Water quality monitoring: national and international approaches

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INTRODUCTION

Global water quality issues

Freshwater is a finite resource, essential for agriculture, industry and human existence itself. Without freshwater of adequate quantity and quality, sustainable development will not be possible. Water pollution and wasteful use of freshwater are threatening development projects, making water treatment an indispensable requirement to produce safe drinking-water. Discharge of toxic chemical wastes, over-pumping of aquifers, long-range atmospheric transport of pollutants and enrichment of nutrients are some of today's major causes of water quality degradation. As early as the beginning of the 1970s it became obvious that the world's water resources could not be conserved and protected for future development without effective global monitoring programmes.

The first global assessment report on freshwater quality, prepared under the present programme, unequivocally demonstrated that water of good quality is a crucial key to sustainable socio-economic development. Aquatic ecosystems are threatened on a world-wide scale by a variety of pollutants and destructive land-use practices. Some problems have been prevalent for a long time but have only recently reached a critical level, whereas others are newly emerging issues which affect water resources on a continental or even global scale (Meybeck et al., 1989).

Gross organic pollution leads to disturbance of the oxygen balance and is often accompanied by severe pathogenic contamination. Accelerated eutrophication results from nutrient enrichment from various origins, particularly domestic sewage, agricultural runoff and agro-industrial effluents. Lakes and river impoundments are primarily affected.

Agricultural land use, without environmental safeguards to prevent over-application of agro-chemicals, is causing widespread deterioration of the water-soil ecosystem as well as the underlying aquifers. The main problems are salinization, nitrate enrichment, pesticide contamination and erosion. Irrigation has enlarged the land available for crop production but has also led to substantive losses of soils deteriorated by salinization.

Metal contamination due to direct discharges from mining, smelting and industrial manufacturing is a long-standing phenomenon. Only recently have the emissions of metallic air pollutants reached such proportions that long-range atmospheric transport causes contamination not only near industrialized regions but also in rather remote areas. Acid precipitation, emitted from fossil-fuel burning and transported via the atmosphere, has caused acidification of lakes and other surface waters. Contamination by synthetic organic micropollutants is a more recent phenomenon, but results from
both direct discharges and atmospheric transport. Today, trace contamination is not only found in surface waters but has reached groundwater bodies due to leachates from waste dumps, mine tailing disposals and industrial production sites.

The magnitude of anthropogenic activities influencing the environment has increased dramatically during the last few decades and has affected terrestrial ecosystems, the freshwater and marine environment, and the atmosphere. Large-scale mining and fossil fuel burning have started to interfere measurably with natural hydrogeochemical cycles resulting in a new generation of environmental problems. The scale of socio-economic activities such as urbanization, industrial operations and agricultural production, has reached a level where they interfere not only with natural processes within the same watershed, but also have a world-wide impact on water resources. As a result, very complex interrelations between socio-economic factors and natural hydrological and ecological conditions have emerged.

As a consequence of these developments, a general need has emerged for a comprehensive and accurate assessment of trends in water quality, world-wide, to raise awareness of the urgency of contamination threats, and to provide a rational basis for international action. Reliable monitoring data are the indispensable basis for such assessments.

**Needs for measuring water quality**

Any water quality management programme requires information on the existing water quality, the influence of man's activities on water quality and criteria for the present and planned uses. In many instances, this information can be generated only from a record of long-term water quality data and past experience of water use of known quality. Further, in order to endorse the laws developed on the basis of the above information and to evaluate the effectiveness of the management programme, water quality measurements become necessary. Many reasons can be listed for carrying out water quality measurement programmes. Their scope, in many instances, will overlap and the information obtained in one may be useful for another. The information obtained in these programmes will be useful for water resources management of the country, but may also contribute to international environmental quality measurement programmes. Where water bodies are shared by more than one country, a water quality measurement programme can yield information which may serve as a basis for international agreements regarding water use, as well as provide a basis for evaluating compliance with any of these agreements.

Water resources management requires that reliable information on water quality be collected, analysed and evaluated in a timely and efficient manner. Specifications regarding collection of data should be uniform to ensure compatibility and make it possible to apply experience gained at one place to another. Networks for water quality measurements need to be developed in close cooperation with water data-collection agencies and wherever possible they should be in conformity with the hydrometric network in that area. This will not only minimize the cost of establishing and operating the network but will also make the water quality data readily interpretable. The amount of data required for hydrological measurements and water characteristics will differ from one water resource to another. For example, velocity of flow and intensity of longitudinal mixing are important factors to assess in streams,
whereas evaporation and thermal regimes are important factors to assess in lakes. The discharges of low nutrient concentrations in rivers are less important to assess than the same discharges to lakes because lakes trap nutrients and in time may collect enough nutrients to cause eutrophication.

Networks for water quality measurement must also conform to the objectives of the programme. A clear statement of objectives is therefore necessary. This will ensure collection of all necessary data and avoid needless and wasteful expenditure in time, effort and money. Furthermore, evaluation of the data collected will provide a basis for judging the extent to which programme objectives were achieved and thus justify the undertaking. Other aspects which should be clearly delineated before commencement of observations include establishing siting criteria for the location of sampling stations, determining the frequency of sampling and the water quality variables to be determined. Analytical procedures for measurement of most water quality and hydrometric parameters have been developed and are readily available in standard reference manuals. In addition, the design and operation of water quality monitoring programmes is available in textbooks, manuals and guideline documents. Some of the most important ones are referred to in this paper.

DEVELOPMENT OF WATER QUALITY MONITORING

Definitions

The main reason for the assessment of the quality of the aquatic environment has been, traditionally, the need to verify whether the observed water quality is suitable for intended uses. The monitoring has also evolved to determine trends in the quality of the aquatic environment and to determine how the environment is affected by the release of contaminants, land use and other anthropogenic activities such as waste treatment and effluent discharges. Another important aspect of monitoring is to establish the background quality of the aquatic environment to provide a means of assessing environmental impacts. General definitions for various types of environmental observations have been proposed which may be applied to the aquatic environment as given in Table 1.

<table>
<thead>
<tr>
<th>Water quality assessment operation</th>
<th>Definition</th>
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<tr>
<td>Monitoring</td>
<td>Long-term, standardised measurement, observation, evaluation and reporting of the aquatic environment in order to define status and trends.</td>
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<tr>
<td>Survey</td>
<td>A finite duration, intensive programme to measure, evaluate and report the quality of the aquatic environment for a specific purpose.</td>
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<tr>
<td>Surveillance</td>
<td>Continuous, specific measurement, observation and reporting for the purpose of water quality management and operational activities.</td>
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Monitoring, survey and surveillance are all based on data collection, evaluation and reporting. Data are principally collected at given geographical locations in the water body, often described by the longitude and latitude of the sampling or measurement site, and further characterized by the depth or discharge at which the sample is taken. Monitoring data must also be characterized and recorded with regard to the time at which the sample is taken or the \textit{in situ} measurement made. Thus any physical, chemical or biological variables will be measured as a concentration, or number, which is a function of these parameters. In rivers, flux determination and detailed data interpretation also require knowledge of water discharge. Monitoring data, therefore, must provide an unequivocal determination of these parameters if they are to be used for data interpretation and water quality assessments.

\section*{Objectives of monitoring and assessment}

No assessment programme should be started without critically scrutinizing the real needs for water quality information. Since water resources are usually put to several competing beneficial uses, monitoring should reflect the data needs of the various water users involved. Consequently, there are two different types of monitoring programmes: single-objective monitoring which may be set up to address one problem only; or multi-objective monitoring which may cover various water uses such as drinking-water supply, industrial manufacturing, fisheries or aquatic life. The process of determining objectives should start with an in-depth investigation of all factors and activities which exert an influence, directly or indirectly, on water quality.

The implementation of the assessment programme objectives may focus on the spatial distribution of quality, temporal trends, or specific pollutants. Full coverage of all three requirements is virtually impossible, or very costly. Consequently, preliminary surveys are necessary to focus the operational programme. Table 2 summarizes the existing types of water quality assessments in relation to their main objectives.

\section*{Design of water quality monitoring systems}

Water quality networks developed thus far have evolved more on the basis of need rather than any predetermined scientific criteria, and have been essentially use oriented. There are, however, certain crucially important components in any national or international monitoring programme. The major aspects of these components are summarized in Table 3.

Monitoring of water quality can be accomplished in two ways: one approach is the operation of a vast network of strategically located long-term observation stations and a second approach is the repeated operation short-term surveys, each providing limited spatial coverage. In either case, the location of stations or sampling sites should account for the following factors:
- existing problems and conditions;
- potential growth centres (industrial and municipal);
- population trends;
- climate, geography and geology;
Table 2 Objectives and aims of water quality assessments (Meybeck et al., 1992).

<table>
<thead>
<tr>
<th>Type of assessment</th>
<th>Major focus of water quality assessment</th>
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<td><strong>Common assessments</strong></td>
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<tr>
<td>1. Multipurpose monitoring</td>
<td>Space and time distribution of water quality in general</td>
</tr>
<tr>
<td>2. Trend monitoring</td>
<td>Long-term evolution of pollution (concentrations and loads)</td>
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<tr>
<td>3. Basic survey</td>
<td>Identification and location of major survey problems and their spatial distribution</td>
</tr>
<tr>
<td>4. Operational surveillance</td>
<td>Water quality for specific uses and related water quality descriptors (variables)</td>
</tr>
<tr>
<td><strong>Occasional assessments</strong></td>
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<tr>
<td>5. Background monitoring</td>
<td>Background levels for studying natural processes; used as reference point for pollution and impact assessments</td>
</tr>
<tr>
<td>6. Preliminary surveys</td>
<td>Inventory of pollutants and their space and time variability prior to monitoring programme design</td>
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<tr>
<td>7. Emergency surveys</td>
<td>Rapid inventory and analysis of pollutants, rapid situation assessment following a catastrophic event</td>
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<tr>
<td>8. Impact surveys</td>
<td>Sampling limited in time and space, generally focusing on few variables, near pollution sources</td>
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<tr>
<td>9. Modelling surveys</td>
<td>Intensive water quality assessment limited in time and space and choice of variables, for example, eutrophication models or oxygen balance models</td>
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<tr>
<td>10. Early warning surveillance</td>
<td>At critical water use locations such as major drinking-water intakes or fisheries; continuous and sensitive measurements</td>
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- accessibility of station locations;
- available manpower, funding and laboratory facilities;
- degree of interjurisdictional cooperation.

The aim should be to cover the water resource with a minimum-density observation network to ensure no serious deficiency occurs in managing the water resource and interpreting the data.

Sampling frequency depends on the variability of the data. Therefore, knowledge of the variability in the variables of interest is necessary. Initially, a rather arbitrary frequency must be set which is later adjusted according to a statistical evaluation of the data. Sampling frequency is also influenced by the relative importance of the station for water management and the seasonal changes that can affect water quality causing variables to approach and exceed critical levels.

The water quality variables selected for a station will be determined largely by the water quality measurement objectives. However, to minimize costs of operation, the selection may be based on known characteristics of the water resource, and that of the polluting sources. Furthermore, samples may not always need to be analysed for all selected variables. Variables can be chosen based on their relative importance and analytical cost. However, analytical procedures must be standardized and adhered to by all laboratories participating in the monitoring programme.
Table 3 Activities of a water-quality monitoring programme (WMO, 1988).

<table>
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<tr>
<th>Monitoring objectives</th>
<th>Data handling</th>
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<tr>
<td>— legislation</td>
<td>— data reception (a) laboratory and (b) outside sources</td>
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<td>— mandate</td>
<td>— screening and verification</td>
</tr>
<tr>
<td>— resources</td>
<td>— storage and retrieval</td>
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<td>— programmes</td>
<td>— reporting</td>
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<td>— programmes</td>
<td>— dissemination</td>
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<th>Network design</th>
<th>Data analysis</th>
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<td>— station location</td>
<td>— basic summary statistics</td>
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<td>— parameter selection</td>
<td>— regression analysis</td>
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<tr>
<td>— sampling frequency</td>
<td>— water quality indices</td>
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<tr>
<td>— sampling frequency</td>
<td>— quality assurance and quality control interpretation</td>
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<td></td>
<td>— time-series analyses</td>
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<td>— water quality models</td>
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<tr>
<th>Sampling frequency</th>
<th>Information utilization</th>
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</thead>
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<tr>
<td>— sampling techniques</td>
<td>— obtain other data and information, e.g. land use, water use, socioeconomic data, and aquatic life – past, present and planned</td>
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<tr>
<td>— sample preservation</td>
<td>— water quality objectives</td>
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<tr>
<td>— sampling point</td>
<td>— impact assessment</td>
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<td>— sample transport</td>
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<th>Laboratory analysis</th>
<th>Decision making</th>
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<tr>
<td>— analysis techniques</td>
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<td>— operation procedures</td>
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<td>— quality control</td>
<td></td>
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<td>— data recording</td>
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The information collected in a water quality measurement programme should be recorded and stored for immediate and future use. The various steps in data handling are collection, processing, transfer, publication and storage. The raw data from a water quality measurement programme may be processed at a central location with respect to the network and then published so that it is readily available to users. In cases where a country has a water quality data bank or centre, it may be deposited there.

Monitoring of water quality is not an activity which stands alone, but is instead an important part of any comprehensive water quality management scheme. Water quality data will therefore be compared to criteria and standards, leading to water quality management decisions. Thus, the ultimate aim of monitoring is the assessment of water quality. The design of a monitoring programme should therefore start with the definition of the assessment task. For example, the activities listed in Table 3 should be designed by establishing requirements of the decision-making process and related information needs and then with this focus determine the monitoring objectives and design an appropriate data collection network.

THE GLOBAL APPROACH TO MONITORING

The Global Environment Monitoring System (GEMS)

GEMS is the collective effort to monitor the world environment to protect human
Water quality monitoring: national and international approaches

health and preserve essential natural resources. The coordination centre for GEMS was established within the United Nations Environment Programme (UNEP) in 1979, but the scope of GEMS extends beyond projects supported by UNEP. For more than 30 international monitoring projects implemented by UNEP, World Health Organization (WHO), World Meteorological Organization (WMO), United Nations Food and Agricultural Organization (UNFAO), United Nations Educational, Scientific and Cultural Organization (UNESCO) and other United Nations and inter-governmental organizations, national activities in countries worldwide are strengthened and united under the GEMS programme (Gosovic, 1992). The quality and comparability of data are stressed to provide useful input for environmental assessments. The monitoring includes climate, health, terrestrial natural resources, the oceans and long-range atmospheric transport of pollutants. The ultimate aim of GEMS is to support the rational management of the world environment.

Through several GEMS projects, WHO and UNEP have been actively involved in health-related monitoring of environmental quality for more than 15 years. This is being done by monitoring air and water quality, food contamination and human exposure to pollutants. One objective is to compile and analyse environmental quality data globally, and other objects are to improve and harmonize measurement methodologies among countries, increase the validity and accuracy of measurements, and support the development and strengthening of national programmes. During the past 15 years, achievements have been considerable in each of these areas.

Results of these monitoring projects are based on data supplied by participating countries. While the geographical coverage of monitoring is increasing, large areas of the globe still exist where information on environmental quality for global analysis is missing. It should also be appreciated that the number of measurement points is extremely limited, and that precise characterization of the pollution situation in individual rivers, cities or countries, or comparison among them, on the basis of these data alone is not possible. However, great care has been taken in selecting strategically located measurement points, harmonizing measurement methods and carrying out inter-laboratory quality assurance exercises to improve the validity of the global data base. The implementation of these global projects has been facilitated by the active support of national institutions. In fact, many technical functions of these projects have been carried out by national institutions. In each country, a national focus and participating institutions (laboratories) were designated. In addition, global responsibilities were assumed by collaborating centres such as the National Water Research Institute of Canada which provides a global water quality data bank for GEMS.

The Global Water Quality Monitoring Programme (GEMS/WATER)

The global programme on freshwater quality monitoring, commonly referred to as GEMS/WATER, was launched in December 1977 when a group of experts agreed on the scope and purpose of this activity. Bearing in mind the immediate data needs of countries for water quality management as well as the data requirements of the global scientific community, a joint programme was designed by four UN agencies: UNEP, WHO, WMO and UNESCO.

Monitoring stations were sited at points of water abstraction for public supply, in important fishing and recreational areas, at points of abstraction for agricultural uses,
at river confluences with one another and with lakes and oceans, and at international boundaries. When designating such stations, network design criteria were observed which account for a regional allocation of stations according to their natural water quality regime, effects of various human activities on water quality, description of representative geophysical and socio-economic regions, problems of international rivers and lakes, and the importance of extended aquifers for various uses. The global network was conceived to ultimately contain about 1,200 stations. The goal for the first phase was to establish a skeleton network containing from 300 to 400 monitoring sites (WMO, 1977).

Initially, GEMS/WATER was based its monitoring on the collection of about 50 descriptors of water quality. The descriptors included basic measurements such as dissolved oxygen, biochemical oxygen demand, faecal coliforms and nitrates, as well as analyses of chemical constituents such as major, minor and trace contaminants, heavy metals and toxic organic compounds. Analytical quality control exercises were conducted within-laboratory and among laboratories.

Monitoring methodology has been developed for network design, sampling and analytical procedures, and data processing. These methods were provided worldwide to water, health and environmental agencies for their water quality monitoring programmes. Several national water quality monitoring networks in developing countries were established according to the GEMS/WATER Operational Guide (WHO Collaborating Centre, 1992) of which three editions were issued and made available in more than 2000 copies in English, French and Spanish.

A standardized global network has been established for the first time in freshwater bodies, which covers not only surface, but also groundwaters. By 1990, about 450 stations were formally designated in 59 countries. Routine data submission has been achieved for 344 stations which include 240 river stations, 43 lake stations and 61 groundwater stations. Forty-two countries from all continents are actively participating and contributing to the global data bank which was established at the National Water Research Institute in Canada and contains more than 800,000 observations.

Training of national staff has been a prime concern of the programme. A total of 14 training courses, most lasting 2 weeks, have been organized in all continents and are presented in English, French and Spanish. These courses cover monitoring methodology and analytical quality control. To date, 269 trainees have attended these courses from national health and water authorities and participating laboratories in 56 countries.

Analytical quality control (AQC) was early recognized as a cornerstone of data reliability and comparability. Accordingly, a regular quality control programme was operated through the Environmental Monitoring Systems Laboratory (EMSL) of the US Environmental Protection Agency (USEPA). Quality control check samples were sent biannually to 250 laboratories worldwide and two inter-laboratory comparison studies were conducted (Britton, 1986; WHO, 1992).

Global assessment of freshwater quality was undertaken by the programme for the first time in 1987-1988 (UNEP & WHO, 1988). A condensed assessment report highlighting global issues and future monitoring needs was prepared by a group of scientists and reviewed by a governmental expert group in 1988 (WHO, 1988). A comprehensive publication appeared in late 1989 entitled "Global Freshwater Quality: A First Assessment" (Meybeck et al., 1989). In addition, a special assessment was conducted for rivers (Meybeck & Helmer, 1989).
A programme of global scope and diversity of participating institutions like GEMS/WATER is inevitably bound to experience some deficiencies. Furthermore, water quality management is rather heterogeneous on a global basis, with water use and environmental protection in most countries being guided by national interests and priorities. Critical evaluation led to the identification of major problem areas such as geographical coverage, limited analytical programmes, particularly in developing countries, and inadequate groundwater quality monitoring.

GEMS/WATER – PHASE TWO

Revised programme objectives

A group of experts convened in 1990 in St Petersburg (WHO, 1991) to review the GEMS/WATER programme design as it relates to emerging global priorities. They came to the conclusion that more emphasis should be placed on data interpretation and, in particular, assessments of water quality issues and trends. However, given the limited analytical capabilities of many developing countries, phasing out technical assistance to national monitoring efforts, especially for data quality control, was considered to be premature. Therefore, a set of long-term objectives were decided as follows:

1. To provide water quality assessments to governments, the scientific community and the public on the quality of the world’s freshwaters relative to human health, aquatic ecosystem health and other global environmental concerns; specifically to:
   (i) define the status of water quality;
   (ii) identify and quantify trends in water quality;
   (iii) define the causes of observed conditions and trends;
   (iv) identify the types of water quality problems that occur in specific geographical areas; and
   (v) provide the accumulated information and assessments in a form that resource management and regulatory agencies can use to evaluate management alternatives and make necessary decisions.

2. To provide to governments, the scientific community and the public information on the transport and, if necessary, assessments of the fluxes of toxic chemicals, nutrients and other pollutants from major river basins to the continent/ocean interfaces.

3. To strengthen national water quality monitoring networks in developing countries, including the improvement of analytical capabilities and data quality assurance. Achievement of the various assessment objectives requires the existence of an operational global monitoring network based upon national or regional programmes. The support rendered to national networks has two aspects: a global one to achieve data compatibility; and a country-specific one to upgrade the capabilities of participating laboratories.

The global monitoring network

Based upon the revised objectives of the programme, some monitoring stations were
modified and new ones identified in accordance with the purpose of the underlying assessments. Three aspects were to be measured: baseline, trends and global fluxes.

**Baseline monitoring stations** Such stations are to be located in areas where no direct sources of pollutants are likely to be found. Baseline stations should typically be placed in small, undisturbed basins without any direct human activity, including roads, and more than about 100 km away from major air pollution emission sources such as cities or industries. Headwater lakes, sampled at overturn periods and when biological activities are low, are most suitable to determine a representative natural baseline level using a limited number of samples. They should have a water residence time between 6 months and 2 years.

Baseline stations will be used not only to establish background levels for essential water quality indicators, but also to determine whether trace contaminants are reaching remote water bodies through atmospheric transport and deposition. The occurrence of synthetic organic substances (particularly those which are persistent) and gradually increasing levels of certain trace metals are prime indicators of such transport. To provide a set of representative baseline stations for comparative use, basins which include unusually high proportions of metal-bearing rocks should be avoided.

A total of 10 baseline stations was considered a bare minimum to start with, but the optimal number will be about 40-50, distributed over all continents. This number of baseline stations should provide GEMS/WATER with a sparse but reasonable coverage of the major climatic, hydrogeological and phytogeographic regions of the world.

**Trend monitoring stations** Trend stations are intended to represent human impacts on water quality and should, therefore, be located in medium-sized basins which respond in a moderate time frame to pollution influxes and changes in land-use. To provide a general overview of trends in water quality, most of the trend stations will be located in basins with a range of pollution-inducing activities. However, to determine the water quality impacts of specific and important types of human activities, a number of the trend stations should be located in basins with single, dominant activities. The network as a whole must, therefore, also cover all major human influences upon water quality. A careful selection of stations will allow trend and statistical cause-effect analyses to be performed and validated. The sampling frequency should be sufficiently high to permit detection of important long-term trends and major seasonal variations in both concentrations and loads.

Complementary to rivers are lakes and reservoirs with a moderate water residence time (1-3 years). Lake stations can be sampled at a far lower frequency than comparable river stations. River trend stations may sometimes coincide with global river flux stations and, thus, one station may serve dual monitoring purposes. Groundwater stations for the monitoring of toxic chemicals, salinization, nitrate increases etc. also fall under the category of trend stations.

The number of trend stations will need to be high to address the large number of water quality issues in the world. The appropriate number will be determined by the defined information needs for comprehensive assessments. The trend monitoring network will begin with about 100 stations, but will eventually expand to between 300 and 400 stations.
Global river flux monitoring stations

The ultimate purpose of this sub-programme in GEMS/WATER is to determine the fluxes of organic and inorganic trace contaminants, as well as of water constituents contributing to large-scale geochemical cycles, to the continent/ocean interfaces. The latter includes substances containing carbon, nitrogen, phosphorous and sulphur.

Candidate river basins must be selected by evaluating such factors as drainage area, population, major human activities and the relative significance of the river to the receiving coastal water. The river basin selection process must also consider the global geographical distribution so that major land masses, oceans and regional seas are adequately represented. It is estimated that a total of 60 to 70 river basins are needed to meet this objective.

Each basin selected for global river flux monitoring will be characterized by the most downstream station which is not influenced by tides. The station must be representative of the cross-sectional characteristics of the river. Chemical fluxes are primarily affected by discharge characteristics. Consequently, regime sampling is more effective than equal-interval sampling for estimating fluxes in most systems. Regime sampling also produces data which relate directly to runoff and particulate matter transport. Sampling and interpretive design should, therefore, incorporate an understanding of hydrological characteristics of the station and sample collection should be biased towards high discharge conditions. This is especially important for determining sediment-associated variables such as toxic pollutants and phosphorus.

Other monitoring programme components

Research has demonstrated that sampling the water only is ineffective for assessing the status or conditions for such water quality variables as trace metals, persistent trace organic compounds and nutrients. This fact will require a major change in how monitoring agencies conduct water quality assessment programmes and also poses a challenge to interagency cooperation at the national and international level to achieve a scientifically sound set of measurements. The methodological basis for expanding the monitoring process from water to biota and sediments was addressed by a group of experts brought together by UNESCO, WHO, UNEP and leading Russian institutes. An earlier guideline (UNESCO & WHO, 1978) was revised and the transition from emphasis on surveys and monitoring to comprehensive assessments was documented. The guidebook which resulted from this process (Chapman, 1992) also describes the application of assessment methods to various types of aquatic environments including rivers, lakes and groundwaters.

Suspended matter analysis

At moderate to high total suspended-solids concentrations, the suspended-sediment fraction is of primary importance in assessing the transport of nutrients and contaminants. Also for refractory substances, the sediment-associated concentration can be decisive for estimates of flux. Particulate matter analysis therefore is essential for global river flux monitoring stations. For trend monitoring stations, the incorporation of particulate matter analysis should be considered station-by-station, and the benefits from the particulate matter information should be weighed against the analytical costs.
Sampling and analysis of particulate matter requires definition of the size range of interest which, in turn, requires acceptable methods of physical separation. Based on input from the group of experts, GEMS/WATER defines the upper size limit of particulate matter to be \(< 63 \mu m\). The separation from a sample containing larger sized particles will be obtained by wet sieving. Further work is required to define a theoretically acceptable size breakpoint and a standardized method that provides this separation.

**Bottom sediment analysis** Bottom or deposited sediments can also be a useful matrix for assessing contamination. Here also, it is the smaller \(< 63 \mu m\) size fraction that is usually most relevant. Geochemical normalization techniques can be used for evaluating the extent of abnormality or contamination of the sedimentary material.

**Biological tissue analysis** It is generally recognized that a menu-driven approach to toxic chemical identification is always incomplete and provides little information concerning the ecological significance of the measured variables. Furthermore, exclusive use of the chemical-specific approach is very expensive. Therefore, inexpensive biological screening tools should be used, where possible and appropriate, to reduce the amount of chemical analyses and to provide information concerning both the biological condition of the water and ecological significance of the chemical data. Biological indicators can also be used for eutrophication, acidification and salinization.

For example, bivalve tissue analysis is a very cost-effective means of focusing monitoring programmes on relevant chemical variables. Because bivalves bioaccumulate toxic chemicals from the water column through time, they provide useful integrating information and reduce the necessity of frequent chemical sampling of the water phase.

Bioaccumulation data may be collected in two ways. First, organisms native to the water body may be collected and analysed for accumulated substances. Second, organisms may be artificially placed in the water body so that subsequent analysis will show the degree of accumulation within a known time period, for example caged fish.

**Ecological monitoring** Biotic indices are another use of biota in defining water quality conditions. The presence of indicator species or determination of diversity provides a comparison of quality over time within a water body. At the present state of knowledge, biotic indices cannot be used for comparing water quality in widely different environments. They are most useful in examining trends in water quality at individual stations.

**WATER QUANTITY MONITORING**

National hydrological services in most countries of the world have established networks of hydrometric stations for many purposes such as flood control, energy production, river navigation, and irrigation. Unfortunately, responsibilities for measuring water quantity and water quality are often housed in separate organizations. Moreover, different criteria exist for selecting optimal sampling stations for water quantity and quality. For gauging stations, a relatively stable river cross section is a prerequisite, and the sites are determined by hydrological requirements.
cases, gauging stations are unsuitable for water quality monitoring due to proximity to wastewater discharges or incomplete mixing of tributary flows. Consequently, a compromise has to be made, and the gauging station nearest the point of sampling is used. When revising the global network, each proposed water quality station will be evaluated with regard to the availability of discharge data.

It is a declared goal of GEMS/WATER to strive to integrate water quality and water quantity. Hydrological services responsible for discharge, flow and water-level monitoring have to further develop interest and, in the long run, capabilities to deal with water quality issues beyond the natural chemical composition of surface and groundwaters. WMO has taken the first step by compiling a manual on water quality monitoring (WMO, 1988), which was published under its Operational Hydrological Programme (OHP). The introduction of global river flux monitoring in GEMS/WATER mandates that the water quality measurements for this purpose are complemented by simultaneous instantaneous discharge measurement and, in some situations, sediment sampling. Long-term records of flow and sediment transport are also required for the assessment of a variety of other global water quality issues. A GEMS/WATER expert consultation provided relevant guidance (WMO, 1992a).

The collection of hydrological data for the rivers monitored for GEMS/WATER has been entrusted to the Global Runoff Data Centre (GRDC) at the Federal Institute of Hydrology, in Koblenz, Germany. Under the auspices of WMO, this centre collects flow data for the verification of global models of atmospheric circulation and for other international programmes.

**GLOBAL WATER QUALITY ASSESSMENTS**

The first global assessment (Meybeck et al., 1989) was followed by regional consultations and studies providing recommendations for water quality management in the 1990s. This report identified the priority of water quality issues regionally and provided a sectoral contribution to the review of progress achieved under the Mar del Plata Action Plan. These assessments provide a comprehensive global overview of major water quality problem areas including their geographical distribution and evolution with time. They also identified gaps in water quality information and defined needs for supplementary in-depth studies (WHO & UNEP, 1991).

Complementary to global assessments, the programme has started a sequence of regional water quality assessments. These will allow for a more in-depth analysis of water pollution issues and socio-economic developments with impacts on the aquatic environment. The assessments are to be summarized in a publication series which will accompany and expand on a world water quality atlas, which is in preparation at the National Water Research Institute in Canada. This atlas will summarize all of the monitoring data from phase one of GEMS/WATER and incorporate results from other studies and survey reports.

In addition, issue-specific reviews of important water quality problems will be published. Examples of likely topics are:
- baseline water quality,
- relation between water quality and water use,
- toxic contaminants in surface and groundwaters,
— historical records of surface water pollution,
— global nutrient fluxes,
— regional trends in groundwater salinization,
— new developments in bio-monitoring techniques,
— quality assurance and data validity,
— application of information.


LINKAGES WITH OTHER PROGRAMMES

Over the past decade, a variety of international programmes and organizations have emerged with immediate interests in global water quality issues. The programmes and organizations may be global or regional, but each has a specific bearing on GEMS/WATER. As phase two commences, the following specific programmes can be identified as examples.

UNEP's Programme Activity Centre for Oceans and Coastal Areas (OCA/PAC) has a primary interest in riverine fluxes of land-derived pollution into the regional seas. Whenever possible, region-specific river flux assessments will be undertaken by GEMS/WATER for this purpose.

The UN Economic Commission for Europe, through a programme centre at the Norwegian Institute for Water Research (NIVA), coordinates an International Cooperative Programme for Assessment and Monitoring of Acidification of Rivers and Lakes. The methods and results of this programme are directly relevant to the GEMS/WATER trend stations network, which includes acidification as a specific issue (NIVA, 1987).

The International Geosphere-Biosphere Programme (IGBP) undertakes studies of global change which are related to the assessment of global water quality issues and global river fluxes undertaken by GEMS/WATER.

UNEP's programme for the Environmentally Sound Management of Inland Water Resources (EMINWA) provides a framework for the development of water quality management and monitoring services, particularly in Africa. Initially, EMINWA efforts are concentrated on the Zambezi and Nile river basins, thus offering an opportunity to meet the development objective of GEMS/WATER in several African countries. Similarly, collaboration with the Mekong Committee was initiated to provide support to information management and assessment studies in this river basin.

Finally, there are a variety of other international and regional programmes which are relevant or complementary to GEMS/WATER. These programmes might offer conceptual models to follow or provide data sets which are useful for global water
quality assessments. Furthermore, the reports issued by GEMS/WATER are also used by other international agencies in preparing environmental data reports or global assessments of world resources. Examples are UNEP’s Environmental Data Reports and the World Resources reports issued by the World Resources Institute.

REFERENCES


