Citation: Ongley, E.D. Water quality management: design, financing and sustainability considerations. *In* Proceedings of the African Water Resources Policy Conference, Nairobi, May 26-28, 1999. The World Bank (in press).

WATER QUALITY MANAGEMENT: DESIGN, FINANCING AND SUSTAINABILITY CONSIDERATIONS

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ABSTRACT

High rates of mortality and morbidity from water-borne diseases is well known. The 1997 United Nations report on freshwater also found that serious degradation of water quality in large parts of the world contributes to water scarcity through loss of beneficial use. Although freshwater contamination by toxic chemicals from municipal and industrial wastes is not wide-spread at this time in Africa, future industrialization and associated effluents, and potential expansion of use of agro-chemicals to achieve food security, are likely to have serious future consequences for water quality, both for public and environmental health, and for increased toxic contamination of the coastal and marine environment.

The sustainable management of water quality has policy, technical, institutional and financial components. In Africa, restricted funding is usually combined with fragile or unstable institutions and limited technical capabilities to deal with an expanding range of water quality problems. Therefore, there needs to be a priority on establishing a coherent and realistic national policy response to water quality management so that limited funds and strengthening of capacity are strategically focused on essential issues. For example, the present state of many national data programmes, for which there are no clear data objectives and no defined users of the data, represents an expensive failure of national policy.

At the technical level, there has been great progress in developing more cost-effective monitoring and analytical protocols, especially in the development of field kits and in the use of toxicologically-based approaches for determining public health and environmental health impacts. Technical advances will be more or less applicable depending on the degree of national development and institutional stability. Decentralization of some of the basic health-related monitoring to the community level together with simple testing procedures for health-related measurements may have significant advantages over centralized national agencies that cannot respond in a timely manner to local needs for data .

Financial sustainability is a vexed issue in the African context. It requires, in the first-instance, a well-defined and targeted programme that meets specific management needs. It includes potential for cost-reduction as well as cost-recovery and income generation. It also depends on management and business skills at the laboratory level and on fiscal policies and accountabilities at the state level that permit earnings retention and reinvestment. Experience suggests that redesign of national data programmes, including technical, institutional and legal components, is an effective first step to achieving cost-efficiency.

INTRODUCTION

Although the "water crisis" tends to be viewed as a water quantity problem, water ***quality*** is increasingly recognized in many countries as a major factor in the water crisis. Historically, poor water quality has been principally associated with public health concerns through transmission of water-borne diseases that are still major problems in Africa and in many other parts of the developing world. In recent years, the contribution of degraded water to the water crisis is also measured in loss of beneficial use – that is, water that is lost for beneficial human, agricultural, and ecological uses through excessive pollution by pathogens, nutrients, heavy metals and acid mine drainage, trace organic contaminants such as agricultural pesticides and pesticides associated with wood treatment, and localized high levels of oil and related pollutants, including salt, hydrocarbons, metals and other toxic wastes, and high levels of turbidity and sedimentation from excessive loadings of sediments.

Freshwater pollution is also a major contributor to coastal and marine contamination with negative impacts on coastal and pelagic species of fish, marine mammals, and sea birds. These impacts are recognized under the 1995 United Nations Global Programme of Action for Protection of the Marine Environment from Land-Based Activities.

The largely silent killers in national economies are the multitude of economic costs/losses due to freshwater pollution. These losses include:

- Costs to expand water treatment facilities and to develop alternative potable water sources.
- Loss of commercial fish species.
- Degradation or loss of habitat and biodiversity and related loss in tourism revenues.
- Direct and indirect costs of disease, including treatment costs and reduced economic productivity through mortality and morbidity.
- Loss in agricultural production from increasingly salinity in irrigation water, or inability to use severely polluted water.
- Loss, or increased cost, of industrial production due to impaired water quality.
- Cost of social unrest and population migration associated with extremely degraded aquatic environments.

In China, where an attempt was made to calculate the overall cost of water pollution to the national economy (Smil, 1996), the cost in 1990 was estimated to be 0.5% of GDP or, in dollar terms, more than the value of all exports from China in that year.

The situation in Africa is highly variable – from moderately developed to very under-developed countries. And while not all countries are facing a crisis of water shortage, all have to a greater or lesser extent serious problems associated with degraded water quality. In some countries these are mainly associated with rivers, in others it is groundwater, and in yet others it is large lakes. Also, the range of polluting activities is highly variable from one country to another. Agricultural runoff and uncontrolled disposal of human wastes into surface waters are ubiquitous in Africa and are particularly evident in highly eutrophic lakes and reservoirs, and in high levels of gastro-enteric diseases especially in young children. Although major polluting point sources such as municipal and industrial effluents tend to be localized, as in the Kenyan side of Lake Victoria, Mzimbazi Creek in Dar es Salaam, and Lake Chivero in Harare, these can greatly exacerbate large scale problems as in Lake Victoria. Mining activities are also localized, but create serious toxic conditions in surrounding and downstream environments as in Zambia, Tanzania, Ghana, etc. Oil extraction is also a major contributor to regional pollution as in Nigeria. A useful review and bibliography of pollution in the African aquatic environment is that of Calamari and Naeve (1994).

National programmes of water quality monitoring in much of sub-Saharan Africa range from limited to non-existent. Many national programmes are dysfunctional due to years of neglect, chronic under-funding, and lack of focus. The primary sources of data often come from donor or specialist scientific programmes, however these are often not in the public domain and may be difficult to access and usually are of limited time spans.

In this paper, we explore the key aspects of water quality monitoring and management that should enter into national water management programmes irrespective of the type of pollution or the type of water body concerned. These components reflect important technical, institutional, and legal issues which should be included in national water policies.

THE POLICY REGIME IN WATER QUALITY MANAGEMENT

Apart from effluent regulations and, sometimes, national water quality guidelines, a common observation is that few developing countries include water quality within a meaningful national water policy context. Whereas water supply is seen as a national issue, pollution is mainly felt at, and dealt with, at the local level. National governments, with few exceptions, have little information on the relative importance of various types of pollution (agriculture, municipal, industrial, animal husbandry, etc.) and therefore have no notion of which is of greatest economic or public health significance. Consequently, it is difficult to develop a strategic water quality management plan or to efficiently focus domestic and donor funds on priority issues.

In the African context, a national water policy should include the following water quality components:

1) A policy framework that provides broad strategic and political directions for future water quality management.
2) A strategic action plan for water quality management based on priorities that reflect an understanding of economic and social costs of impaired water. This plan will include the

following components:

- A mechanism for identifying national priorities for water quality management that will guide domestic and donor investment.
- A consideration of options for financial sustainability, including donor support, public-private sector partnerships, regional self-support initiatives, etc.
- A plan for developing a focused and cost-effective data programme for water quality and related uses, as a basis for economic and social planning.
- Establish specific mechanisms for providing drinking water monitoring capabilities at the community level.
- Establish (national) data standards: These must realistically reflect national needs and capabilities. Nevertheless, the objective is to ensure reliable data from those organizations that produce information for national water management purposes and at the community level for drinking water monitoring.
- A regulatory framework that includes a combination of water quality objectives and effluent controls. This includes both surface and groundwater.

RETHINKING THE PRINCIPLES OF DATA PROGRAMMES

Water quality monitoring, as developed in western countries, is based on the premise that with enough data, a well designed programme can answer most types of water quality management issues. This has been referred to as a data-rich or data-driven approach in which the objective is primarily to gather data. This has recently been challenged by the United States government which found that, despite years of expensive data programmes, one cannot tell whether the nation's waters are getting better or worse. The consequence has been the realization that these mainly chemistry-focused programmes are expensive, often do not reflect the types of data that managers need, and can be replaced by cheaper and more effective methods. The outcome has been a substantial shrinkage of conventional water quality data programmes in Canada and the United States, and an expansion of alternative techniques. Regrettably, this chemistry-focused approach is the one now being adopted by developing countries and recommended by international organizations and major consulting companies. It is true, however, that some of the principles of conventional water data programmes are valid for any type of data collection, such as quality control of data.

Developing countries are "data-poor" environments. This poses a major challenge for environmental management and decision-making. However, one of the benefits of the "information revolution" is the availability of knowledge about a wide variety of issues. New information technologies (IT — see below) now permit the transfer of knowledge about these issues so that the need for hard data is considerably reduce for many types of situations. This is not be confused with technologies such as GIS (Geographical Information Systems) that provide mainly (spatial) data acquisition, analysis and mapping functions. Rethinking the principles of data programmes should also include a fresh look at how new IT tools can reduce the demand for new data by bringing knowledge directly into the hands of decision-makers.

In view of the severe economic restrictions, lack of sufficient technical and institutional capacity, and the different social context of African water quality issues, the conventional "western" approach to water quality monitoring and management is not well suited to much of

Africa. ***It is, therefore, timely to invent an new water quality paradigm that is more suitable, affordable, and sustainable in the African context.***

The over-arching problem of data programmes (monitoring and data use) was summarized by Ongley (1993) as:

> "… a common observation amongst water quality professionals is that many water quality programmes, especially in developing countries, collect the wrong parameters, from the wrong places, using the wrong substrates and at inappropriate sampling frequencies, and produce data that are often quite unreliable; the data are not assessed or evaluated, and are not sufficiently connected to realistic and meaningful programme, legal or management objectives. This is not the fault of developing countries; more often it results from inappropriate technology transfer and an assumption by recipients and donors that the data paradigm developed by western countries is appropriate in developing countries."

Regrettably many countries, including some western countries, spend money on water quality data programmes for which there is no real or identified users of the data. The consequence is that data programmes are data-driven rather than client driven. The usual outcome is that these programmes become rapidly outdated by failing to shift programme priorities towards modern pollution issues, are not subjected to periodic and critical technical review, are not cost-effective, and produce data which are rarely used. Such programmes usually do not produce information that is useful for national planning, for policy development, for investment targeting, or for regulatory purposes. It is not surprising that such programmes lack political and institutional support and have been the subject of considerable cutting when national budgets are under stress. The remediation of this situation is a process now referred to as "modernization" of monitoring (Ongley, 1997, 1998) and which takes advantages of a large number of improvements in monitoring and assessment technologies that reduce costs, improve accuracy, and focus programmes on meaningful data objectives.

DESIGN ISSUES IN WATER QUALITY MONITORING

Data Objectives

The first design criteria in any water quality programme is to determine what are the management issues for which water quality data are required. The technical aspects of data collection will flow from this decision, especially as there are now very cost-effective alternatives to conventional monitoring practice. Establishing of data objectives in Mexico, for example, resulted in a radical shift in national monitoring practice which produced a 66% savings over the budget that had been proposed based on conventional methods (Ongley & Barrios, 1997). Also, these new methods will permit a much higher level of regulatory compliance. Most importantly, data programmes are now seen to have value insofar as they will provide a service for someone other than the monitoring agency itself.

Generally, there are three categories of data objectives. Entries in the following categories may shift between categories, depending on the situation.

1) ***Descriptive data*** that are typically used for government policy and planning and for public information. This can include the following:

- status & trends of important water bodies,
- conformance of water bodies to use-specific water quality objectives such as fisheries, recreation, etc.,
- transboundary issues, including international treaty obligations (this can also appear in #3 below, depending upon the type of agreement or treaty.

2) Data specific to ***public health***, including:

- pathogens, chemical attributes, etc.,
- protection of waters of touristic value,
- monitoring of fish tissue for health-related purposes.

3) ***Regulatory concerns***, including:

- effluent permitting and enforcement,
- identification of contaminants requiring control measures,
- emergency response, including monitoring for spills, etc.

Establishing of data objectives includes a prioritization of issues, identification of those organizations that have need of specific data for these types of issues, and the development of practical interactions with these organizations to ensure that data of the correct type, with appropriate quality assurance, and mechanisms of transmission to the user(s) are mutually acceptable and affordable. Questions of finance are explored below, however the importance of "affordability" must be dealt with at the time of interacting with data users so that the costs are understood, and the client knows what is, and is not, possible under the prevailing economic situation.

The reader will note that "research/science" is not a data objective. Experience indicates that national programmes of monitoring that mix scientific with management objectives of the type noted above often become hybrids that are (1) more expensive that is necessary and often ill suited for management purposes, and (2) often not sufficiently rigorous to produce the type of data required by researchers. Therefore, monitoring for research purposes should be clearly separated from other monitoring programmes, or added to them only within a very specific context.

Technical Innovation

Historically, and still in most developing countries, the focus in monitoring has been on the production of simple chemical (such as major ions) and indicator bacterial data. With some limited exceptions, major ion data is of little practical value. Bacteriological data tend to be intermittent and too frequently are not disseminated to those that are drinking the water. Unfortunately, in addition to faecal pollution, large parts of Africa are now facing one or more of the types of water pollution that exist in highly developed countries – acidification, eutrophication, and contamination. The value of modernization of water quality programmes lies in the prioritization of issues and the development of cost-effective data and management programmes that can focus on these issues.

In most countries, the technology of monitoring has not changed since the 1970's, yet some of the largest advances in monitoring in recent years involve technical innovation that serve to reduce costs and increase efficiency. Types of innovation include:

- Biological assessment, including miniaturized laboratory and field bioassays for toxicity, and use of rapid in-stream assessment techniques.
- Kits and other innovative approaches that lend themselves to decentralized community-based bacteriological monitoring of drinking water supplies.
- Simple histological techniques using red and white blood cell counts from fish to determine presence of pollutant stress.
- Use of enzymatic indicators in organisms such as fish to determine presence/absence of categories of toxic contaminants.
- Miniaturization, automation and simplification of laboratory analytical methods.
- Field techniques such as "lipid bag" technology for sampling for low levels of lipophilic toxic chemicals that are otherwise difficult to detect.
- Greatly improved understanding of use of sediment as a chemical indicator of water quality.

Clearly, not all of these are suited for African use, however there is clear trend in many developed countries towards use of non-professional monitoring by citizen's groups. Canada's International Development Research Centre (IDRC) has developed a basic monitoring protocol for application in developing countries by school children and administered over the Internet. This types of innovation may have useful applications in Africa.

For more developed countries or where there are issues such as contamination from point and nonpoint sources as in, for example, Lake Victoria, the conventional and expensive chemical approach to monitoring can be effectively replaced by new diagnostic tools such as diagnostic chemistry and biological assessment. While these never completely replace bench chemistry, the trend is to use these inexpensive diagnostic tools to determine whether or not the pollutant load meet certain predetermined levels of risk before any chemistry is performed. Many of these tests are now field portable in kit form and/or are capable of automation in the laboratory so that large numbers of analysis can be produced with a high degree of quality control at low cost. While field kits and other diagnostic tests require an initial investment, they can greatly reduce the cost of equipment and number of skilled personnel that are required to operate central laboratories. Moreover, the data produced by these techniques have immediate relevance in decision-making about quality of the sampled environment.

Another area of technical innovation that has considerable merit in developing countries is the application of new decision-support capabilities drawn from the field of information technology (IT). These techniques are particularly useful in data-poor environments that are typical of developing countries and offer an alternative to data-rich (and therefore expensive) models that are conventionally used in many water quality management problems (Ongley & Booty, 1999). They also address a particular problem in many developing countries – that is, the fact that the pace of development and scope of water quality problems almost always grow faster than any ability to build and sustain in-country capacity. There is, however, a large knowledge-base (*domain knowledge*) in the scientific community on most types of water quality management issues which, when supplemented by *local knowledge*, can greatly facilitate decisions on water quality management. The objective of a well–designed decision support system (DSS) is to put domain knowledge into the hands of local practitioners in such a way that the user is guided through a complex task to a conclusion for which the results can be expressed in degrees of confidence. Although decision-support technology is now well known, there has been no effort by the international community to systematically develop these technologies and related data and knowledge bases so that these can be applied to typical water management issues in developing countries.

Network Design

In general, technical innovation has had a major impact on the design of monitoring networks. For example, the conventional fixed site network is adequate mainly for production of descriptive information that is useful for public information and for broad policy issues. Generally, however, such networks are of little value for regulatory purposes, for determining management options in cases of aquatic pollution, or for related investment decision-making. For this latter group of issues, technical innovation and progress in our scientific understanding of cause and effect has provided a broad range of diagnostic and analytical tools that make regulatory monitoring and enforcement much easier and more enforceable in courts of law.

The conventional concept of a national water quality network is probably not appropriate in many African countries that have neither the economic nor technical resources to operate a national network. The fixed site network that is recommended by most water agencies, is expensive and inflexible, especially as many priority issues can be more effectively dealt with by the more flexible survey approach. In the African context fixed sites should be mainly limited to drinking water sources that require regular monitoring either by a national or community-based organizations.

For a substantial number of African countries where the priority water quality issue is that of public health, there is further reason to rethink the conventional wisdom of a national network of water quality stations operated by a central agency. In many countries, this type of network is not able to provide timely public health data to communities due to limited budget, small number of stations, poor communication facilities, etc. Technical innovation being developed by IDRC (1999) for use in under-developed Latin American and Asian countries provides an interesting decentralized monitoring alternative. In this approach, simple indicators of bacterial pollution are used by each village on its own water supply. Using a simple concept of risk, the community decides if treatment is necessary or, if the water has been treated, whether or not the level of treatment is satisfactory. The essential requirements are for (1) the creation of a community-based group that takes responsibility for water quality, and (2) provision by donors or by the central government of the basic supplies and quality assurance required to operate the programme. This approach does requires a shift in thinking from conventional analysis which, although it provides accurate indications of bacterial contamination, is largely unavailable to local populations, to a risk-based approach that identifies the potential for health effects but which is easily implemented at the local level.

Institutional and Legal Issues

In addition to economic uncertainty, many of the problems of water quality monitoring and management are institutional in nature and are too broad to deal with in detail in this paper. The principal institutional issues tend to be:

- Isolation of the data collecting agency from any users of water quality data.
- Failure to institutionalize adequate quality assurance and quality control over data.
- Lack of communication protocols and/or facilities for transmitting data/information to users.
- Lack of human resource strategies to build and promote competence.
- Uncritical acceptance of donor assistance — this tends to be seen in
  a) donated equipment which can not be sustained due to lack of skilled personnel, maintenance, spare parts or reagents;
  b) uncritical acceptance of training that is not focused on priority issues;
  c) lack of follow-up by the donor;
  d) promotion by donors of technologies that are more sophisticated than are needed;
  e) use of foreign experts rather than local experts.
- Unwillingness to accept low technology solutions even when these are more sustainable and suited to local skills, etc.

As noted by Ongley (1998) efficient water quality management is usually severely hampered by out-dated legal requirements that cover everything from sampling and analytical protocols, to data standards. The most difficult issues tend to be:

- Out-dated legal requirements calling for specified water quality parameters. One example is dissolved metals which has been abandoned by most western countries (at least for routine monitoring) due to insurmountable field and laboratory errors.
- Codification of analytical methods which locks programmes into out-dated methodologies which cannot take advantage of new and more cost-effective techniques.
- Codification of analytical quality assurance and quality control (QA/QC) which, in fact, does little to ensure reliable data in the absence of compliance assessment and enforcement. Unfortunately, codification for QA/QC and for analytical methods, appeals to bureaucrats because of its administrative simplicity.
- Lack of data standards so that there is no ability to develop national data sets using diverse data sources and, therefore, no ability to produce reliable national perspectives on water quality. This also impacts on ODA programmes in that donors have no idea what standard of data quality is expected for any particular investment.
- Uncritical acceptance and codification of water quality standards (usually western standards) that are inappropriate to the local situation and are unenforceable.

FINANCING AND SUSTAINABILITY

Financial sustainability is a difficult issue in the African context. It requires, in the first-instance, a well-defined and targeted programme that meets specific management needs. It includes potential for cost-reduction as well as cost-recovery and income generation. It also depends on management and business skills at the laboratory level and on fiscal policies and accountabilities at the state level that permit earnings retention and reinvestment. Experience suggests that redesign of national data programmes, including technical, institutional and legal components, is an effective first step to achieving cost-efficiency. In some more advanced developing countries in Asia and Latin America, data programmes were found by this writer to be operating at about a 10% efficiency based on purely technical criteria. If one factors in whether or not the data are actually used beneficially, the efficiency may fall to nearly zero.

The first step in achieving financial sustainability is a focused national water policy in which the priorities for action and modes of operation are clearly defined. This will drive local and donor activities and will avoid wasteful investments that are not directed to national goals.

Some specific considerations for financing and sustainability include:

a) Focusing Donor Assistance. Often donor assistance is focused on the donor's preferences for technology (as in tied aid projects) and actions. Closer control over, and scrutiny of, donor assistance and, in particular, the use of low technology approaches, offer greater potential for sustainability once the donor project is completed.

b) Regional Partnerships. Regional centres, funded by donors on a sustained basis, has a much greater chance of success in offering low cost training, quality assurance, and certain types of analytical services that should not be implemented by each country.

Such centres, because they can access a large market for laboratory and environmental services, have potential for commercial and profitable linkages with (western) environmental and laboratory service companies that could make these centres self-supporting. To be successful, however, governments must accept a commercial model in which profits are vested in the operator(s) of the centre. It is probable that, as markets grow, the operator will expand into each partner country in order to facilitate closer cooperation with the marketplace.

c) Public-Private Sector Partnerships. Contracting-out of monitoring and analysis makes economic sense in some developing countries because of greater efficiency in the private sector. An alternative is the operation of government laboratories by private companies under contract to the government. In countries where there is some enforcement of environmental standards, there is potential for commercial linkages with western laboratory service companies. These linkages can be profitable to both parties, but particularly for the government which may obtain many benefits, including a high standard of quality control, importation of new equipment and technologies, in-lab training, etc. Obviously, the commercial entity will be looking for legal and economic stability in which to grow their enterprise. In those countries having profitable economic activities such as mining or oil extraction and for which there are official concerns over polluting activities, a linkage between these sectors and western environmental service companies that can provide cost-effective assessment and remediation, can also be extended to include other related monitoring and assessment with the bulk of the costs paid by the profitable economic sector.

d) Specific Donor Linkages. Donors generally have little interest in supporting unfocused national data programmes. However, narrowly defined priorities such as community-based monitoring of drinking water supplies, are more likely to appeal to donor(s) who can partner with the national government for the provision of training, supplies and quality control. This type of priority meets donor criteria of gender sensitivity, poverty-reduction, and community improvement, at low cost. Also, funds for such a priority are retained almost entirely in the recipient country.

e) National Data Banks. The abundance of scientific and other donor-funded projects that produce useful data is usually not mirrored in the availability of these data. A condition of all such projects is that all scientific data should be in the public domain and be easily accessible. In a recent study of the Nile basin it was found that there was no central database nor central point of access to the many projects underway in that region.

f) Quality Assurance and Quality Control (QA/QC). This merits special attention as it is amongst the most difficult of objectives to finance and sustain. QA/QC is essential to data programmes, is inexpensive, yet donors are reluctant to fund this activity. QA/QC programmes are only effective when operated regionally or locally, hence it is necessary to fund a regional centre(s) to carry out this activity on behalf of member states. One possible method of funding is to require that all externally funded water programmes contribute some small percentage of budget to a designated regional centre that will provide QA/QC services to member states.

g) Sale of Data and Data Services. The principle of selling national data is well established, despite opposition from certain international organizations. An option for government monitoring agencies is to market their data to developers and international project managers. Clearly, the data must first meet high standards for data quality. A parallel approach could be to require foreign projects to purchase data services from domestic sources rather than importing their own analytical capabilities or exporting samples to their own countries for analysis. In countries with significant potential for this type of business, a commercial linkage between local agencies and foreign laboratory service companies would make very good business sense and would provide a high level of quality assurance to international projects.

CONCLUSION

The African situation is highly variable with many different levels of development and different needs for water quality data. The conventional paradigm of data collection is not well suited to Africa. There is, therefore, an opportunity to invent a new paradigm that is more cost-effective and sustainable. This requires an integration of water quality into national water policies so that priorities are established based upon social and economic benefits. New technologies in data collection and in the application of knowledge-based approaches to environmental problem solving offer new hope for data-poor countries. Institutional change, including rethinking of the centralized monitoring model and the devolution of core monitoring activities to the community level, offers opportunities for cost savings and higher levels of response to the public. Financial and sustainability issues include cost avoidance and cost-reduction, the use of new cost-effective technologies for monitoring, and a variety of donor/public/private sector linkages that focus on commercial benefits that permit off-loading of monitoring and assessment from government to the private sector.

ACKNOWLEDGEMENT

This overview reflects experience in many national water quality programmes in Latin America, Africa, Eastern Europe and Asia while this writer was the Director of the United Nations' GEMS/Water[1] Collaborating Centre. GEMS/Water assists national programmes to improve water quality monitoring (capacity building) and operates a major global database on water quality that is used to develop assessments of water quality at regional and global scales. It is the only international programme in the field of water quality monitoring and assessment. Sadly, even though freshwater is now receiving so much attention and Governing Councils have strongly endorsed GEMS — UNEP has chosen not to support this programme for several years and its future is now very much in doubt.

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[1] GEMS = Global Environment Monitoring System.