaining and restoring conditions in aquatic ecosystems.

V. LEGAL, PLANNING AND INSTITUTIONAL MEASURES

Water laws and other related legislation should reflect ecosystem-maintaining functions of water, thus establishing a legal basis for ecosystems-based water management. Maintaining and improving conditions in aquatic ecosystems should be laid down as basic requirements in this legislation. Moreover, legal provisions should, as far as possible, provide concrete guidance for planners and decision makers in cases where concessions have to be made between ecosystem-maintaining functions of water, on the one hand, and perceived short-term economic benefits, on the other. Responsibility for the enforcement and monitoring of compliance should be clearly defined in that legislation.

Water management master plans should be considered as important instruments in ecosystems-based water management. Riparian countries should incorporate ecosystem considerations both into water management plans for their respective parts of catchment areas of transboundary waters and into bilateral or multilateral action plans for the entire catchment areas of these waters.

For planning purposes, a river basin covering a large territory may be regarded as an ecosystems continuum since it represents at any given time a succession of ecosystems types from headwaters to mouth. The catchment area may therefore be divided into ecosystem planning zones based on physiographic (landforms, topography) and watercourse (drainage pattern, stream order, gradient) features. Such zones may include, for instance, headwaters, midreaches, lower reaches and delta marsh. The ecosystem approach requires planning based on ecosystem boundaries (zones) rather than political or jurisdictional ones. It also calls for increased intergovernmental cooperation at all levels, since many aquatic ecosystems cross national boundaries.

Planning activities based on entire catchment areas or significant parts thereof should allow different uses of water and other ecosystem resources to be placed on an equal footing. Conflicts between various uses and the possible impact of alternative solutions should be analysed in these plans. Methods of conflict analysis used in decision-support analysis should be extended to include the options which address effects on aquatic ecosystems. This approach will not only cause the costs of ecosystem support to be taken into account in the analysis of alternatives, but also improve valuation methods.

Internalization of environmental costs associated with the use of water should be promoted through economic and fiscal instruments, including charges, levies and appropriate incentives. In line with the polluter-pays principle, such instruments should be progressively oriented towards encouraging pollution prevention at source and preventing adverse effects on aquatic ecosystems.

The practical application of ecosystems-based water management requires improved expertise and strengthened coordination of water-management activities carried out in key water-related sectors within the catchment area, including water supply, pollution control, hydropower production, transportation, industry, agriculture, fisheries and aquaculture, forestry, tourism and recreation. Governmental institutions should involve private sector organizations, landowners and public-interest groups, both in the preparatory and the implementation processes of the ecosystems-based action plans, in order to reach broad consensus, and should encourage concerted action by policy makers, industrialists, farmers, planners, water managers, scientists and the general public.

Appropriate institutional arrangements may vary from establishing new bodies to strengthening existing ones. Whatever the case, the promotion and implementation of the ecosystem approach in different administrative settings may be facilitated if carried out by a coordinating body with responsibilities within the catchment area covering, in particular, the preparation of action plans; the coordination and guiding of research, monitoring and implementation activities; reporting on progress; and public information. In transboundary waters, that task should be vested in joint bodies established by riparian countries.

The ecosystem approach to water management could in many ways gain momentum through the channelling of substantial management responsibility to local authorities, as these are generally empowered with decision-making on land use. Land use and activities in the catchment area have an important influence on aquatic ecosystems. Coordination of land-use planning with water-management planning is an important tool in furthering the ecosystem approach.

VI. REGULATORY FRAMEWORK

When analysing the interaction of water management with ecosystem components, it is necessary to determine the effects produced or likely to be produced by a particular water-related activity. This applies, in particular, to multi-purpose water-management systems.

As a result of effects on aquatic ecosystems, various problems may occur. Problem situations may be caused, for instance, by: insufficient information on ecosystem resources and conditions, shortcomings in production organization, resource-intensive types of production and technology, lack of coordination between authorities responsible for natural-resource utilization and those responsible for nature conservation. Various regulatory instruments and procedures should be applied in order to solve such problem situations effectively.

A. Environmental impact assessment

All activities in the catchment area with the potential of adversely affecting the conditions of aquatic ecosystems in terms of water quality and quantity, biological communities and the integrity of aquatic ecosystems, should be subject to environmental impact assessment (EIA) and authorization procedures. EIA should also be applied on an international scale, in particular with regard to activities with a potential transboundary effect on aquatic ecosystems. For this purpose, the methodological base should be improved and standardized under the implementation of the UN/ECE *Convention on Environmental Impact Assessment in a Transboundary Context* (Espoo, 1991).

As ecosystems integrate effects, immediate identification of a problem is not always possible. Time lags and synergistic factors may result in trends being observed by seasonal and cyclical variation. Before undertaking an economic activity which may affect water bodies, data collection for ecosystems should begin as an early priority, not be postponed until the design plans have reached some maturity.

Scoping, as an important early process in EIA, should include such aspects as ecosystem tolerance. Identifying the degree to which a proposed economic activity may reduce choice for future activity, both in the same location and elsewhere, should be an important element of the scoping process and requires early review and the use of integrated data sets on aquatic ecosystems conditions.

Risk assessment should be used in EIA in order to assess the potential risk to ecosystem integrity. Ecosystem damage and risk functions are rarely available for use with existing risk-assessment models and methods, and they therefore need to be developed for practical application in water management.

At present, EIA primarily influences the choice of mitigation measures associated with economic projects. EIA, however, in its present form, seldom questions the economic development *per se* in relation to long-term goals for the well-being of ecosystems. EIA of different economic-development strategies and sectorial policies, plans, programmes and legislative proposals could form part of the ecosystem approach.

Few precedents exist for undertaking EIA on a large scale, with multiple economic-development proposals in the catchment area. EIA procedures should require scoping and study of the potential environmental effects of such proposals, both in a site-specific and cumulative way, and involve the public and regulatory agencies in the assessment. With multi-site development proposed in the catchment area over a long period of time, EIA procedures should provide for an assessment of potential cumulative effects. A cumulative impact assessment (CIA) could be made to this end. It can combine inputs from catchment-wide environmental impact assessments with project-specific assessments, focusing on key ecosystem indicators. The principle of ecosystem (or catchment area) carrying capacity should be explored and integrated into the CIA methodology.

B. Site-specific regulations

Procedures should be elaborated and applied to guide and regulate the site-specific planning, design and execution of such activities as construction, landscaping (including soil removal and filling), stream modification and dredging, water abstraction and effluent discharge. Sensitive aquatic ecosystems or conservation areas may require more detailed regulations in this respect.

C. Water-quality objectives and standards

Water-quality objectives should be effectively applied for the promotion of ecosystems-based water management. Water-quality objectives already address such aspects as accumulation of toxins, acute and chronic toxicity, eutrophication, mutagenicity and carcinogenicity. Water-quality objectives should moreover attempt to express ecological naturalness that may be expected to be achieved in a given time either in all water bodies of a country, in a specific water body or parts thereof. Water-quality objectives should include biological, abiotic, physico-chemical parameters, flow regime and the uses that influence the levels, flows and concentrations experienced by aquatic ecosystems.

Water-quality standards should take into account, *inter alia*, sub-lethal toxicity effects, the transfer and accumulation of contaminants and effects of toxic chemicals in mixtures within an ecosystem. New biological parameters have to be introduced into existing standards in order, *inter alia*, to meet the concern that synergism might impede the desired level of protection, despite the consistency with all individual chemical determinants. The application of biological parameters should however supplement but not replace traditional water-quality parameters.

Water-quality objectives and standards should be subject to revision and upgrading in the light of ongoing developments. The cost and action needed to achieve or comply with them should be assessed in all cases. Water-quality objectives and standards constitute a necessary but insufficient pre-condition for ecosystems-based water management. They need to be accompanied by other appropriate instruments such as environmentally sound regulations for allocating water; harvesting crops, fish and timber; protecting species; and safeguarding sensitive areas.

D. Water-quantity regulations and management tools

Existing instruments and managerial tools for regulating water quantity should be reviewed and adapted, where necessary, in order to address accordingly ecosystem-maintaining functions of water bodies. Inter- and intra-basin water transfers which may alter flow regimes and water quality should be carefully assessed. Every effort should be made to mitigate likely adverse effects. Similar precautions should be taken for groundwater abstraction and recharges, and irrigation schemes, particularly in areas where they may adversely affect water levels or water quality of rivers, lakes and wetlands.

Water storage and associated structures can directly affect important riverside/lakeside wetlands and should only be embarked upon after a full assessment of the likely adverse effects and the consideration of all possible options. Some storage areas may be small, such as reservoirs on farms. What may be small incremental inroads into the total area of ecosystems should, nevertheless, be inventoried and controlled by local authorities.

Ecologically sound river flows should be established, as far as possible, and applied in water management through specific methods and techniques. Environmental weighting schemes can be used for that purpose, which set prescribed flows as a proportion of the dry weather flow, weighted according to a range of environmental characteristics and uses. Such flows should determine the amount of water available for offstream uses, pollution dilution, environmental protection and aquatic ecosystems requirements. The concept of instream flow requirements should be promoted, recognizing that species have habitat preferences with respect to flow conditions, water depth, substrate and vegetation, etc. This quantification of habitat preferences and the relationship with river flow, notwithstanding the inherent imprecisions, permit the negotiation and setting of optimal flows for ecological management.

VII. CONTROL STRATEGIES

Comprehensive control strategies, addressing all sources of pollution, point and non-point including acid deposition and the leaching of contaminants from soil, should be considered indispensable for the promotion of the ecosystem approach. Agricultural, forestry, fisheries and other sectoral policies should be adjusted to aquatic ecosystem requirements, as appropriate. Various selected measures to be included in such strategies and policies are set out below.

Discharge of effluents or cooling water may have significant adverse effects on aquatic ecosystems and, therefore, all such discharges should be recorded, assessed in relation to their loadings and synergistic consequences, authorized and controlled effectively. Permits for discharges of effluents should include controls on pollutant concentrations and loads that may adversely affect aquatic ecosystem components. Every effort should be made to assess the habitats and the communities of species in order to allow for appropriate upgrading, where necessary, of the limits established in permits.

Atmospheric emissions of sulphur and nitrogen compounds, fluoride, etc., can cause acidification of fresh water and affect animal and plant species. Control measures should be strengthened within the overall approach under the implementation of the UN/ECE *Convention on Long-range Transboundary Air Pollution* (Geneva, 1979).

Excessive or inadequate application of manure, mineral fertilizers and the ploughing of grassland on catchment areas enrich waters with nutrients, principally nitrogen and phosphorus, and affect macrophytes and the growth of phytoplankton. Phosphorus losses from soils in peat catchments can be severe and tend to build up in the sediment of water bodies and cause long-term release problems. Whatever the case may be, it is important to assess catchment farm practice, soil type and drainage potential and to implement necessary control measures.

Grazing by stock has a considerable impact on aquatic ecosystems, notably ponds, ditches and riparian vegetation. Bank erosion and siltation can increase diversity of margins and improve migration sites for some species as well as encourage wetland plants which colonize open mud. Conversely, overgrazing can eliminate emergent vegetation important for some birds and invertebrates. Earlier stocking and mowing of drained grasslands should be controlled as it places ground-nesting waders and wildfowl at increased risk of disturbance. The ideal in terms of grazing pressure is therefore a mixture of grazed and ungrazed margins and careful arrangement of fenced and unfenced areas.

Assessment of stocking levels in the margins of aquatic ecosystems should be related not only to grass productivity but also to the throughput of nutrients into water drainage systems. Leakage from slurry pits, silage clamps and septic tanks that may pollute water bodies should be prevented.

Areas should be left as "islands" of habitat within river basin corridors so that species can take advantage of land-use changes by recolonizing areas previously used for food production.

Fish farming and hatcheries may bring with them their own brand of adverse effects, which should be controlled by prevention, *inter alia*, of:

(*a*) Elimination of species, such as herons, sawbills and otters, often considered by fish farmers as pests;

(*b*) Eutrophication of downstream river reaches by excess feed and fish excreta;

(*c*) Toxic effects of chemicals used to control fish disease, parasites and antifowling of net-pens;

(*d*) Escape of cultivated, non-indigenous fishes.

Stocking with fish may pose particular problems since natural communities are becoming rare in some areas. In sites that have intact natural fish populations there should be no introduction or restocking other than with the local gene pool. In sites where fish have not become established and where important invertebrate communities exist, there should be no stocking allowed. Stocking with fish in lakes and, in general, fisheries management of standing waters should take into consideration the likely adverse effects on water quality, turbulence and microphyte communities.

If forestry takes place in areas adjacent to water bodies there should be buffer strips. These strips may vary in width according to local situations. Natural scrub and broad-leaved trees should be left in such areas. In forest areas adjacent to sensitive aquatic ecosystems, control measures should require, *inter alia*, that as few bushes and trees as possible are cleared on banks, and that a proportion of fallen trees is left on river banks for deadwood inhabitants (e.g., otters)

Storage of chemicals should be located in such a way as to minimize the risk to ecosystems. The application of chemicals should be carefully assessed for aquatic ecosystem effects. Direct manipulation of freshwater habitats and the introduction of new species should be subject to prior assessment and appropriate authorization. The use of herbicides and pesticides in sensitive aquatic ecosystems should be prohibited. When applied in other areas, it should:

(*a*) As far as possible eliminate only targeted species;

(*b*) Have no persistent effects;

(*c*) Not spread beyond the area of application.

Recreational activities on water bodies such as angling, hunting, camping, boating, water-skiing, sailing, windsurfing and other water sports should be subject to appropriate regulations bearing in mind aquatic ecosystem requirements.

VIII. RESEARCH AND DEVELOPMENT

Research and development on ecosystems-related problems should promote a holistic approach of developing strategies for the integrated management of air, water, land and living resources within the catchment. This would require refined scientific knowledge particularly on habitat requirements and bounds of species, as well as the resilience of native animal and plant communities to man-made disturbances, such as water abstraction, low-level organic pollution, nutrient enrichment, fish stock management, flow regulation, recreation pressures, sediment input or vegetation removal. Greater use of opportunities for ecosystem experiment should be encouraged as a means of defining cause-effect relationships and testing the effects of real management actions.

The ecosystem approach will require changes in research strategies. More cooperation and coordination, a greater ability to conceive and explore creative and innovative solutions, a greater recognition of the interdisciplinary and interjurisdictional aspects of problems and an ability to sustain long-term research are all important strategic issues. Raising awareness of decision makers and the public of environmental problems should be considered a challenge to the scientific community. Cooperative research arrangements, including those at an international level, should be considered as measures promoting ecosystems-based water management.

IX. PUBLIC AWARENESS AND PARTICIPATION

Ecosystems-oriented education and training should be promoted aimed at raising awareness on ecosystem considerations in institutions of general education, and developing subject-oriented and problem-oriented learning modules, as well as interdisciplinary learning modules, for trainees, employees and managers; and supporting pilot projects. While public perception is not always endowed with a deep appreciation of ecological principles, simple explanatory and educational measures can improve people's ability to make valid judgements.

Improved public awareness and the capability of the public at a local level to play a stronger role in ecosystems-based water management should be promoted, as this type of water management needs a strong local basis for consultation and action within a perspective. The public should be given a possibility to approach policy makers to voice their concerns and demand the effective protection and improvement of conditions in aquatic ecosystems. This makes increased communication with the public necessary, which means that the public should, *inter alia*, be: kept continuously informed; given opportunities to express their views, knowledge and priorities; and given evidence that their views are taken into account.