Development of a Framework for Water Quality Monitoring in Mexico

by Asit K. Biswas, Fellow IWRA
Instituto de Ingenieria, UNAM
Apartado Postal 70-472, Coyoacán
04510 MEXICO, D.F.
MEXICO
Eugenio Barrios Ordoñez
and Jesús Garcia Cabrera
Gerencia de Saneamiento y Calidad del Agua
Comisión Nacional del Agua
Avenida San Bernabé 549
San Jerónimo Lídice
10200 MEXICO, D.F.,
MEXICO

ABSTRACT

An attempt is being made in Mexico to develop a water quality monitoring framework that is cost-effective, reliable, accessible, and one that would actually be extensively used by the potential users. The article analyzes the experiences from other developing countries, where the overall usability of the system leaves much to be desired, outlines the essential requirements of a functional monitoring system, critical monitoring issues that should be considered, and the process recommended for developing efficient water quality monitoring in Mexico.

INTRODUCTION

Experiences from the past 25 years from all parts of the world indicate that no rational national water policy can be formulated and implemented without adequate water quality assessment on a long-term basis. At present, there is no agreement on how to assess water quality efficiently and cost-effectively on a national scale. There is no question, however, that good knowledge of national and regional water quality conditions can only be obtained through a reliable water quality monitoring program, which is a complex task under the best of circumstances. Accordingly, development of a rational framework for water quality monitoring is an essential prerequisite for efficient water management in Mexico.

In Mexico, as in most other countries, water quality considerations are receiving increasing attention because of their adverse impacts on the health of people as well as on ecosystems. It is evident that the adverse economic impacts on the nation in terms of bacteriological contamination of water are alone already very significant. While no reliable estimates are available at present, it is highly likely that economic damage to the nation from bacteriological contamination of water sources alone amounts to billions of pesos.

Increasing population, intensive urbanization, and rapidly escalating human activities in all spheres are having both adverse and beneficial impacts on water quality. Whenever human and industrial wastes are not properly treated, surface waters as well as ground waters become the sink for receiving such wastes. With further rapid industrialization in the coming years, water contamination from industrial chemicals, trace metals, and organic compounds could accelerate as well, unless appropriate environmental safeguards are ensured, and relevant environmental legislation is strictly enforced.

Increasing agricultural production often leads to higher usages of fertilizers and agricultural chemicals, some of which would invariably leach to the water sources. Effective control of such nonpoint sources has become a major concern in nearly all countries, especially in terms of increasing the nitrate content of drinking water sources and eutrophication of enclosed water bodies such as lakes and reservoirs. It has not been possible to find cost-effective and reasonably quick solutions once the problems become critical.

On the positive side, because of the higher levels of water contamination, societal concern with the pollution problems has increased substantially in recent years, as a result of which new industrial and municipal waste treatment plants are being built, old treatment plants are being modernized, and legal instruments and regulatory practices have been significantly updated in terms of environmental control. In spite of such worthwhile attempts, only about 6 per cent of wastewater in Mexico is being treated at present. Accordingly, overall progress has been somewhat limited throughout the nation. The situation is somewhat similar in many other countries as well.

GENERAL BACKGROUND

It is not easy to find water quality monitoring programs in most countries that are cost-effective, reliable, and extensively used by their potential clients. Mexico is no exception to this general picture. The reasons for this are many, and hence it is necessary to review them at the very beginning so that many of the constraints and problems encountered could be better understood, and thus hopefully could be avoided while developing a new framework.

First, comprehensive water quality monitoring is a comparatively new phenomenon in most countries. Even now, water quality monitoring efforts lag very significantly behind water quantity monitoring. For example, UNESCO data indicate that in 1989, for the Latin American and the Caribbean region, there was only one water quality monitoring station for every *17.5* precipitation and discharge measurement stations. The situation is very similar for the Asian and the African continents as well. Thus, general experiences and expertise available within countries on water quality monitoring lag behind water quantity monitoring in many significant ways.

Second, water quality management requires more complex and difficult processes when compared to water quantity measurements. The instruments required are significantly more sophisticated, expensive, and difficult to manage and operate properly; their maintenance needs much higher degrees of knowledge and expertise, and the type and level of manpower required to collect, analyze, and manage water quality data are equally much higher. Not surprisingly, as a general rule, water quality data tend to be less reliable than water quantity data.

Third, water quantity monitoring and management require a different type of knowledge and expertise when compare to similar efforts in the area of water quantity. There are of course certain commonalities between the two, since water quantity and quality are closely interrelated in the context of water use. One affects the other, and is in turn affected by the other. This, however, does not mean that just because one has knowledge and experience in water quantity monitoring that one automatically becomes an expert on water quality monitoring as well. This is an important distinction that should be noted since an overwhelming majority of water professionals in government ministries and international organizations have a good knowledge of water quantity, but lack similar levels of understanding of water quality issues.

Unless this distinction is clearly appreciated by the individuals and institutions concerned, the probabilities of making inappropriate analyses and wrong decisions about water quality issues increase steadily.

Fourth, there is an overall tendency in developing countries all over the world to think that water quality monitoring, as it is practiced in the Western world, is the best approach available, and thus should be duplicated to the extent feasible. While it is not difficult to understand why this thinking exists, it is for the most part erroneous and such thinking has created numerous problems in many different parts of the developing world. What is appropriate and works well in a developed country often may not be suitable or sustainable in a developing country for a variety of reasons, including, but not necessarily limited to, differing climatic, economic, institutional, legal, and educational conditions. Equally, developing countries as a group are not homogeneous. Accordingly, what could be a functional and workable water quality monitoring framework in Mexico may not be appropriate for Burkina Faso and vice versa. Straight technology transfer in this area, from one country to another, generally has a poor record in terms of effectiveness, reliability, and sustainability.

What is appropriate and works well in a developed country often may not be suitable or sustainable in a developing country

It is thus essential that a framework for water quality monitoring should be specifically developed for the Mexican social, economic, and environmental conditions in order that its water resources be rationally managed in the 21St century. Experiences from other countries should certainly be considered, but in the final analysis, the water quality monitoring program adopted should very specifically address Mexican conditions, realities, and requirements.

Fifth, for water quality monitoring, it is highly likely that the most sophisticated system, with the latest and most advanced scientific instruments, is likely to be the most inappropriate one for the country. What is needed is a good and functional system that would provide the information required reliably and economically in a timely manner. It should be possible to operate and maintain the system relatively easily and economically. For all water quality monitoring systems, Voltaire's statement that the best could often be the enemy of good should be taken seriously.

MONITORING GOALS

Water quality monitoring is an expensive process. Collection of samples, analyzing them properly, and making results available to the various potential users within a short period requires both money and expertise. In addition, considerable funds have to be invested in establishing, upgrading, and maintaining water quality laboratories in different parts of the country Furthermore, as the monitoring instruments become continuously more and more sophisticated, their shelf lives become less and less. Thus, continuing investments will be needed in regularly updating all the laboratory facilities in the country as well as continuous training of the people associated with the monitoring system to assure quality control and quality assurance.

Naturally such high investments can be justified only if the water quality monitoring system produces information that is reliable and usable, and it satisfies the information requirements of its various clients. Accordingly, the goals of the monitoring system should be clearly stipulated before it is designed and implemented. While this may appear to be a standard and noncontroversial step, sadly, numerous monitoring systems all over the world have basically ignored this aspect in the past. It is often assumed that a water quality monitoring program has to be initiated as a pragmatic and urgent exercise. The fundamental question as to why such a program should be developed, or is needed, for the most part remains unasked.

For the water quality monitoring program in Mexico, various goals should be considered simultaneously depending upon the types of users. These goals could be as follows:

(i) assessments of water quality trends in the country as well as regional and local trends at desired locations;
(ii) assessments to ensure that the international obligations of the country under the various agreements and treaties signed can be met successfully;
(iii) regulatory monitoring to ensure that the standards established and legal requirements are being met satisfactorily on a regular basis;
(iv) decentralization of monitoring activities, and promotion of participation by the private sector and academic institutions.

In addition to the above set of macrogoals, specific microgoals can also be identified. Among these could be the following:

(i) estimation of waste assimilative capacities of the rivers;
(ii) assessment of the appropriateness and implementation of water quality regulatory strategies;
(iii) surveillance to detect adherence to or violation of water quality standards;
(iv) detection of sudden changes in water quality due to accidental and/or deliberate discharge of pollutants;
(v) forecast of hydroecological emergencies due to low flows;
(vi) estimation of reduction of pollutant loadings so as to meet legal water quality standards; and
(vii) forecast of water quality conditions due to expected changes in waste discharges, e.g., construction of a new industry.

It should be noted that regulatory or compliance monitoring generally requires a different approach compared to standard trend monitoring. Similarly, monitoring of groundwater quality often requires a different approach compared to surface water quality monitoring since contaminants could be transported in dispersive flows rather than in primarily linear flows.

REQUIREMENTS **OF A** FUNCTIONAL **MONITORING SYSTEM**

There are some fundamental requirements for a functional water quality monitoring system. Historically, most national water quality monitoring programs were generally planned and implemented based on experience, individual intuitions, and subjective judgments. Not surprisingly, this approach has not resulted in the development of cost-effective and usable systems. It has mostly contributed to the development of "data rich but information poor" systems, i.e., the program may collect lots of data, but information generated for management and decision-making purposes remains somewhat limited. Most water quality monitoring systems normally suffer from this general syndrome.

This syndrome can often be overcome by asking the following three fundamental questions and then incorporating the answers in the monitoring framework. The three questions are:

(i) Who are the potential users of the data that would be collected and information that would be generated?
(ii) How and for what purposes would the collected data be used?
(iii) Why are data in specific locations and on specific parameters being collected?

Unless satisfactory answers to the above three questions can be obtained by extensive and intensive interactions with the potential users of data and information, the results of the monitoring program are unlikely to be used widely.

In addition, any functional monitoring program should consider the following factors:

Cost-effectiveness of the Program. In the present era of environmental awareness, countries – including Mexico – are often under national and international pressure to institute a "comprehensive" water quality monitoring program, whatever it may mean. While no one would argue with the need for a monitoring program, an important issue that needs to be carefully considered is its cost-effectiveness.

Unlike a water quantity monitoring program, collection, analysis, processing, dissemination, and management of water quality data require significantly higher degrees of financial resources, manpower, levels of multidisciplinary professional expertise, equipment, laboratory, and transportation facilities. Since the ready availability of the requisite resources and facilities is invariably constrained, the cost-effectiveness of any system proposed must be very carefully considered.

Cost-effectiveness, in the context of water quality monitoring, essentially means a sensible tradeoff between the depth and context of data to be collected as well as among amount, relevance, and accuracy. As a general rule, it can be said that the overall value of data collected in terms of their subsequent use for any appropriate purposes should exceed the cost of obtaining that information. In other words, cost-effectiveness can be considered to be somewhat similar to the concept of benefit-cost ratio, which is often used for economic analyses of water projects. In other words, benefits from collecting data should always exceed the collection costs, resulting in a benefit-cost ratio higher than 1.0.

From planning and management viewpoints, the value of data collected, and thus the usable information that could be generated from analyses of these data, generally increases with the increasing extent and accuracy of data available. The value of information, however, for most decisions generally approaches a plateau at a certain stage, beyond which it increases only marginally. In contrast, however, the cost of collecting data beyond that stage increases very significantly with more coverage and higher accuracy, This is diagrammatically shown in Fig. 1.

The shaded area in Fig. 1 can be considered to be the cost-effective zone, beyond which the cost of obtaining data would rapidly exceed its intrinsic value. Exactly where in the shaded area a decision should be made in terms of limiting collection of data on water quality would depend on a variety of factors such as the reasons for data collection, management experience, types of decisions that are to be made, and the potential impacts. These are complex issues, and accordingly such tradeoff considerations can often be determined somewhat subjectively, through value judgments.

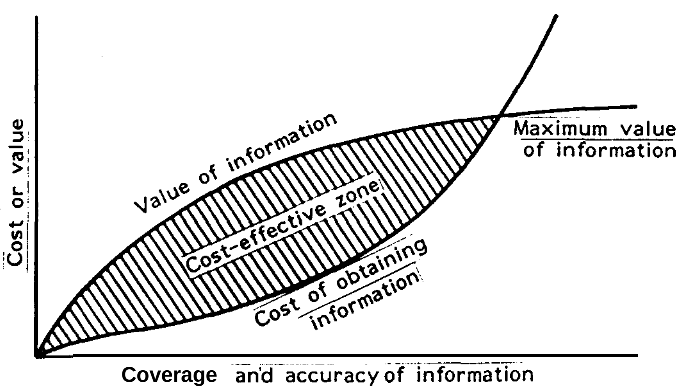

Figure 1. Cost-effectiveness of data collection.

There is often a tendency to collect more water quality data than necessary, or sometimes even to collect totally unnecessary, or very marginally useful data. For any monitoring program to be efficient and cost-effective, it is essential — as discussed earlier — to have clear ideas about the parties who are going to use the data, what type of data would be needed, how would the information collected be used, and when and in what form they should be made available to the users. In the absence of such a clear focus, a monitoring system may not be cost-effective since some necessary data may not be collected, but some nonessential data may be collected.

The above requirement means that any national framework developed needs to be reviewed periodically since in the area of water quality, the potential users of collected information invariably change with time. In addition, the data needs of individual users may also change with time. This aspect will be discussed next.

Dynamic Nature of Water Quality Monitoring Program. Unlike water quantity monitoring, water quality parameters that are to be monitored change with time. In direct contrast to water quantity parameters that are normally monitored, which are few in number and remain mostly the same from one location to another, as well as over time, water quality parameters that could be considered initially for monitoring are numerous. One could develop a list of over one thousand parameters that could be monitored. While certain water quality parameters like DO, BOD, and pH may have to be monitored at each station, there are large numbers of chemicals, organic compounds, and trace metals that could be considered for monitoring only if they are a problem, or likely to be a problem at any specific site. Since there are hundreds of organics, trace metals, and chemicals, as well as their derivatives, that could contribute to water contamination, it is essential that the framework finally agreed to carefully and rationally selects the parameters that need to be monitored at different locations. Decisions also have to be made on the frequency of monitoring of each parameter at specific locations, since a consistent approach is unlikely to be necessary or cost-effective.

The issue is further complicated because of the dynamic nature of a water quality monitoring program. The nature of contamination changes with time, and hence any monitoring program agreed to needs to be objectively reviewed and then updated at periodic intervals. For example, if a major existing industry makes a process change that radically alters the composition of its effluents, the parameters that were being monitored earlier need to be carefully reviewed, especially near the location where the effluent is being discharged. Such a review could indicate that certain parameters no longer need to be monitored, or monitored less frequently, and equally some new parameters may have to be monitored, which were not considered to be relevant before. Similarly if a new major industry moves to a region, or the type of pesticides used to increase agricultural production is changed radically, a review may have to be initiated in order to determine what changes, *if* any, should be considered in terms of the parameters that are being monitored as well as the frequency of their monitoring.

The dynamic nature of water quality monitoring program is an important factor to realize since water professionals are primarily used to the concept of basically a static monitoring system, which is generally adequate for water quantity monitoring. The concept of a dynamic monitoring system is not only difficult to implement but also generally alien to their mindset. Accordingly, if an effective water quality monitoring system is to be maintained, many mind sets need to be changed.

Timeliness of Data Collected Must Be an Important Consideration. The timeliness of water quality data collection, analysis, and dissemination are all important considerations. For example, if there is an accidental spill of hazardous chemicals or wastes to water sources, collection of data is not enough: water quality managers must be given the relevant information as soon as possible so that appropriate decisions can be made immediately. Similarly many water quality samples need to be analyzed fairly quickly, following their collection, according to well-established guidelines. If these procedures are not strictly followed in a timely fashion, the results of the chemical analyses – irrespective of their level of accuracy – may become meaningless. A good example is BOD samples, which if not promptly analyzed shortly after collection, will give erroneous results.

Measurement Errors Should be Kept to a Minimum. During the past two decades, the levels of sophistication of laboratory instruments have increased very significantly. Many water quality parameters that could only have been measured in parts per million earlier, can now be reliably detected at much smaller levels of contamination, in parts per billion. Many pollution standards have recently been tightened to take advantage of the increased levels of technological advances in instrument design. For such low levels of contamination, it is essential that the measurement errors should be very low or negligible, if the data are to be meaningful for water quality control and management purposes.

Data Collected Should be Promptly Analyzed and Transformed into Useful Information, Which Can Then be Used by Various Clients. This is a fundamental problem with water quality monitoring system in many countries, which has not been easy to overcome. Extensive amounts of data are collected, but these are not properly analyzed as to their information content. As a result, only a very minor amount of data collected is ever used for planning, management, and decision-making purposes. Not by any deliberate design, but mainly through a form of benign neglect, data collection becomes an end unto itself, instead of being an important means to an end, which should be an efficient water quality management process. Thus, if the aluminum content in the water of Presa El Cuchillo is high, it serves no major purpose if this information is not extracted from the data collected and brought to the attention of managers so that necessary actions could be considered. If this fact remains "hidden" in the data, chances are that no remedial actions would be undertaken, since managers would continue to be unaware of a potential problem. Unfortunately, analyses to identify the information contents of the data collected are generally ignored, which gives rise to the "data rich but information poor" syndrome mentioned earlier.

Unlike Water Quantity Monitoring, Creating Institutional Arrangements for Water Quality Monitoring Is a Very Complex Task. Creating institutional arrangements for water quantity monitoring is a comparatively simple task. Invariably, a water ministry is in charge of such a monitoring program.

In contrast, developing proper institutional arrangements for water quality monitoring has been a difficult task in most countries, and Mexico is no exception. Currently, ministries dealing with water, health, agriculture, and environment collect water quality data. In addition, cities and municipalities collect water quality data, especially as they relate to the drinking water sector.

A significant percentage of these data collection efforts are planned and designed without adequate consultation for and cooperation with the potential partners. Consequently, there often exists considerable duplication, and equally, major gaps may go unnoticed. Water quality laboratories may remain uncoordinated and hence they could be underused, improperly equipped, and may not have a sufficient cadre of trained people to ensure proper quality control and quality assurance. Experiences from other countries indicate that a functional and cost-effective national water quality monitoring program can exist only when there could be close collaboration between the institutions concerned. However, it has to be admitted that it has not been an easy task to organize interministerial coordination in the past, and the general indications are that it would continue to be difficult in the future.

Equally, data collected in the past by one ministry have not been easily available to other ministries. Such practices have contributed to some frustrations and tensions among the institutions concerned. Equally, absence of coordination has often contributed to the development of incompatible philosophies, software, and data systems on many aspects of monitoring.

It is thus essential that any new framework for water quality monitoring be formulated in such a way that all major institutions concerned can make meaningful contributions and inputs to its development. Data available could be transferred automatically and electronically between the various institutions as well as the potential users of that data. This would mean that individual institutions would not be able to claim "sovereignty" over the data, and the various hardwares and softwares used by the different institutions could be made compatible.

Capacity Building for Water Monitoring Is a Difficult and Time-consuming Task. Water quality laboratories are comparatively easy to design. Equally, it is not difficult to decide what is the "best" equipment available on the world market, which could be bought for the laboratories.

Provided adequate funds are available, it should be possible to design, build, and equip a state-of-the-art water quality laboratory in about two years.

Experience indicates that what takes much longer is to build up the capacity of the staff members to a level where they can perform their tasks reliably and efficiently on a routine basis. It is a difficult process to train an adequate number of staff members who can collect samples, transport and analyze them properly, ensure accurate results are available to the potential users promptly, and that adequate documentation is available on each component of the monitoring process. The entire process could be duplicated by any competent person, and the final results would be very similar. All staff members should not only be aware of the importance of quality control and quality assurance, but they must strongly believe in it as well. It has been a difficult task to change the mindset of people so that they perform their tasks properly each time according to well-established guidelines and procedural requirements. As a general rule, a water quality monitoring program fails not because a good laboratory and instruments are not available, but because the staff members do not carry out their work properly as a matter of routine as they were trained to do. Equally, for the most part, it is not that the staff members do not know what they must do, and how each step should be carried out, but rather after a while they tend to "cut corners," and accordingly the quality control aspects deteriorate steadily.

MONITORING ISSUES

The decision as to what water quality parameters should be monitored is as important as deciding why certain parameters should be monitored, as well as where and with what frequency. Historically, these decisions have generally been made primarily by civil engineers in the water ministries based on their experience, intuition, and subjective judgment. Very seldom were potential users of water quality data consulted as to the type of data they require, at what intervals, and how they plan to use that data. Thus, not surprisingly, without the users' involvement, much of the data collected are seldom used. It is now evident that while such an approach could be a good beginning, exclusive reliance on it is unlikely to produce an optimum and usable system.

Equally, much of the emphasis has been to measure individual physical, chemical, and bacteriological parameters. Considering the advances during the past few years, the time has come to seriously consider the desirability or necessity of using composite indicators or indices on a regular basis. These composite indicators generally select several parameters that could be considered critical for certain purposes, and then consolidate them into one single value. The main advantage of using such indicators is their ready understanding by the public, media, and higher levels of decision-makers. The main disadvantage is that scientifically it is not possible at present to suggest an all-purpose indicator that is reliable and would give a good snapshot of the water quality conditions at any specific point in time. Also, their very simplicity could be a problem, since the numbers may not necessarily indicate the success or failure of any water pollution control policy.

In spite of the constraints, however, the use of indicators — especially bioindicators — is gaining momentum. Bioindicators could be an important alternative when impacts of contamination on aquatic ecosystems are to be considered. Australia currently uses bioindicators in its water quality assessment program. However, while bioindicators could be useful, considerable caution needs to be exercised in their selection and use. It is not an easy task to identify suitable indicator organisms for specific boundary conditions. Extensive research would be needed to identify suitable bioindicators for Mexican conditions.

For finalizing the Mexican framework for water quality monitoring, the most desirable approach is likely to bring together all major institutions that are interested in the subject, and all the important users of the data. Collectively, decisions could then be made as to what parameters to monitor, frequency of monitoring, and the locations of the sampling stations. It should, however, be noted that water quality monitoring should be an iterative process. Irrespective of what is agreed to initially, the whole process needs to be reviewed periodically.

Very seldom were potential users of water quality data consulted

Sampling Frequency. Determination of sampling frequency is an important issue since confidence intervals of estimates are a function of samples taken. As the number of samples taken is increased, the standard error of the mean value is reduced. However, since the standard error of the mean varies inversely as the square root of the number of observations, there is often a limited benefit in increasing the number of samples beyond a certain point. For example, if the number of samples is increased from 16 to 25 (a 56 per cent increase), precision is likely to increase by only 20 per cent. Since increasing sampling frequency will cost additional money, the final decision normally becomes a tradeoff between the level of reliability needed and the cost of achieving that reliability. Accordingly, cost-effectiveness will generally determine the sampling frequency selection.

Compliance Monitoring. Compliance or surveillance monitoring will require a different approach to ambient and trend monitoring. In order to ensure that municipalities and industrial concerns do not violate water quality standards, different approaches would have to be considered. Equally, when random variables like water quality parameters are being considered, there is always a definite probability that the norms would be exceeded by chance. Accordingly, different approaches need to be considered, including different statistical techniques that could be used to interpret water quality monitoring data collected for compliance with the legal requirements.

Fixed Stations and Intensive Surveys. In 198 1, the General Accounting Office (GAO) of the United States published a report that was highly critical of the fixed stations' concept of water quality monitoring. The GAO preferred intensive surveys to fixed stations. This view dominated during the first half of the 1980s. Some five years later, the GAO reversed its views and urged the development of better frameworks for the planning and design of fixed station networks.

There is no question that fixed station networks are an essential component of any water quality monitoring program. These need to be complemented with intensive surveys as and when required (these are often necessary for compliance monitoring) or for answering specific questions like what would be the water quality and environmental impacts due to the construction of a new industrial plant or a hydraulic structure.

SOFTWARE FOR WATER QUALITY DATA MANAGEMENT

In Mexico, some time ago an ad hoc decision was made to use RAISON to analyze the water quality data collected. While no special study was concluded to determine if RAISON was the most appropriate software for the country, it appears that a de facto decision has been made to keep using this software. While RAISON has many advantages, including a user-friendly approach, it also has some drawbacks, especially in terms of data management.

There are many other softwares for analyzing water quality data that are being used successfully in other parts of the world. What is needed is a review to determine which is the most useful and cost-effective software for Mexico at present and in the foreseeable future. The software selected should be compatible with other major systems that are being currently used by the National Water Commission. If software other than RAISON appears to be the most appropriate, and more cost-effective, it is necessary that this change be instituted as soon as possible. The complexities and costs of any changeover from RAISON to another system will increase with time, and thus if it is necessary, it should be done as soon as possible. If, however, it is decided that RAISON is the best option, a formal decision to that effect should be made.

PROCESS RECOMMENDED

An effective framework for water quality monitoring can only be developed through a consultative process between the various concerned ministries and all major users of such data and information.

During the early part of the present mission, extensive consultations were initiated with the concerned ministries as well as the users of the data collected. It is recommended that a one-day consultation be organized at the earliest possible opportunity to discuss the following and other related issues, with the primary objective of finalizing a rational framework.

Identification of Monitoring Objectives and Their Relative Importance. The reasons for monitoring water quality should be clearly and precisely identified at the outset. If, as is likely, the network would have to meet several objectives, each should be identified and prioritized relative to the others. Conflicting objectives may require certain compromises, and the relative priorities could provide guidance later as to the types of compromise feasible.

After objectives have been articulated and agreed to, these need to be translated into data requirements.

Determination of Sampling Station Locations. Determining the location of fixed stations is a critical requirement. Two types of location could be considered: macrolocation, which is a function of the specific objective of

An effective framework for water quality monitoring can only be developed through a consultative process

the network, and microlocation, which is somewhat independent of the objectives but is a function of the representatives of the water samples to be collected. Macrolocation in a river basin usually can be determined by population centers, areas of major pollution loads, etc. This will allow location of sampling stations in a systematic manner by maximizing information for the entire basin at a few strategically located stations. The macrolocation would identify the river reach to be sampled, while microlocation would specify the reach that need to be sampled.

Determination of Variables to Be Monitored. Parameters that could be monitored will depend on the objectives and the budget availability. Water quality can be defined in terms of five or 1,000 variables (depending upon the objectives). Accordingly, it is essential that there is general agreement on how many variables should be monitored.

Sampling Frequency. Once sampling stations have been located so that the samples collected are representative in terms of space, sampling frequencies need to be specified so that the samples are representative in terms of time.

Budget Availability Budget available is an important factor that would have a direct impact on the number of sampling sites, sampling frequency, and the variables to be measured. Invariably some compromises have to be made between the above-mentioned three factors and budget available. An implementable framework can only be developed when there are clear ideas as to budget availability in the coming years.

Capacity Building. Assuming all the above five items have been resolved properly, what types of manpower resources and institutional capacities are required to make them a reality? If appropriately manpower is not available, which could be a real possibility, how can such capacities be built up promptly?

Software and Hardware Requirements. With so many parties interested in water quality monitoring, it is desirable that the softwares and hardwares used are compatible, easy to use, and economic. Some joint decisions should be made in this area.

Transformation of Data into Information. The data collected have to be promptly analyzed and transformed into information. How will this be done? And by whom?

Feedbacks to Fine-tune the Program. Feedbacks from the users will be regularly necessary to fine-tune the program. No water quality monitoring program can ever be considered final. There will always be reasons for "improving" the program due to changing objectives, laws, technology, and users. What process could be identified for receiving and utilizing feedbacks — both solicited and unsolicited?