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JOINT GROUP OF EXPERTS ON THE SCIENTIFIC ASPECTS
OF MARINE POLLUTION
- GESAMP -

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ENVIRONMENTAL CAPACITY

AN APPROACH TO MARINE POLLUTION PREVENTION

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Reports and Studies No. 30

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ENVIRONMENTAL CAPACITY
An Approach to Marine Pollution Prevention

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 1986

Notes

1. GESAMP is an advisory body consisting of specialized experts nominated by the Sponsoring Agencies (IMO, FAO, Unesco, WMO, WHO, IAEA, UN, UNEP). Its principal task is to provide scientific advice on marine pollution problems to the Sponsoring Agencies and to the Intergovernmental Oceanographic Commission (IOC).

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DEFINITION OF MARINE POLLUTION

Pollution of the marine environment means: "The introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) which results in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water and reduction of amenities".

IMO/FAO/Unesco/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP)

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PREPARATION OF THIS STUDY

This document is the Report of the GESAMP Working Group on the Methodologies and Guidelines for the Assessment of the Impact of Pollutants on the Marine Environment, which met from 26 to 30 September 1983 in Rome, Italy, from 29 October to 9 November 1984 in Bangkok, Thailand, and from 23 to 27 September 1985 in Rome, Italy.

The following members participated in the preparation of the Report: Yves Adam, J. Michael Bewers, Davide Calamari, Lisandro Chuecas, Antonio Cruzado, Wolfgang Ernst, Edgardo D. Gomez, Gwyneth D. Howells, Manuwadi Hungspreugs, Taku Koyanagi, Uri Marinov, Jean-Marie Martin, Edward P. Myers, Heiner Naeve (Technical Secretary), Twesukdi Piyakarnchana, Teerayut Poopetch, John E. Portmann (Rapporteur), Velimir Pravdic (Chairman), Alan Preston, Marco Antonio Retamal, Lothar Riekert, Chelliah Satkunananthan, Anne E. Smith, Francisco Szekely (UNEP RS/PAC), Philip Tortell, Herb L. Windom.

The sessions of the Working Group were jointly sponsored by the Food and Agriculture Organization of the United Nations (FAO), the United Nations Educational, Scientific and Cultural Organization (Unesco), the World Health Organization (WHO), the International Maritime Organization (IMO), the International Atomic Energy Agency (IAEA) and the United Nations Environment Programme (UNEP).

EXECUTIVE SUMMARY

The aim of this Report is to provide guidelines for the assessment of the impact of potentially harmful substances released into the marine environment.

The Environmental (also known as receiving, absorptive or assimilative) Capacity is defined as a property of the environment, a measurement of its ability to accommodate a particular activity or rate of an activity, such as the discharge of contaminants, without unacceptable impact. The Environmental Capacity can be apportioned for various uses.

The Report proposes the use of a strategy to combat marine pollution based on this concept of Environmental Capacity. It provides the scientific rationale for the assessment of this entity, the methodology of calculation based on modelling, guidelines for its systematic application, monitoring and reassessment, and provides a number of case studies in the form of examples involving various contaminants and different geographical areas.

The Report opens with a short introduction outlining the basic concepts and premisses which lie behind the acceptance of disposal of wastes in the sea. When a development is first proposed, its impact on the whole environment, together with the costs and benefits to society as a whole, must be taken into account before the plans are actually implemented. The procedure is often now known as environmental impact assessment (EIA). This wide-ranging procedure embraces far more than the scientific assessment of the impact of pollutants on the environment and as such lies outside the terms of reference of GESAMP.

Accordingly, this Report concentrates on describing the parameters and processes which have to be taken into account in the assessment of the impact of pollutants on marine organisms, ecosystems, amenities and human health, as a consequence of any discharges to the marine environment.

The methodology of assessment of Environmental Capacity as proposed in the Report, involves critical pathway analysis for both conservative and non-conservative contaminants, establishment of environmental and water quality objectives, criteria and standards. Faced with the inevitability of several sources of uncertainty in real-life conditions, a probabilistic approach is proposed as an alternative to deterministic analysis. The approach proposed is Decision Analysis, and this is exemplified by a flow diagram.

The Report does not describe in detail how to gather the basic data or to carry out practical tasks such as conducting toxicity tests or measuring water movements. To have done so would simply have duplicated material which is already available in the open literature and therefore accessible to those persons who will be brought in to advise or otherwise provide expert opinon on any project. The Report does, however, provide guidelines on how to utilize information to assess the overall impact of the activity on the marine environment. Guidance is provided on those procedures wich are most likely to ensure that the activity can be contained within the capacity of the marine environment to receive wastes without causing unacceptable effects.

The methodology of assessment of the Environmental Capacity is based on scientific research and resulting data. It is, by definition, site- and contaminant-specific. It is accomplished in stages, the preliminary assessment can be accomplished using approximations such as single-box and simple mass-balance models, and by averaging over larger time scales on the assumption of steady-state conditions. As more data become available and transport and modification processes become better understood, more accurate values of Environmental Capacity will be obtained. These can then be used in environmentally compatible development planning and project implementation. The need for monitoring and iterative assessment is emphasized as an essential component of the procedure proposed, both as a safeguard against errors and as a means of fine tuning the controls so as to be less conservative and make them fit the precise conditions of each situation.

The strategy based on the concept of Environmental Capacity is presented as a high order interactive environmental management technique. The traditionally used complex strategy based on environmental quality objectives, or the simple but readily enforceable strategies such as those based on uniform emission standards, maximum allowable concentrations in effluents, the black/grey lists of contaminants or the application of the principles of best available technology or best practical means available, are shown to be but simple components of the adaptive, interactive strategy proposed.

The examples given in the final section illustrate how the concepts and premisses are put into practice and how the guidelines can be applied.

Reports and Studies GESAMP

The following reports and studies have been published so far. They are available from any of the organizations sponsoring GESAMP.

1. Report of the seventh session, London, 24-30 April 1975. (1975). Rep.Stud. GESAMP, (1):pag.var. Available also in French, Spanish and Russian
2. Review of harmful substances. (1976). Rep.Stud.GESAMP, (2):80 p.
3. Scientific criteria for the selection of sites for dumping of wastes into the sea. (1975). Rep.Stud.GESAMP, (3):21 p. Available also in French, Spanish and Russian
4. Report of the eighth session, Rome, 21-27 April 1976. (1976). Rep.Stud.GESAMP, (4): pag.var. Available also in French and Russian
5. Principles for developing coastal water quality criteria. (1976). Rep.Stud. GESAMP, (5):23 p.
6. Impact of oil on the marine environment. (1977). Rep.Stud.GESAMP, (6):250 p.
7. Scientific aspects of pollution arising from the exploration and exploitation of the sea-bed. (1977). Rep.Stud.GESAMP, (7):37 p.
8. Report of the ninth session, New York, 7-11 March 1977. (1977). Rep.Stud. GESAMP, (8):33 p. Available also in French and Russian
9. Report of the tenth session, Paris, 29 May - 2 June 1978. (1978). Rep.Stud. GESAMP, (9):pag.var. Available also in French, Spanish and Russian
10. Report of the eleventh session, Dubrovnik, 25-29 February 1980. (1980). Rep.Stud.GESAMP, (10):pag.var. Available also in French and Spanish
11. Marine Pollution implications of coastal area development. (1980). Rep.Stud. GESAMP, (11):114 p.
12. Monitoring biological variables related to marine pollution. (1980). Rep.Stud. GESAMP, (12):22 p. Available also in Russian
13. Interchange of pollutants between the atmosphere and the oceans. (1980). Rep.Stud.GESAMP, (13):55 p.
14. Report of the twelfth session, Geneva, 22-29 October 1981. (1981). Rep.Stud. GESAMP, (14):pag.var. Available also in French, Spanish and Russian
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17. The evaluation of the hazards of harmful substances carried by ships. (1982). Rep.Stud. GESAMP, (17):pag.var.

18. Report of the thirteenth session, Geneva, 28 February - 4 March 1983. (1983). Rep.Stud. GESAMP, (18):50 p. Available also in French, Spanish and Russian

19. An oceanographic model for the dispersion of wastes disposed of in the deep sea. (1983). Rep.Stud.GESAMP, (19):182 p.

20. Marine pollution implications of ocean energy development (1984). Rep.Stud. GESAMP, (20):44 p.

21. Report of the fourteenth session, Vienna, 26-30 March 1984. (1984). Rep.Stud. GESAMP, (21):42 p. Available also in French, Spanish and Russian

22. Review of potentially harmful substances. Cadmium, lead and tin. (1985). Rep.Stud. GESAMP, (22):114 p.

23. Interchange of pollutants between the atmosphere and the oceans (part II). (1985). Rep.Stud. GESAMP, (23):55 p.

24. Thermal discharges in the marine environment. (1984). Rep.Stud.GESAMP, (24):44 p.

25. Report of the fifteenth session, New York, 25-29 March 1985. (1985). Rep.Stud. GESAMP, (25):49 p. Available also in French, Spanish and Russian

26. Atmospheric transport of contaminants into the Mediterranean region. (1985). Rep.Stud.GESAMP, (26):53 p.

27. Report of the sixteenth session, London, 17-21 March 1986. (in press). Rep.Stud. GESAMP, (27). Available also in French, Spanish and Russian

28. Review of potentially harmful substances. Arsenic, mercury and selenium. (in press). Rep.Stud.GESAMP, (28)

29. Review of potentially harmful substances. Organosilicons. (in press). Rep.Stud. GESAMP, (29)

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1. INTRODUCTION

Environmental management consists of formulating and applying strategies by which the resources of a given ecosystem can be utilized in an efficient and sustainable manner in the context of the overall and specific socio-economic and political goals of a society. The use of the marine environment for waste disposal must only be undertaken after first conducting as rigorous an assessment as possible of the probable impact. The procedures by which this assessment is conducted should be based on a comprehensive scientific assessment of the local environment as well as on forecasting the potential effects that an activity might impose on that environment and human well-being dependent on it.

Recognizing the importance of social, economic and political considerations in the ultimate policy decisions, this document has been restricted as far as practicable to a description of an approach to a comprehensive scientific assessment in which 'hard' scientific data on local conditions are often limited. Because the criteria used in the scientific assessment must make reference to, and in many cases will change in response to, larger social decisions about the relative value of various amenities and uses, the report touches on how the scientific assessment process can be placed within the context of a generalized, illustrative, social evaluation process. To this end, the document describes the application of probabilistic analysis in decision-making.

The process by which the final decision is taken often centres on a document known by different names - Environmental Impact Report, Environmental Impact Assessment, Environmental Impact Statement. These documents contain the results of wide-ranging investigations. Input is required from economists, social scientists, engineers, scientists and other specialists.

The type of assessment undertaken in environmental impact assessment can follow one of two approaches:

(1) To make a 'deterministic' assessment of permissible effluent or water quality standards based on relatively simple techniques and applying empirical safety factors, and making conservative assumptions where uncertainties exist (Section 3.2).

(2) To perform a probabilistic assessment of the Environmental Capacity for the contaminant, based on the techniques described in Section 3.4. This permits an explicit weighing of risks associated with each effluent standard.

There can be many reasons for adopting one or other approach, but the planners should be aware that the choice between them should be a conscious step in the management process. The second approach is preferable when costs and risks can be explicitly balanced.

The assessment process may be enhanced by ranking options in social preference so that the appropriate research priorities for scientists are clear. It is essential that monitoring is undertaken as a follow up of the initial assessments, once the project has been implemented, in order to permit the accuracy of the assessment to be checked and correction made if necessary.

There is no methodology of assessment, which in itself would remove the requirement for difficult and often controversial decisions. The process of impact assessment serves to clarify objectives, quantifying potential impacts and risks, helps identify the opportunities for reducing undesirable consequences and assists in the decision-making process by systematizing information. The Environmental Impact Assessment process involves more than scientific considerations, and consequently is beyond the terms of reference of GESAMP, in that it considers political, economic and social, as well as scientific components.

Scientific input to the process of environmental impact assessment may be required, first when the scope of the investigations is being determined, secondly in the specific investigations required to provide the necessary data and, finally, in direct advice to decision-makers in interpreting scientific data and in allaying public concern. Further scientific input is required as follow-up action such as monitoring and review.

The wastes of society can be placed on land, in the atmosphere or in the water. It seems only reasonable to consider the comparative consequences of disposal in each of these receiving environments and to choose between them on the basis of scientific, technical, economic and social grounds. While GESAMP's brief is limited to the marine environment, other disposal options cannot be ignored.

The disposal of wastes in the marine environment, even those produced by the best available technologies and after extensive treatment, may have an impact on the marine ecosystem and resources, human health, amenities and other legitimate uses of the marine environment.

Identifying and assessing such potential impacts in view of the characteristics of the wastes and of the receiving environment, as well as available waste management options, is basically a scientific exercise requiring close harmonization with other aspects of environmental management.

The scientific concepts and methodologies discussed in the following sections and the guidelines put foward are intended for the scientific assessment of the impacts produced or expected by the disposal of wastes in the marine environments.

2. PREMISSES, CONCEPTS AND DEFINITIONS

The basic premisses for this document are that:

(1) a certain level of any contaminant will not produce any unacceptable effect on the marine environment or its various uses;

(2) the environment consequently has a finite capacity to accommodate wastes;

(3) such capacity can be quantified.

The last of these may prove difficult to achieve in practice but in principle is always possible.

2.1 Acceptability of Impact

Acceptability of impact is a subjective judgement often reflected in water quality standards and objectives which are set nationally or internationally within the political process. However, acceptability can be determined from a more scientific perspective, based on the GESAMP definition of pollution. According to this definition, any discharge which does not cause pollution would be deemed as acceptable from the scientific point of view.

The concentration (level) of a substance (or waste) at which deleterious effects on one of the various components of the ecosystem or uses of the marine environment occur may be defined through toxicological, epidemiological or other studies.

In some cases, that concentration (level) may be based on the acceptability or risk of exceeding the point at which deleterious effects actually occur.

2.2 Environmental Capacity

Various terms are used to describe the extent to which the environment is able to accommodate waste without unacceptable effects. One such term is Environmental Capacity. As commonly used, and certainly as used throughout this report, Environmental Capacity is a property of the environment and can be defined as its ability to accommodate a particular activity or rate of activity (e.g. volume of discharge per unit time, quantity of dredgings dumped per unit time, quantity of minerals extracted per unit time) without unacceptable impact. Definition of this capacity must take into account such physical processes as dilution, dispersion, sedimentation and evaporation, as well as all chemical, biochemical and biological processes which lead to degradation or removal from the impacted area by which a contaminant or an activity loses its potential for unacceptable impact. It should take into account processes which may lead to reaccumulation of the contaminant in question and the possibility that the substance may be transformed into a more toxic compound (e.g. mercury to methylmercury).

It must be stressed that Environmental Capacity will vary with the characteristics of each site and with the type and number of discharges or activities or affected resources and uses. Use of the capacity of an environment to assimilate a waste or activity must recognize the defined capacity as an upper limit. Proper management of the marine environment, giving attention to waste treatment and alternative means of disposal, should be successful in preventing excesses, as has been the case where effective management of river water quality has been practised. If the overall cost to society implied by the restrictions of the scientifically-defined Environmental Capacity is judged to be too high, e.g. a factory cannot be built, with consequent massive unemployment, the social decision process may lead to acceptance of some environmental damage in order to extend the Environmental Capacity. The procedure described here will ensure that such a revision of Environmental Capacity is the result of conscious, scientifically-informal decision.

2.3 Recovery of Polluted Ecosystems

Although pollution impacts may severely damage the marine environment, corrective measures tending to eliminate or reduce the pollutant load should in general allow recovery albeit to an altered state. In cases where serious pollution has occurred, identification of the cause and the resulting remedial action, which only rarely has necessitated total cessation of the input, has resulted in recovery of the affected environment.

It is important to recognize that many ecosystems do have a potential to recover from pollution, including that caused by accidental releases of pollutants. The ability of the system to recover should be assessed before any discharge of waste is allowed to take place. Knowledge of detoxification processes and of recovery potential may help to optimize remedies if an accident occurs or damage is suddenly detected. It is also important to understand the causes and time course of polluting events. Only if these are known, can effective remedial measures be applied.

3. SCIENTIFIC RATIONALE AND METHODOLOGY FOR THE ASSESSMENT OF THE IMPACT OF POLLUTANTS ON THE MARINE ENVIRONMENT

3.1 Approaches to Effluent Control

Waste management strategies should aim at selecting the disposal option which involves the least collective impact in terms of human health detriment, disturbance and/or damage to the natural environment and associated social and economic penalties.

The methodology recommended for the assessment of the impact of pollutants on the marine environment is schematically shown in Figure 1. It consists of three stages (decision loops): (i) the planning loop, (ii) the preliminary scientific assessment loop, and (iii) the monitoring and adaptation loop. The scheme recognizes scientific and socio-economic inputs as two parallel, interactive and complementary activities in decision-making in integral, environmentally compatible, development planning. It emphasizes the objectivity and independence of scientific assessments, but also their deep involvement in influencing socio-economic feasibility decisions.

In the planning loop, socio-economic goals trigger an activity. Scientific assessment is needed in the identification of available present and future resources. The process also requires initial consideration of alternative options.

In the next stage the essence of the assessment process is to translate the defined environmental quality objectives (EQO) into the maximum allowable inputs. The assessment process proceeds through the identification of development activities, and of present and expected future contaminants. The process of adoption of water quality criteria will involve choice of the most sensitive target or population to be protected and investigation of the critical pathway of the contaminant to it. This accomplished, by use of toxicity data for the target and the contaminant along with a proper application factor, water quality criteria can be derived. Using environmental data and end points based on water quality criteria, the assessment of the Environmental Capacity, and apportionment of a fraction of it for the particular project, enables the setting up of allowable inputs. Such a procedure will always involve several sources of uncertainty, requiring approximations based on experience.

This final and most important stage is shown in the monitoring and adaptation loop. Monitoring provides a test of whether the Environmental Capacity is (i) balanced, thus allowing the project to become operational. If monitoring shows that Environmental Capacity is (ii) exceeded, the project must be revised or would require alternative technology, primarily in the waste and effluent treatment. If no economically or technologically acceptable alternative is available, environmental consideration would require cancellation of the project. If in conservative assessments too low application factors (see 3.2.1) were used, the Environmental Capacity might be found (iii) underutilized. In such cases, if economic and development needs dictate, allowed inputs may be increased, but only with caution and relying on long time series monitoring data.

3.1.1 Removal/reduction of contaminant levels by effluent treatment

From a purely technical standpoint it is possible to devise treatment processes to deal with most contaminants in most types of effluent. Treatment processes already exist for many industrial wastes, and methods are available to reduce the impact of such activities as dredging and sea-bed resource exploitation. The capital and running costs of effluent treatment usually increase the greater the degree of contaminant removal required. However, there may be a cost return in addition to environmental benefit if potentially re-usable or saleable materials are recovered or generated in the waste treatment process.

Given that there is to be a discharge, the greatest level of environmental protection is provided if the effluent is treated with the best available technology (BAT), i.e. that which allows the maximum removal of the substance in question, regardless of costs. If economic factors are taken into consideration the level of treatment called for may be less. This option, which takes account of economic aspects, is often described as using the best practicable means available (BPMA).

This type of approach to environmental protection has been adopted by the European Economic Community as the procedure preferred by most of the member countries for the implementation of the Directive on Pollution Caused by Certain Dangerous Substances Discharged to the Aquatic Environment of the Community (EEC, 1976). This Directive seeks to eliminate pollution of surface waters, including estuaries and coastal waters, by various so-called black-list substances and to reduce pollution by so-called grey-list substances. The approach takes account of what is achievable in terms of effluent quality and sets limits on the concentrations of particular substances concerned. This approach is called the uniform emission standards (UES) approach because the same limits are applied to all discharges of the substance in question or all processes of a particular type. The limits are usually set in terms of the concentrations allowed in the effluent and, in the case of a particular process, in terms of the amount of product produced. For example, the limits for mercury arising from chlor-alkali production are expressed both in terms of grams of Hg per ton of chlorine produced and of mg/l of the effluent.

These approaches to environmental protection all seek to reduce the potential impact of contaminants on the marine environment by reducing the input of wastes. Because such limits are based purely on praticable treatment technology, they cannot guarantee, and certainly are not designed for, protection of the environment on a site-specific basis. They do, however, have the additional advantage of being relatively easy to organize, administer and monitor, and they do not require detailed investigation of environmental variables, which inevitably vary from site to site.

It must be recognized that these approaches to environmental protection may require costly technology to be used, because they do not take account of the extent to which the environment can assimilate wastes. Consequently, although effluent treatment (whether BAT or BPMA) may reduce pollutant levels in effluents, pollution may not be avoided. Thus, for example, the discharge from an extremely large plant may cause pollution, even though that from a small one may not. Equally, a small plant discharging to a small river or estuary may have a disastrous effect whilst several quite large plants discharging to a large river, estuary or open coastline may have no detectable effect at all.

3.1.2 Water quality classification systems/water quality criteria

An approach to environmental protection, which attempts to ensure that pollution does not occur and takes Environmental Capacity into account, involves the adoption of environmental quality criteria. These may be adopted as standards within a legal framework of control. In their simplest form water quality criteria are derived so as to protect aquatic and human life, the more stringent of the two usually being applied. The use of water quality criteria within an overall environmental quality objective framework is discussed in detail below.

Protection of aquatic life is sought by assessment of all available toxicity data from both acute and chronic exposure tests. If data are sparse it may be necessary to apply a safety factor or to otherwise accommodate uncertainties, e.g. that other species may be more sensitive or other pollutants may be present and have an additive effect. Implementation of the resulting value as the maximum allowable concentration (MAC) in the aquatic environment would be expected under normal conditions to protect aquatic life. Different criteria may be derived for marine and freshwater life and may be further sub-divided, e.g. into standards to protect crustacea, molluscs or fish.

A similar procedure is used to ensure that human health is not at risk through use of the water for drinking purposes, for swimming or other recreational purposes, or through utilization of fish

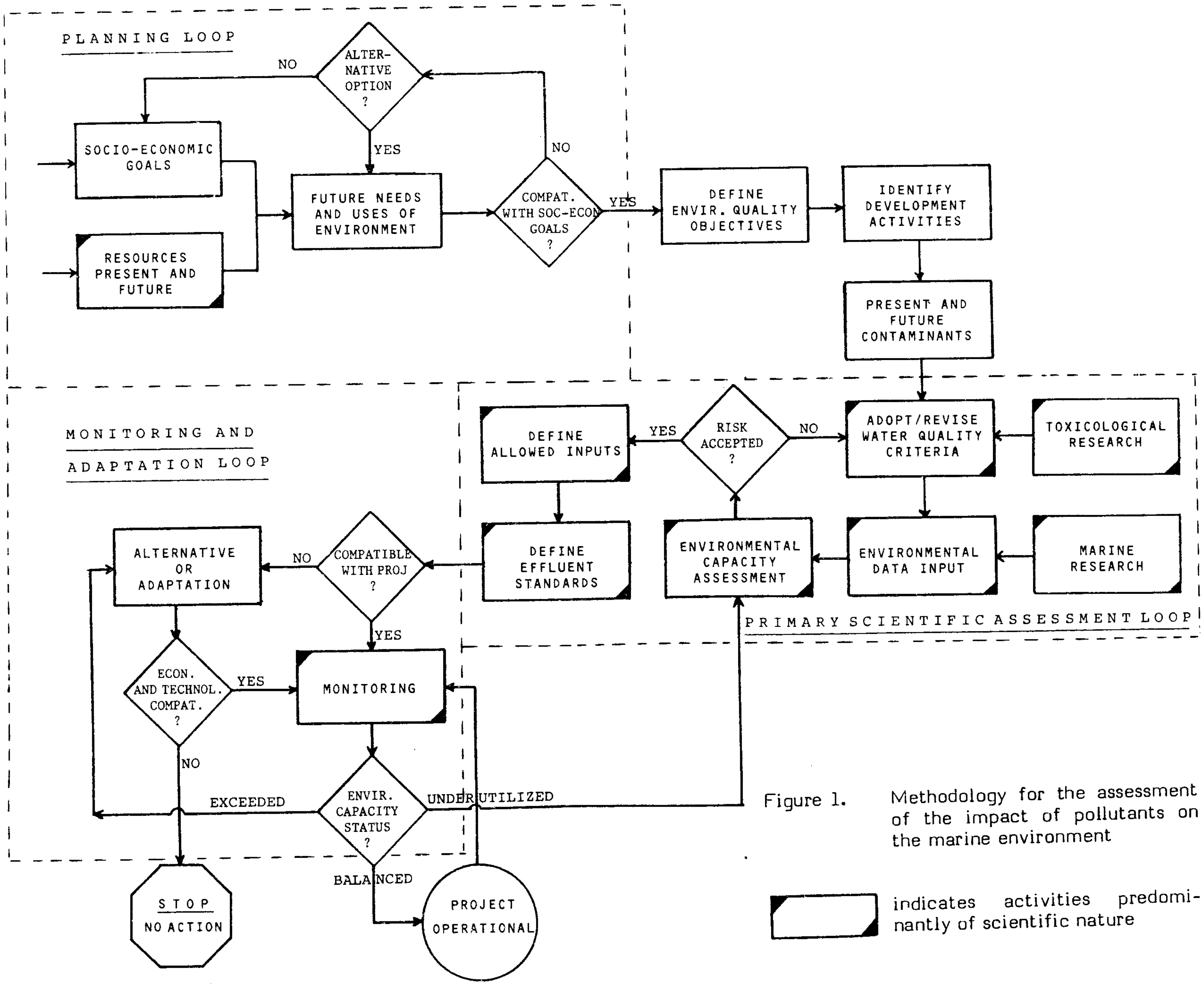

Figure 1. Methodology for the assessment of the impact of pollutants on the marine environment

◩ indicates activities predominantly of scientific nature from the impacted area for food - marine organisms may accumulate the substance of concern and whilst not at risk themselves may be dangerous to man. In deriving criteria to protect man, the consumption rates used will be those of the most exposed group, e.g. in the case of an exposure pathway involving seafood consumption, they will be those who habitually eat large amounts of sea food. Values are usually set on the basis of the habits of an average member of the most critically exposed group of the population (Hunt et al., 1982).

A further dimension of the water quality criteria approach is that which permits the derivation of criteria to meet a whole series of Water Quality Objectives. Such a system acknowledges that, for a variety of reasons, it may not be desirable or practicable to require criteria to protect human health or aquatic life in every sector of the aquatic environment. For example, it may be decided that the most important use of a particular stretch of water is for navigation or irrigation and that protection of fish or other aquatic life is less important. To this end, different standards may be adopted to protect the various possible uses of the water. Those usually considered in a marine environment protection context are:

- a source of food for man

- abstraction of water for desalination for drinking water purposes

- abstraction of water for industrial purposes

- a recreational medium, i.e. for bathing and other water sports

- an environment which is aesthetically pleasing

- an environment which supports a normal population and diversity of aquatic life

- an environment which supports an exceptionally rich, productive, diverse or rare population of aquatic life.

Apart from the additional complication of having to derive separate standards to protect each of these uses, decisions also have to be made as to what single or multiple use is desired for the particular stretch of water. In common with other decisions which will be required, this clearly involves much more than inputs by scientists and will entail various value judgements being made.

The main advantage of the water quality objectives approach is that standards can be set according to the particular uses of the environment. It provides a set of management goals upon which further decisions can be based.

The main disadvantages are that, in order to derive the criteria, a considerable amount of basic information may be required on the substances concerned and their behaviour in the environment, including their interaction with other substances. The application of water quality criteria also requires discharge limits to be set with regard to use and characteristics of the area into which each discharge is to be made. Discharge limits may be more relaxed than would be required under the best practical technology type approaches. However, discharge limits would normally be set to ensure that the water quality criteria are met with adequate safety margins. The extent of the safety margin would be determined by economic and other factors. Situations will also arise where the discharge limits may be such that they simply cannot be achieved even using best available technology and the project has to be abandoned, or moved elsewhere. This is particularly likely to arise if several similar discharges are already being made to a particular area, especially if the principle of setting individual discharge standards as low as reasonably achievable was not followed for the earlier plants. Also, for political reasons, the same water quality criteria could be adopted for all water bodies of a country, resulting in a diversion of discharges from already polluted areas to still undisturbed environments of a higher ecological value.

Water quality criteria have been set at international and national levels. These can be used as guidelines for application elsewhere. It should, however, be recognized that such criteria were derived with the particular needs of those regions' and countries' environments in mind. They may not therefore be sufficient to protect particularly sensitive ecosystems.

The criteria selected to ensure that water is suitable for the use desired will be a major component in the process of calculating the Environmental Capacity. This latter will include the amount of the contaminant which can be added to a particular body of water without the level defined by the criteria being exceeded.

3.2 Quantification and Derivation of Environmental Capacity

Any assessment of the capacity of the environment to assimilate wastes will require Maximum Allowable Concentrations or Water Quality Criteria to be set. At least some data have to be available for both these aspects and the level of precision of the evaluation is dependent on the quality of data available.

The quantification of capacity involves the following main components:

- characteristics of the contaminant, i.e. chemical physical and toxicological
- environmental distribution
- environmental fate
- definition of boundaries of the impacted ecosystem.

3.2.1 Characteristics of the contaminant

The most significant characteristic of the contaminant is its toxicological properties. The scientific basis for water pollution control regulations is the definition of water quality requirements. Depending on the intended use of the water, human utilization and aquatic life are the most demanding uses. Although most examples quoted in the following sections refer to freshwater experience, the same approaches have been used for coastal and marine waters, for example by EPA in the United States of America (U.S. EPA, 1980) and by the European Communities.

The criteria are defined by reviewing available scientific information and critically defining a limit not to be exceeded. This procedure can be applied only to thoroughly studied, well-known substances but, at least in fresh waters, its usefulness has been clearly demonstrated. According to EIFAC (1964), criteria for freshwater fish should satisfy the following needs:

> 'Water quality criteria for freshwater fish should ideally permit all stages in the life cycles to be successfully completed and, in addition, should not produce conditions in a river which would either taint the flesh of the fish or cause them to avoid a stretch of river water where they would otherwise be present, or give rise to accumulation of deleterious substances in fish to such a degree that they are potentially harmful when consumed. Indirect factors like those affecting fish-food organisms must also be considered, should these prove to be important'.

Each toxicant is usually reviewed on the basis of its chemistry in water, sublethal effects on fish, type of toxic action, factors which influence lethal levels, and then field observations in polluted waters, data regarding toxicity on algae and invertebrates. Tentative quality criteria for aquatic life are subsequently published. In the cases where validation has been possible, the results were consistent.

When data are scarce, several other approaches are helpful, depending on the type of information available. For example, in the U.S.A. the <u>maximum acceptable toxicant concentration</u> (MATC) (Mount and Stephan, 1967) is experimentally determined as that concentration which allows for the full life cycle of target organisms, usually fish, to be completed successfully (from egg to egg). Another way to identify a non-dangerous concentration is the <u>no observed effect level</u> (NOEL) approach which is used where a few consistent data are available, including some long-term exposures, but where full toxicity information is lacking. In some circumstances, a number of acute toxicity tests have been completed at various levels of biological organization. These provide the basis for evaluation of ecotoxicological characteristics of the substance in question by means of an <u>integrated rating system</u> (IRS) (Weber, 1977; Calamari <u>et al.</u>, 1980, 1983; Schmidt-Bleek <u>et al.</u>, 1982). This method involves the summation of empirical and consistent toxicological "scores" by which the substance can be ranked among others with known properties. In the case of necessity, therefore, this method allows tentative water quality criteria to be derived from the few data available, on the basis of analogy.

A further approach when data are scarce, and there is uncertainty, is the use of an <u>application factor</u> (AF) (Lloyd, 1979). This may be used to transform short-term LC50 data or chronic toxicity data available for a limited number of species into a concentration which should protect either also other species or all development stages of those species it is desired to protect. Whilst the use of an application factor may appear arbitrary, the concept is based on experience gained from toxicological studies of a wide variety of substance, verified by field experience, and is thus soundly empirically based. The usual toxicity curves showing the relationship of concentration with time of response for a chemical substance or an effluent will allow the identification of an appropriate application factor. For example, in Figure 2, curve (A) shows a well defined threshold of response (or incipient effect level) while curve (B) shows only a tendency to a threshold, whereas (C) has no threshold for the period of time tested. In this case, the application factors could be 0.1, 0.05, 0.01. The allowable concentration for the species tested is then the effective concentration multiplied by the application factor. Application factors should be used with care and the appropriate value is best judged by experienced toxicologists. Values less than 0.01 may be advisable in certain circumstances.

A further factor may also be needed to take account of different patterns of response so as to provide additional safety, e.g. in order to try to protect all life stages of all species concerned. The common relationship between effect and concentration is represented in Figure 3 by curve (D) which shows little effect at lower concentrations but a sharply increasing response at some higher concentration. Curve (E), on the other hand shows a sharp response at lower concentrations, but minimal response thereafter. This, therefore, could be regarded as a more sensitive system requiring a lower application factor. In the absence of evidence to the contrary, curve (E) should be assumed so as to ensure protection.

When more than one chemical substance is present in a water body, possible interactions have to be taken into account, in the event that more than additive effects (synergism) or less than additive effects (antagonism) can occur. However, in the majority of cases for which data exist the response is simply additive. This was the clear conclusion reached in a review of data on the acute toxicity of mixtures to freshwater organisms made by the EIFAC Working Party on Water Quality Criteria (Alabaster and Lloyd, 1982). Although most of the available data relate to freshwater organisms and very few to marine organisms, as a first approximation it is reasonable to assume that synergistic or antagonistic effects will arise equally rarely in the marine environment.

Furthermore, on the basis of their extensive review, the EIFAC Working Party concluded that for the common pollutants, e.g. metals and ammonia, there was no additive effect of concentrations below the no-observed effect level. However, in up-dating this review on the basis of recent information, the EIFAC Working Party acknowledges that for mixtures of certain organic compounds which have a well defined common quantitative structure-related activity (QSAR), the combined toxic action is additive at all concentrations. Also, for complex mixtures which in part include some of the common pollutants, the combined effect may be that of partial addition. Other groups (e.g. EPA in the U.S.A.) ask for a reduction in the established acceptable levels when more than one substance is present. The extent to which established acceptable levels have to be reduced in such cases will be determined to some extent by the information available on the joint action of the substances present. A conservative approach would be to assume additive joint action in all cases, but unless there are more than three disparate substances each present at their individual established acceptable level, it is unlikely that these levels would need to be reduced by more than two-fold in order to take joint action into account.

In the case of accumulative substances, control of the concentration in water may not be the best means to protect the ecosystem or any of its components, including man. A few metals, radionuclides and some organic substances are selectively retained in the living tissues of organisms where they may cause direct effects, or may be transferred via the food chain to other organisms. In these cases, the concentration in the tissues should be measured and used to derive control measures. For example, the level of mercury in aquatic organisms has been used in the U.K. to arrive at a maximum allowable discharge of mercury to coastal waters (Preston and Portmann, 1981). A second example of indirect protection of fish-eating sea birds against the effects of accumulative chemicals is the definition of an acceptable level of induced enzyme activity (e.g. acetyl-choline-esterase and mixed function oxidases) in bird liver.

The bioconcentration factor (BCF) can be used as an instrument of control. Potential bioconcentration factors for organic substances can be predicted on the basis of physico-chemical properties, using water solubility and/or partition coefficients in n-octanol/water (Neely et al., 1974). This has also been shown to apply to marine organisms (Ernst, 1980). In some instances, where biodegradation occurs, the BCF derived from physico-chemical properties may be too high. In contrast, if biomagnification via the food chain occurs, the derived BCF will be too low; such cases are rare.