

1. INTRODUCTION

The idea of a world-wide linkage of national and regional environmental monitoring networks is exciting and challenging. The concept has already been accepted at Stockholm and will hereafter be referred to as GEMS (Global Environmental Monitoring System). GEMS will bring many opportunities for interdisciplinary and international cooperation.

Monitoring is defined here as the process of repetitive observing, for defined purposes, of one or more elements or indicators of the environment* according to pre-arranged schedules in space and time, and using comparable methodologies for environmental sensing and data collection. Monitoring provides factual information concerning the present state and past trends (over the period of record) in environmental behavior. As examples, monitoring could include hourly observations of trace gases, daily measurements of water-quality indicators, annual surveys of forest cover, and periodic sampling (at 5- to 10-yr intervals) of the heavy metal concentrations in food or seaweed. The observations need not be made at fixed times or at fixed locations. The system could include, for example, a mechanism for activation of supplementary data collections whenever pre-designated criteria were met, e.g., during high pollution episodes, during natural disasters, or whenever a few cases of cholera were detected in a region. The system could also include random or cluster sampling (of biota) according to standardized procedures. An important constraint, however, is that the observations be made in a systematic way.

Assessment is defined as the process of interpretation of data obtained from monitoring networks and diverse other sources. The word *assessment* has three distinct meanings in the context of monitoring:

- (a) quality control,
- (b) examination of the efficiency of networks, including optimization of space and time densities of observations so that interpolations between observations can be made with the desired accuracy,
- (c) examination of the state of the environment, the determination of trends, and the prediction of future states, often for use in comparisons with environmental criteria or standards.

These definitions differ from those adopted in 1971 by the Intergovernmental W/G on Monitoring or Surveillance, which defined *monitoring* as a system of continued observation, measurement and evaluation for defined purposes. It is useful, however, to make a distinction between *monitoring* and *assessment* (or *evaluation*).

At the outset it should be emphasized that the design of an interdisciplinary monitoring network is not an easy task. The environment can be observed only imperfectly, the pathways through the biosphere

* Indoor environments are excluded from GEMS, unless particularly specified.

of many substances such as PCB's are not well understood, and the knowledge of the effects of various substances on human health and other biological systems is fragmentary.* Nevertheless, there is already sufficient scientific information to make a modest start towards GEMS, recognizing that an optimum design will only be reached after several decades of monitoring and assessment.

The Action Plan developed at Stockholm is divided into three parts:

1. Earthwatch,
2. Environmental management activities,
3. Supporting measures.

Earthwatch includes not only GEMS but also environmental assessment, the International Referral Service (IRS), the development of environmental criteria (e.g., dose-response relations), and supporting activities. GEMS is to provide basic data sets for environmental assessment while *Earthwatch* is to provide the necessary information for environmental management, e.g., for the preparation of alternative strategies for decision makers.

2. TIMING

GEMS cannot become fully operational in a day or in a decade. The program must therefore be divided into several phases. At the first session of the Governing Council of UNEP, there was agreement that the program should at first be limited to monitoring of the concentrations of a small number of priority pollutants of broad international significance. Although the monitoring of other kinds of data (indicators of human health and biological effects; information on food and natural resources; emission strengths) is equally important, in many cases there is not yet sufficient international agreement on methodologies for monitoring to be feasible.

The Inter-Governmental W/G on Monitoring at its meeting in Nairobi in early 1974 may wish to recommend a modest program of monitoring priority pollutants. If the recommendations are accepted at the Second Session of the UNEP Governing Council, Member States may wish to participate in GEMS, in the knowledge that methodologies for monitoring have been accepted internationally. A complete world coverage is not likely to exist (even for a few priority pollutants) in less than a few years, however. In the case of the world meteorological networks, for example, despite continued expansion over the last century, the network is still not complete.

The Phase I Action Plan will include not only proposals for monitoring a selected list of pollutants but also pre-programming activities of three types:

* Because pollutants usually occur in combination, multiplicative (synergistic) effects may take place. Furthermore, these effects are sometimes not detectable until after several generations.

(a) Expansion of the list of priority pollutants and of the media in which they may be monitored;

(b) Examination of other kinds of relevant environmental indicators (related to effects on human health and biological systems, to food and natural resources, to emission strengths, and to socio-economic states);

(c) Development of physical, chemical, biological and sampling methodologies to improve network design in the light of assessment requirements.

In some cases, field experiments (similar in concept to GATE) and intercomparisons of instruments and reference standards will be necessary.

At the end of Phase I (1976), the Inter-Governmental W/G on Monitoring, and subsequently the UNEP Governing Council, may be asked to examine a preliminary analysis of the GEMS data collected in Phase I, as well as substantive proposals for Phase II of GEMS. Thereafter the system may continue to develop stepwise, but consideration might be given in 1976 to extending the duration of Phase II to 4 years. Special note should be made of the fact that the 1976 assessment will necessarily be very preliminary. The data banks available from the various components of GEMS will most certainly be incomplete.

3. OBJECTIVES OF MONITORING

In August 1971, the Intergovernmental W/G on Monitoring or Surveillance, convened in preparation for the Conference on the Human Environment, laid down the following objectives for a world-wide environmental monitoring system (UN, 1971):

"To provide the information necessary to ensure the present and future protection of human health and safety and the wise management of the environment and its resources by:

a) (i) increasing quantitative knowledge of natural and man-made changes in the environment and of the impact of these on man's health and welfare;

(ii) increasing understanding of the environment, and, in particular, of how dynamic balance is maintained in ecosystems, as a basis for managing resources;

b) providing early warning of significant environmental changes (including natural disasters) in order that protective measures may be considered;

c) making it possible to check the effectiveness of established regulatory mechanisms and to plan optimal technological development."

These objectives were submitted to the Conference which took them as a basis for the Action Plan.

It might be emphasized that not all human activities degrade the environment. There are many instances in the last century of environmental restoration and of useful modification (e.g., reforestation, and

the reduction of soot in urban and industrial areas). One of the objectives of monitoring should therefore be to provide continuing reassurance concerning the health of the environment in certain regions or media and to determine the progress in environmental enhancement in others.

Another objective of monitoring is to provide unbiased sets of data which can be disseminated widely both for public information programs and for the use of specialists around the world. The interpretation to be placed on the data sets may, of course, vary widely. By accepting internationally agreed comparable methodologies and intercalibrations, however, Member States may avoid local criticism (quite often unfounded) of the accuracy of their published data on environmental quality.

Finally, the importance should be re-emphasized not only of detecting environmental changes in the biosphere (harmful effects in particular), but also of determining the causes, i.e., of explaining the complex linkages between cause and effect. Only then can predictive models be formulated.

4. PRINCIPLES OF MONITORING

4.1. INTRODUCTION

There are two sets of principles that must be considered in the development of GEMS. On the one hand, there are institutional principles that have already been accepted at the Conference on the Human Environment. On the other hand, there are a number of scientific guidelines that provide a framework for network design.

4.2. INSTITUTIONAL PRINCIPLES

In 1971, the Intergovernmental W/G on Monitoring or Surveillance agreed on the following principles for GEMS.

1. Intergovernmental co-operation in monitoring should build on the basis of existing national and international systems to the maximum possible extent. Within the ICES programs, for example, considerable attention has already been directed towards the question of defining sampling requirements and methods of data presentation.
2. Existing United Nations Specialized Agencies should be used to the maximum extent possible as the institutional base for co-ordinating and implementing monitoring programmes. It is essential to improve co-ordination mechanisms within the United Nations framework.
3. With regard to monitoring on an international basis, priority should be given to global and regional (multi-national) problems.
4. The exchange of information about local problems that are of wide occurrence, and about the methods used to monitor them, is of high importance.

5. Special emphasis should be given in global monitoring to the variables of most critical importance that are capable of adequate scientific measurement at the present time. Where the measurement techniques for variables of critical importance are deficient, special attention should be given to their development.*
6. Monitoring systems should be designed to meet clearly-defined objectives, and arrangements for the evaluation of the data must be an integral part of the design of the system.
7. Nations that agree to participate in a system of global or regional monitoring incur an obligation to exchange promptly appropriate data or evaluations of the data, especially in relation to the early warning of natural disasters.
8. As international monitoring implies the participation of many nations, assistance, including assistance in training, should be given where necessary, to ensure the effective involvement of appropriate countries without regard to their stage of economic development.
9. Nations should share the responsibility of implementing international monitoring systems in areas outside national jurisdiction such as oceans and space. Activities carried out on national territories will be the responsibility of the nations concerned.

These principles were subsequently accepted by the Conference on the Human Environment. They provide a useful framework for a GEMS Action Plan.

Implied in the principles, and in the objectives given in Section 3, are several points that have been brought into sharper focus since 1972. For example, in the Report of the Executive Director to the First Session of the UNEP Governing Council (UNEP/GC/5, April 1973), reference is made to the "rising levels of harmful chemicals in food causing preoccupation that the exports of developing countries may be denied admission in order to protect the consumer. Conversely there is the danger that some developing countries unwittingly admit imported food which is harmful to their citizens", and it is suggested that "an important element in any monitoring system should be the repetitive measurements of harmful contaminants in food being traded so that trends may be identified at a sufficiently early stage to allow preventive action."

GEMS must of course be built upon existing national and regional monitoring activities. In many countries at the present time, monitoring is entirely on a sectional basis; thus, national interdisciplinary coordination will be required. There are more than a few cases of published data being in unsuitable forms for scientists and managers who are interested mainly in a particular discipline but who require interface data from another discipline. For example, National Meteorological Services do not always prepare climatic publications in a meaningful form for air pollution specialists; pollution control officers, on the other

* This is a scientific rather than an institutional principle but it has been placed here to preserve the original ordering.

hand, do not always publish air quality data in a form suitable for meteorological analysis and interpretation. Thus a significant benefit flowing from GEMS will be the strengthening and unification of national monitoring activities.

Important questions to be resolved, however, are:

1. What national data are to remain within a country, being of only local or national interest?
2. What national data are to be exchanged regionally?
3. What national and regional data are to be exchanged globally (the GEMS system)?

Finally, one basis for establishing inter-governmental monitoring priorities might be the degree of reversibility of effects. Arctic and alpine biomes recover very slowly when disturbed by man while contaminated ground waters may require decades or centuries to purify themselves. In other cases, however, environmental quality can be restored in days or weeks by the simple act of controlling emissions. This principle is recommended for consideration in the setting of priorities for Phase II of GEMS.

4.3. SCIENTIFIC PRINCIPLES

4.3.1. Historical Perspective

With the invention of the telegraph, the first international monitoring network (meteorological) began to develop about the middle of the nineteenth century. It was found that synoptic observations from locations 200 km apart could be used to *predict* the behaviour of the atmosphere. This provided a justification for network expansion and for international standardization of observing and coding procedures. Continuous review was, of course, required and is still necessary in the light of advancing knowledge of weather processes. The Global Atmospheric Research Programme (GARP) is a further step in this chain. Thus atmospheric monitoring has been of value not only for predicting the weather for the next day or so, but also for improving the accuracy of the prediction (by providing data sets for testing models).

In the middle of the nineteenth century too, phenological networks were established in many countries; voluntary observers kept careful records of the dates when fruit trees blossomed, when the spring break-up of river ice occurred, and so forth. The information was of considerable scientific interest but proved to be of little value as a predictive tool. Nevertheless, the networks were maintained for decades. In the United Kingdom, for example, publication of the annual phenological reports was not terminated until the 1940's.*

* In the last decade, there has been a mild upsurge of interest in the use of phenological events as indicators (and integrators) of man-made environmental impacts. For example, the first autumn killing frost occurs later in a city than in the surrounding countryside.

The differing experience with meteorological and phenological networks illustrates one of the fundamental problems associated with the design of operational monitoring programmes. On the one hand, there is a fear that large networks operating over decades will yield "curiosity" data and that the selected indicator chemical substances or biota will not be particularly useful for describing or predicting the total global environment. On the other hand, there is a fear that if monitoring is not begun at once, valuable information on trends (and data for testing models) will be lost. In the latter case, it is argued that the cost-benefit ratio may be attractive, even if only a small fraction of the observations prove to be useful.

Two strategies are possible, both of which should be explored.

a) Let the networks expand, for components where present knowledge justifies regional and global coverage and where feasibility of measurement has been demonstrated.

b) Undertake a few intensive pilot studies (as in the case of GARP), with a time limitation on the data-gathering phases, for components where present knowledge is inadequate.

In both cases, periodic assessments of the data are essential, in the light of improved models and changing environmental concerns. In this connection too, it is important to stress that sampling requirements are likely to change over the years due to improvements both in environmental models and in sampling technologies. An ultimate desirable goal is a reduction in the number of observations but during the learning process, frequent measurements in both space and time should be encouraged.

As a footnote, it is perhaps valuable to explain why the phenological data were not useful predictors. The timing of annually recurring events depends upon a large number of environmental factors, some averaged over the previous day or so, others averaged over a few weeks or months, making the interpretation of such data difficult.

4.3.2. The recent Literature on the Scientific Principles of Monitoring

There is a growing body of knowledge on monitoring principles, some of which is referenced in the annotated bibliography given in Appendix B. Inspection of the Appendix will reveal that most of the references refer to specific media, one exception being SCOPE 1 (SCOPE, 1971), which includes important discussions of the magnitude of the problem, and provides some general scientific principles for the design of monitoring systems. Admittedly SCOPE 1 contained inadequate proposals for monitoring *biological* systems, largely because the biologists had not reached a consensus. The same was true for the monitoring of sociological and economic indicators of the health of the environment. Nevertheless, SCOPE 1 provides a useful departure point for further discussions of monitoring systems. In a recent Canadian report (Environment Canada, 1973) the recommendations of a Workshop on a small (but

interdisciplinary) segment of biology, namely aerobiology, are given. Member States can make useful conceptual contributions to GEMS by organizing similar workshops on specific monitoring activities.*

4.3.3. Monitoring and Modelling

In order to predict, a conceptual model for an environmental system must be formulated and verified with experimental data. The initial model is usually crude but it suggests data gaps and becomes more refined through successive approximations. GEMS is likely to develop in this way. The data requirements will, of course, change with time. Experience may reveal, for example, that two monitoring stations are sometimes yielding duplicate information. In other cases, it may be found that several substances behave in similar ways in their travel through the biosphere, so that only one of them requires intensive monitoring.

The simplest approach often is a "box" model, in which the mass budget of a pollutant is used, requiring estimates of the input, storage and output rates from a medium such as the atmosphere. The USSR proposal for a monitoring system for pollution in the world's oceans (IOC, 1973) illustrates the principle and shows how such a model is invaluable in prescribing the general framework of the monitoring network. Several boxes may be joined together conceptually to obtain an estimate of the rates at which substances are flowing along various pathways in the biosphere. Czeplak and Junge (1974) have recently examined inter-hemispheric exchange of pollutants in the troposphere. They have found that a simple 2-box model yields predictions that are in reasonable agreement with those obtained from a more complicated diffusion equation. For very complex systems, however, the possibility of feedback mechanisms (so-called *non-linear interactions*) increases and there may be unexpected amplification or damping of physical and biological processes. As a simple physical example, suppose that through a combination of rare events, there is an unusually cold spell in the arctic winter, causing ice to form over a part of the polar seas that is normally open. Then there will be less cloudiness (because the oceanic moisture supply is cut off), resulting in increased surface radiative heat losses, and producing a tendency for the ice to perpetuate itself and in fact to expand outward. There will, of course, be a number of factors that will ultimately prevent a runaway situation but nevertheless, the positive feedback mechanism may be of at least temporary significance. In some other examples, environment changes may be virtually irreversible (e.g., cutting a forest-clearing in temperate latitudes, producing a frost pocket and thus preventing regeneration).

Feedback mechanisms in ecological systems have not been studied extensively as yet. Glover *et al.* (1972) have emphasized, however,

* Recommendations for monitoring tropospheric aerosols have been made at a recent Seminar held at the University of Stockholm (Charlson, 1973).

that sublethal concentrations of pollutants in the sea "may give rise to subtle effects in natural eco-systems which are exposed to them over long periods of time. Moreover, pollution at a sublethal level may interact with 'normal' natural stresses and so create effects which are out of all proportion to the component risks". "In dramatic pollution incidents as well as the long-term accumulation of 'trace-pollutants', there is a possibility that populations and communities which are not themselves exposed to pollution may be affected by disturbance of the ecosystem".

A perceptive contribution to the principles of monitoring is contained in an IAEA document (IAEA, 1965) concerning marine radioactivity. A distinction is drawn there between the monitoring approaches required to meet two different objectives:

- a) to define the state of the environment, and thus to provide a basis for predicting its future state,
- b) to determine whether there is a present risk to man's health and welfare.

The network designs may be quite different in the two cases. This may be illustrated by considering urban air pollution monitoring. If the objective is to ensure that standards are met, the samplers should be located where concentrations are likely to be highest (subject, of course, to the criterion that receptors spend a significant number of hours per day in the vicinity of these sites). If the objective is to predict future trends over the entire city, using multiple-source simulation models, the network design must take account of the main topographic and meteorological features. For regional land-use planning, particularly with respect to siting new industry, a network designed to monitor only the highest concentrations will be of little value.

A related topic concerns monitoring of a few substances that have no impact on man's health and welfare but have one of the following properties:

- a) They are useful tracers of pathways through the biosphere.
- b) They are almost entirely produced by man and therefore are useful indicators. A prime candidate for consideration is fluorocarbon 11 (CCL_2F), which is released from aerosol dispensers, fire extinguishers, refrigerant fluids and anaesthetics (Lovelock et al., 1973). Monitoring of fluorocarbon 11 cannot be justified in terms of toxicity because the substance has no known effects at concentrations six orders of magnitude greater than the present level 10^{-10} by volume).^{*} Yet routine monitoring would be invaluable because most of the priority pollutants have very large naturally occurring global sources, making it difficult to isolate and follow the man-made components (except near populated areas, where the latter predominate).

^{*} Because the gas is an intense infrared absorber in the 8-13 nanometer region, a future rise in concentrations to above 10^{-9} by volume might be of concern in discussions of climatic change.

Finally, the point should be made that an interdisciplinary environmental monitoring system must meet the needs of all possible sectorial users. In addition, it must not be tied too closely to a particular model of the biosphere. An existing model may not require that certain elements or indicators be monitored with more than order-of-magnitude accuracy. A problem will almost invariably arise later, in that the data sets may be used for entirely different purposes than was intended initially. Thus the need for high-quality observations cannot be stressed too strongly. The meteorological and oceanographic communities have a long tradition in quality control and storage of physical data; the biologists have only recently realized the importance of preserving their observations in data banks (in comparable form) for the use of investigators several decades later. In this connection, the view is still expressed occasionally that there is no need for organized data-collection systems, that the results are available in the scientific literature. This overlooks the recent publication explosion, which makes it difficult for even a specialist to locate critical data, or to evaluate their accuracy. The International Referral Service will assist substantially but the scientific community still has a clear need for certain types of data banks and regular data publications.

4.3.4. Classification of Monitoring Sites According to the Degree of Human Impact

It is valuable to designate monitoring sites or areas as *remote*, *intermediate* and *impact* (SCOPE, 1971; WMO, 1971). In the *remote* category, the WMO criteria for a *baseline* air chemistry station (WMO, 1971) are as follows:

1. The station should be located in an area where no significant changes in land-use practices are anticipated for at least 50 years within 100 km in all directions from the station.
2. It should be located away from major population centres, major highways and air routes, preferably on small isolated islands or on mountains above the tree line.
3. The site should experience only infrequent effects from local natural phenomena such as volcanic activity, forest fires, dust and sand storms.
4. The observing staff should be small in order to minimize the contamination of the local environment by their presence and their living requirements.
5. All requirements for heating, cooking, etc., should be met by electrical power generated away from the site.
6. Access to the station should be limited to those whose presence is necessary to the operation of the station. Surface transportation should be by electrically powered vehicle, if at all possible.

Ideally, although this is hardly possible yet, baseline stations should be fully automatic with remote interrogation.

The suggestion has been made that before selecting a baseline location pilot studies should be undertaken at two adjacent sites (about a kilometre apart). If the measured values at the two sites are highly correlated, then the area may indeed be suitable for baseline measurements. This is not to suggest that the values will not vary from day to day or month to month; the important criterion is that the time sequences at the two sites are in phase, demonstrating that the cycles or trends are on the large scale. It should be noted, however, that this is a *necessary* but not a *sufficient* condition for a baseline location. For example, two adjacent sites downwind of a large swamp could certainly not be used to estimate the world background levels of methane, although concentrations measured at the two stations might be highly correlated.

The discussion in the previous paragraph introduces a question of some importance. Is the objective of baseline monitoring to determine background levels of various environmental substances and indicators, or merely to determine secular trends? In the latter case, the siting criteria need not always be so restrictive. As an example, the pH of lakes varies widely from lake to lake, even in remote areas. However, measurements in one or two adjacent lakes may yield valuable information of regional secular trends in acidity.

The WMO baseline program was designed for studies of climatic change. The sites may therefore not always be suitable for biological or resource monitoring, and other stations will undoubtedly be required. UNESCO (IHD and MAB) can play a useful role here in the selection of stations. In fact, the possibility of using a few of the IBP *ecological reserves* and/or IHD benchmark basins and decade glacier stations should not be overlooked. A guiding principle in the formulation of criteria for siting biological baseline stations is that the WMO criteria should be accepted, if at all possible, with additional restrictions as appropriate.

The point of view has sometimes been advanced that there is no point in monitoring insignificant concentrations of even potentially harmful substances at remote stations. This philosophy is not always valid, however, because threshold concentrations that cause biological effects are not absolutes. In many parts of the world, biological systems are in delicate equilibrium with their natural environments through the process of adaptation. Minute increases in the concentrations of particular substances may have significant effects, particularly if there are accumulating organisms in the food chains. Acid rains provide essential nutrients to lakes and forests in many areas; in podsol regions where the soils and lakes are naturally acidic, however, precipitation scavenging of small amounts of industrial pollutants may seriously disturb the natural equilibrium. In this connection, the point should be made that many so-called *pollutants* are plant foods when found in moderation. In some parts of the world, natural deficiencies in these substances (e.g., nitrogen compounds in the arctic) may be growth-limiting. A case may therefore be made for monitoring what might be called *negative pollution* at remote

stations. Cowling *et al.* (1973), for example, have found that when ryegrass is grown in sulfur-deficient soil in laboratory cabinets, the yield is increased when the airflow contains a modest amount of SO_2 (0.05 ppm by volume in this particular experiment).

Another justification for measuring on the global scale is in connection with trends and cycles. In the first place, there is likely to be less day-to-day variability at remote stations, so that long-term trends and seasonal cycles are easier to detect. Secondly, a network limited to a single region does not permit separation of regional from global effects. This separation is of particular importance if the trends are due to natural geochemical phenomena. If, for example, it can be demonstrated that an environmental trend in the North Atlantic Ocean is the same as in the North Pacific, the search for causes will turn to the global scale. Useful additional information will be provided by a knowledge of conditions in the Southern Hemisphere. For example, if an annual cycle in the incidence of certain health effects in the Northern Hemisphere is supposed to be related to the annual climatic cycle, a critical test of the theory could be made by gathering similar data in the Southern Hemisphere (where the cycle should be reversed if the hypothesis is correct).

The criteria for a WMO *regional* station are not so stringent as those listed above. The regional site "should be located sufficiently far away from built-up areas so as not to be dominated by fluctuations in pollution from local sources. The minimum distance of a site from the nearest pollution sources depends on the intensity of the sources. For large sources like fossil-fueled power stations, this distance might need to be as much as 60 km; for smaller sources, the distance can be less". Regional stations will normally be sited at agricultural or forestry research stations, or in some cases in IHD representatives and benchmark basins and IBP ecological reserves. In any event, the site should permit *representative* measurements to be made of elements or indicators, i.e., representative of the regional scale, with some assurance that there will be no major changes in land use during the next 50 years. The selection of sites will of course be difficult, often requiring pilot studies.

Finally, there are the *impact* stations, located in cities, polluted lakes and estuaries, for example. Monitoring at these places has the primary objective of measuring the amounts of pollutants to which receptors are exposed, for the purposes of (a), research investigations of effects or (b), pollution control. The sampling problem is most difficult here because of the great variability in space and time, and because of gaps in ecotoxicological knowledge, due in part to the presence of synergistic effects and biological adaptation. For most impact situations, the siting criteria have not yet been adequately defined, and there is a need for expert committees and pilot studies (see Section 4.3.7).

Certain monitoring activities may not fit within the WMO frame-

work of baseline and regional stations. As a first example, concentrations of some potentially toxic substances may sometimes be higher in rural settings than in cities. The quality of drinking water and food supplies may be more uncertain in the countryside, while concentrations of pesticides and fertilizers in all media may be relatively high.

A second difficulty arises because certain kinds of monitoring data are collected as broad space and/or time averages. Examples include epidemiological statistics (averaged over the life history of the respondents, and therefore representing exposures in various settings—home and work environments, countryside, etc.), indicators of species diversity, and observations obtained from remote sensors, which have only finite space resolutions. For lichen sampling, a 50-km transit may sometimes be necessary to obtain a representative value, depending on the spatial variability and on the purposes of monitoring.

A third difficulty is institutional in character. Some of the Specialized Agencies have already defined particular words in particular ways: to change the terminology would undoubtedly lead to confusion amongst Member States. For example, UNESCO-IHD has identified five types of hydrologic monitoring areas or stations:

a) *Representative basins* are basins which are selected as representative of a hydrological region, climate or environment. They are used for intensive investigations of specific problems of the hydrologic cycle (or parts thereof) under relatively stable, natural conditions. Data collected on these basins can be extrapolated and put to practical use in other regions of similar types, for which little hydrologic data are available. Because the research objectives of most representative basin studies involve the measurement of hydrological processes in relatively undisturbed environments, such basins present an excellent opportunity for monitoring the hydrological response to natural environmental changes.

b) *Experimental basins* are basins which are relatively homogeneous in soil and vegetation and which have uniform physical characteristics. On such basins, the natural conditions, i.e., one or more of the basin characteristics, are deliberately modified and the effects of these modifications on the hydrologic characteristics are studied. This general objective makes it imperative that the research organization has the right to manipulate the land at will. Because more detailed studies are required on experimental basins than on representative basins, and also because of the necessity of owning or leasing experimental basins, these basins are normally restricted in size to a maximum of about 4 km².

c) *Benchmark basins* are representative basins which are still in their natural state and which have soil and vegetation conditions which are not expected to change for a long time. They provide data on hydrologic parameters for places representing various environments protected from the effects of man's activities.

d) *Vigil basins* are located where observations can be made over long periods of time to record changes in landscape features. Sites are

selected to represent typical environments that will be affected by nearby cultural influences. Vigil stations differ from benchmark stations in that the latter are located in areas protected from man's influences. Types of data collected at Vigil stations vary and the same observations are not necessarily made or recorded at every site. In effect, each Vigil station could be the site for different specialized investigations.

e) *A Decade Glacier station* is a specialized form of hydrologic benchmark, which has been selected to provide data on ice and water balances, combined heat, and glacier fluctuations as related to meteorological processes on local, regional and global scales.

As another example of a special use of terms, marine scientists employ the word *baseline* to mean a pilot study, an initial survey of a polluted estuary or enclosed sea, to determine the extent of human impact on water quality and marine biota.

In view of these very real difficulties in terminology, the following rather general phrases are adopted in this report:

Remote stations and areas—to be interpreted in the sense of the WMO *baseline* stations;

Intermediate stations and areas—to be interpreted in the sense of a rural or forest environment; (Note that a specific location may be suitable for studies of climatic change but not for monitoring the effects of pesticides and herbicides.)

Impact stations and areas—to be associated primarily with toxicological studies.

Special note is to be taken of the fact that there will not always be a one-to-one relation between GEMS siting criteria and those developed for other purposes. For example, there will be a need for careful examination of all types of UNESCO-IHD hydrologic basins to determine the ones that are suitable for monitoring water quality, noting the fact the original IHD siting criteria were developed for investigations of the hydrologic cycle.

4.3.5. Time and Space Network Resolution

A factor of importance in predicting environmental changes is the time and space resolution of monitoring networks. In studying effects on living organisms, an averaging time of a year or longer for pollutant concentrations may sometimes be desirable. Particularly in impact situations, however, the most appropriate averaging times may be as small as a few days to a few minutes. Human respiratory ailments may worsen after a few hours of exposure to an air pollution episode while plant injury may occur almost instantaneously if concentrations are sufficiently high.

These considerations are important in physical as well as biological systems. For example, mean values of the meteorological elements averaged over the globe and over a year are not very useful predictors of climatic change; much of the essential information has been lost in

the averaging process, the relevant time scale for simulation models being six hours. Finally, an example from the field of food monitoring will illustrate a related point. Chemical analysis of bulk samples of the total diet of a human population will provide information on secular trends in the uptake of various substances and will yield useful data for epidemiological analysis; however, because diets change over decades, and food distribution is related to world trade patterns, which also change over decades, trends in the chemical composition of total diets will be difficult to interpret. In the latter case, it would be preferable to monitor individual foods separately.

To summarize, the choice of an averaging time or of a network density immediately prescribes to a certain extent the resolution of the effects that can be usefully examined. In this connection, it should be noted that many data publications are merely summaries (containing mean values and perhaps also frequency distributions) that have been designed to meet the needs of particular users. For multidisciplinary assessments, however, the original observations must be readily retrievable upon request from data banks.

4.3.6. Complementary Monitoring Activities

In order to interpret cause-effect relations and to predict, a number of associated elements and indicators must be monitored. For example, there have been changes in fish populations and perhaps also in water quality in the Gulf of St. Lawrence over the last several decades. It seems, however, that a major contributing factor has been the increasing control of the tributaries flowing into the St. Lawrence River, through hydro-electric power generation. This has been reducing the range of the annual cycle of freshwater outflow into the Gulf. Because the freshwater outflow induces an underlying salt-water inflow, the physical and biological properties of the Gulf have changed. A simple analysis of fish population indicators versus water quality would therefore be misleading.

Many similar examples will come to mind but suffice it to say here that the relevant environmental indicators should be monitored. In an unpublished document (FAO, 1971), the point is rightly made that "monitoring on specific aspects of the environment such as soil degradation, water pollution, etc., carried out by random spot checking may prove difficult to interpret and lead to false conclusions unless the findings can be reviewed in the light of the nature, distribution and inter-relationship of natural resources and environmental factors obtained from basic monitoring, surveys and research".

4.3.7. Expert Committees and Pilot Studies

Expert Committees are very useful in recommending methodologies and procedures to be adopted inter-governmentally, in assigning priorities,

and in bringing scientific problems into focus. However, Expert Committees rarely solve problems. There is often a need, therefore, for pilot studies, some of which can be undertaken in an individual laboratory but others requiring large field programs and international cooperation.

The scientific literature on monitoring is consistent in its philosophy that pilot studies must precede routine monitoring. The space and time variabilities of environmental indicators must be determined as a prerequisite for rational network design. In this connection, a number of pilot studies are in progress or are planned; in the marine environment, for example, there are the experimental studies of the Baltic, the Mediterranean and the Gulf of Mexico. In the field of community health, the CHESS studies in the United States are another example.

There are a number of ways in which GEMS and the Specialized Agencies can help in the promotion of pilot studies, through coordination, the provision of technical experts, training, funding for equipment, etc. However, the role that Member States can play should not be overlooked, and they should be invited to undertake pilot studies in areas of their own special competence.

4.4. OPERATIONAL PRINCIPLES

Mention should be made of a number of operational principles whose relevance is so obvious that little comment is required.

a) Comparable sampling techniques should be agreed upon internationally. The recommended methods, siting criteria, units of measurement, etc., should be published in manuals.

b) Periodic inter-calibrations are required, and reference standards or samples will be necessary in some cases.

c) Data banks should be compatible but there is no need for a single world environmental data centre. There are many mechanisms for storing observations, and each Specialized Agency will have its own preferred mode of operation. The important consideration is that a detailed and up-to-date inventory of data banks be maintained by GEMS, or its delegated authority.

d) There is an evident requirement for quality control. Even in the most competent research laboratories, arithmetic mistakes may occur when measurements are made repetitively.

e) Deadlines for submission of data should be recommended, and reporting forms should be standardized.

f) Physiogeographic descriptions (and photographs) of each monitoring site should be prepared and regularly updated.

g) Station log-books should be maintained, including complete documentation on instruments, calibrations, dates of power failures, occurrences of unusual natural or man-made phenomena, etc.

h) Because of the increasing mobility of man (with aeroplanes, snow-mobiles, etc.), remote sites are becoming more and more accessible.

Attempts should therefore be made to develop indicators of temporary breaks in the fidelity of the observations because of campfires, snowmobiles or other compromising conditions. In the case of the WMO baseline stations, Aitken nuclei counters might be useful detectors of human intrusions.

i) Over decades, there will be changes and improvements in monitoring techniques. The need is obvious for at least one year of overlapping records whenever a new type of instrument is introduced.

j) The initial data obtained at each site should be analysed statistically to determine the variability of the signal, the objective being to optimize sampling frequencies. At the outset, therefore, a continuous signal should be recorded if at all feasible. Similarly, data from groups of stations should be analyzed statistically to determine spatial variability. The calculation of spatial correlation coefficients will be useful here in optimizing network densities and in the discovery of local anomalies.

4.5. THE SYSTEMS APPROACH TO MONITORING AND ASSESSMENT

The biosphere is often subdivided for convenience into components such as the atmosphere, the oceans and the continents. Ultimately, however, models of each medium must be coupled in order to undertake simulations of the total system. In this connection, an important distinction should be drawn between those media (e.g., oceans and atmosphere) that diffuse and dilute, and those media (e.g., food chains) that concentrate. Because the characteristic time scales are quite different, the linkages between the two types of media are difficult to specify in any practical way.

Simulation models are required to meet one of the objectives of Earthwatch—the development of alternate environmental management strategies. To replace an air pollution problem by a water pollution problem is no solution.

Multidisciplinary simulations are also essential tools in many scientific investigations: the problem of climatic change, for example, requires models of the linkages between the atmosphere and the biosphere, the oceans and the ice-covered regions of the world.

In view of the above, it is evident that GEMS should be designed in such a way that interactions between media can be studied, permitting delineation of the pathways of biogeochemical cycling. Here the approach developed by UNSCEAR (e.g., UNSCEAR, 1972) for ionizing radiation is commendable.

The Sections to follow are organized according to media rather than substance, at the suggestion of the Inter-Agency W/G on Monitoring. In Appendix D, however, each of the priority pollutants is discussed separately, and some indication of pathways through the biosphere is given.

The action Plan takes note, in a qualitative sense at least, of the need to design a total system. Some gaps are unavoidable, however, for at least two reasons:

a) Physical understanding of global biosphere processes is limited by a lack of suitable data. GEMS should include a feedback capability to adapt its network design in response to the data it generates. Charlson (1973) has suggested that 'institutionalized measurement programs often result in a freezing of methodologies' and he implies that this may ultimately lead to a network that is not in tune with current knowledge of the biosphere. Such a tendency should be resisted in the case of GEMS.

b) The feasibility of monitoring interface flux rates has not yet been demonstrated in many instances. The transfer of pollutants across the air-sea boundary is an example. It is therefore not yet possible to design a global monitoring system that includes the data required for even existing models of the biosphere.