Monitoring Environmental Quality

In order to determine the effectiveness of actions to improve environmental quality, it is necessary to be able to measure relevant environmental parameters at a level of detail accurate enough to distinguish the anticipated changes. Because the establishment and maintenance of monitoring systems is time consuming and expensive, the scale of such systems needs to be kept to a realistic minimum, and the greatest possible use must be made of the data collected. Experience with monitoring systems in World Bank projects has been mixed, but a number of key factors can be identified, including clear objectives, quality control, and sustainability.

Monitoring in World Bank Projects

Monitoring of environmental quality is often included in World Bank projects to aid understanding of the state of the ambient environment or to monitor the emissions and impacts of specific discharges. Although monitoring is usually only a small component (except in technical assistance projects), it is often important in measuring and evaluating the outcomes of a project. Feedback on the success of these components has been limited to date, but this is changing as more emphasis is placed on monitoring the impacts of projects. However, comments in a number of World Bank reports indicate that the information available on the environment is often incomplete or unreliable (see Box 1). While technical consultants can advise on the design of systems, ensuring the long-term effectiveness and performance of such systems is much more difficult.

Box 1. Insights from a Sample of Bank Reports

The systems are often not providing useful data.

- "Data and information systems (physical, technical, socioeconomic, etc.) relating to water resources in terms of quantity, quality, accessibility, and use are generally inadequate throughout the region" (African Water Resources project).
- "With adequate information, setting priorities is not difficult, requiring only a comparison of benefits and costs. But environmental data are generally incomplete, so uncertainty about costs and benefits is high" ("Study of East Asia's Environment").
- "In most parts of the country there is no basis upon which to make informed decisions about ambient environmental conditions. Filling the gaps is a precondition for an assessment of pollution costs in these areas" (Argentina Pollution Study).

A number of causes have been identified.

- "Reduction of budgetary support; lack of understanding of the economic importance of the data; and [technical assistance] programs which are unsustainable because the outputs have not been of use to decisionmakers and therefore programs are not funded" (Sub-Saharan Africa Hydrological Assessment).
- "High turnover rates [of high quality trained technicians] have been a major problem . . . and have contributed to the intermittent operation of a sophisticated network of . . . monitoring stations built with [donor] financing." (Thailand Country Report).
- "The old system of central planning and control has left a legacy of inefficiency and mismanagement resulting from unreliable basic information; narrow segregation of responsibility; poor information dissemination and analysis; incomplete accountability for performance and results; and in certain cases, deliberate misreporting of environmental data" (former Soviet Union).

The most important steps in establishing or upgrading an environmental monitoring system are to agree on the objectives of the system and to design the system to address these objectives. A monitoring system should be designed to provide practical management or scientific information. Better information will improve environmental decisionmaking, up to a point. At the same time, collecting data, maintaining a database, and carrying out appropriate analyses are costly in terms of both human and financial resources. It is therefore important to focus resources and priorities on those areas where the information is most needed and most useful.

Monitoring is always included in the preparation and design of major projects that may have a direct environmental impact, such as power stations and sewage treatment plants. There are other examples in the portfolio in which specific support has been given to monitoring components (see Box 2). In these more focused cases, success with monitoring has typically been greater.

Box 2. Examples from the Portfolio

- *Shanghai Environment Project.* Water quality monitoring was a significant part of this project, which had as a key objective the relocation of the water supply system intake to a point in the river where industrial pollution was a minimum threat to the supply. A sophisticated satellite and geographic information system (GIS) was provided to track urbanization in the catchment area.
- *Lake Victoria Environmental Management Programme.* A major objective of this project, which covered the three major lake countries of Kenya, Tanzania, and Uganda, was to collect and share the data necessary to understand the dynamics of the lake system.
- *Bolivia Environment, Industry, and Mining Project.* Detailed sampling and analysis of a mining area were carried out with bilateral (Swedish) assistance, separately from the Bank project but as part of the same overall government program.
- *Brazil National Industrial Pollution Control Project.* This project, which focused on improving industrial pollution control in the city of São Paulo, included a component to strengthen the data management capabilities of the local agency.

Ambient Data and Emissions Data

The conceptual model underlying most pollution management is that emissions of pollutants lead to changes in ambient levels, which in turn control the impacts on health and environment. The ultimate concern is the impacts, but in practice, data on ambient pollution are often used to provide information on background conditions and as a basis for policy setting. In the design and control of a specific project, it is usual to work with emissions data because they are strongly related to the pollution sources and because they are more easily measured and managed at a specific site. The emissions requirements, however, must be related to estimates of the overall impact on ambient levels and, ultimately, on the environment.

The links between emissions, ambient levels, and impacts need to be well understood when a monitoring system is being designed because an error in the assumed relationships can lead to wasteful or counterproductive policies and actions.

Ambient Monitoring

Ambient monitoring is carried out for a variety of reasons, including assessment of environmental problems and evaluation of interventions. The initial design of a program is usually based on the available (but often unreliable) data on existing conditions or sometimes on simple models based on emissions estimates. In any case, the program should have the flexibility to be adjusted in the light of initial results.

The choice of parameters should be based on the sources in the area and on the receptors and impacts of concern. In practice, it is usually worthwhile to measure a basic set of parameters (see Table 1), plus any other indicators of special concern. The monitoring plan should set out the rationale for selecting the number and location of monitoring stations, the monitoring frequency, and the sampling methods and should include a quality control plan. The design of monitoring systems should not be overly ambitious: even in the United States and the countries of the European Union, the management information available from large-scale monitoring systems is less than might be hoped. Such experience reinforces

Table 1. Air Sampling Methods

Method	*Advantages*	*Disadvantages*	*Cost (U.S. dollars)*
Passive samplers	Very low cost; very simple; useful for baseline and screening studies	Unproven for some pollutants; in general, provides only weekly or monthly averages	2–4 per sample
Active samplers	Low cost; easy to operate; reliable operation and performance; yields historical data sequence	Daily averages; labor-intensive; laboratory analysis required	2,000–4,000 per unit
Automatic analyzers	Proven; high performance; hourly data; on-line information and low direct costs	Complex; expensive; high skill required; high recurrent costs	10,000–20,000 per analyzer
Remote sensors	Path or range resolved data; useful near sources and for measurements taken vertically through the atmosphere; multi-component measurements	Very complex and expensive; difficult to support, operate, calibrate, and validate; not always comparable with conventional analyzers	> 200,000 per sensor

Source: GEMS/Air.

the benefits of beginning with a small, focused monitoring system and concentrating on answering key management questions.

A realistic set of monitoring parameters would normally include the following (the exact requirements will vary with specific circumstances).

Ambient Air

- Basic set: suspended particulate matter (preferably including fine particulate matter, PM_{10} or $PM_{2.5}$), sulfur oxides, nitrogen oxides, and lead
- Other: ozone, volatile organic compounds (VOCs), and aerosol acid

Ambient Water

- Basic set: pH (indicating acidity or alkalinity); dissolved oxygen (DO); biochemical oxygen demand (BOD); suspended solids; and flow (if appropriate)
- Other: coliform bacteria, ammonia, nitrogen, phosphorus, chlorophyll, nitrates, and metals

To give an example, Singapore regularly monitors 6 key air pollutants (PM_{10}, sulfur dioxide, nitrogen oxides, ozone, carbon monoxide, and hydrocarbons) at about 15 main sites. It monitors 3 major water quality parameters (DO, BOD, and suspended solids) at about 70 locations around the island.

Emissions Monitoring

Emissions monitoring is usually carried out to collect information for the design and operation of pollution control systems or for regulatory purposes. For operational purposes, a small number of parameters (or surrogates) may be measured on a regular or continuous basis. Sampling schedules for regulatory requirements are typically very specific.

Emissions monitoring should include measurement of flow rates, although a surrogate such as production rate is often used. Flow measurements are necessary to convert measurements of concentrations into estimates of pollutant loads. Continuous monitoring methods are now available for many of the most important air and water pollutants, but the value of the additional data obtained needs to be weighed against the cost and complexity of such systems.

An *environmental quality assessment* is essentially a baseline study, either for the examination of the impacts of a project (in a formal EA) or as a basis for the preparation or examination of policy options. In the more sophisticated type of assessment, cause-and-effect relationships are estimated so that the impacts of different interventions can be determined. In such an assessment, large amounts of useful data and analyses are often obtained, but the details are then frequently stored in a form or location that makes subsequent access difficult.

Monitoring as a System

Monitoring usually refers to the tracking of trends over time. It must be regarded as a system comprising a number of elements, with the overall quality of the system controlled by the weakest segment.

Sampling refers to the collection of data that are representative of a system. In some cases, the data can be measured directly (temperature is an example), but often the representative sample has to be analyzed or tested to determine the value of individual parameters. Important questions are the design of the sampling scheme and the protocols for the collation, storage, and transport of samples. A wide range of national, international, and sector-specific standards for sampling and analysis exists.

Analysis of samples is a critical step; the value of the results of the monitoring depends greatly on the degree of confidence that can be assigned to the analysis. In many cases, a major issue is the capability and credibility of the laboratory system used for the analysis.

Information management refers to processing of the data obtained from the sampling system. This includes recording the data, analyzing it, and presenting the information in a form useful to decisionmakers and other stakeholders.

Box 3 describes an application of monitoring to a river system.

Sampling

The choice of sampling methods should always be made on the basis of an evaluation of factors such as reliability, accuracy, ease of operation, and cost. Documentation from the GEMS / Air program provides an indication of the tradeoffs between simple (but often labor-intensive) methods and more sophisticated approaches.

Analysis

The keyword for analytical systems is simplicity. The developing world is littered with sophisticated laboratories, funded by donors or projects, that are idle because of lack of funds for simple items such as glassware or purging gases or are highly unreliable—often because the laboratory buildings cannot be kept at constant temperature or free of dust and contaminants. The problems are commonly compounded by the lack of a national standards infrastructure to grade or certify the laboratories.

Experience has shown that an incremental approach is often best (see Box 4). Under such a plan, the capabilities and reliability of existing

Box 3. Monitoring the Vistula River in Poland

The Vistula River has been monitored since the 1970s, with the results being used to classify the state of the river. The basic monitoring program involved 35 stations on the main river and over 500 monitoring stations on the tributaries, which collected a standard set of samples. The samples were analyzed in 50 local laboratories across the country. Given the large amounts of data being collected, concerns arose as to the quality of the results. A new set of five key permanent monitoring stations has therefore been set up on the Vistula, together with a certified laboratory testing program, to provide a highly reliable set of baseline data.

Box 4. Laboratory Upgrading

Many World Bank projects have included a component to finance laboratory equipment for pollution monitoring and to train personnel. In the Poland Environment Management Project, a Polish-speaking external expert with many years of experience in managing laboratory systems was brought in to inventory existing facilities and optimize the use of existing equipment. A quality control system was introduced before decisions were made on the expansion of the laboratories and the purchase of new equipment. The laboratories were encouraged to operate as far as possible on a commercial basis and to broaden their client base beyond the state agencies that they had traditionally served. The project also included support for national standardization efforts, designed to increase the reliability of the overall laboratory system in the country.

laboratories are gradually strengthened and expanded. The main emphasis is on maximizing the use and productivity of existing systems and in implementing quality control systems before introducing new equipment or capabilities. External quality control, by national or international bodies, is critical for establishing the credibility and competitiveness of individual laboratories.

Information Management

Definition and collection of data. Decisions on the data required and their collection will be influenced by a range of factors. These include the existing data and their quality; local capabilities in sampling and analysis; the existing information infrastructure, such as the availability of remote-sensing data; the projected life of the monitoring system; and the costs of establishing and maintaining the data collection system. The costs of collecting and entering data can be many times those of the hardware and the initial training.

Data-handling systems and information management. The determination of institutional responsibilities for handling and managing information is frequently difficult. The pragmatic approach is to have the organization that needs the data do the initial collection (or contract for collection). The initial processing should be as simple and straightforward as possible, for example using spreadsheets or simple database software on a standard personal computer. Data should be stored in a format that is simple and convenient to exchange, once agreement on responsibilities has been reached.

More elaborate systems (often based on a geographic information system, GIS) need to be founded on institutional agreements regarding technical issues such as the georeferencing system) and exchange and interpretation of data. The installation of a number of GIS systems in different agencies or organizations is not necessarily inefficient, but care must be taken to avoid duplication and to ensure compatibility.

Costs

The costs of a monitoring system include both capital costs and operating and maintenance costs. The capital costs of equipment can be estimated reasonably well, but operating costs are often highly dependent on local labor costs and the difficulties of obtaining spare parts.

A 1993 estimate of air pollution monitoring costs by the U.S. Environmental Protection Agency (USEPA) indicated an annualized figure of around US$26,000 for continuous monitoring of some key pollutants (see Table 2). These costs generally decrease as equipment is improved. In Germany in 1997, the average cost of these tests was about US$20,000.

Estimates for the establishment of pollution control laboratories in India in connection with a 1991 World Bank project were US$220,000 for a regional laboratory, US$140,000 for a mobile laboratory, US$140,000 for a continuous ambient air monitoring station, and US$11,000 for a continuous water monitoring station.

Estimates for a 1993 project in Ukraine included US$2.2 million for 16 stationary air quality monitoring stations (costing about US$140,000 each), US$1.3 million for 7 mobile ambient air quality monitoring stations (about US$190,000 each), and $1.9 million for 7 mobile emissions monitoring vans (about US$270,000 each). In addition, sample costs for measurement of deposition of toxic substances were estimated to be of the order of US$200–$500 per sample for polychlorinated aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and mercury.

As an example, a basic ambient air quality monitoring program for one large metropolitan area is based on 6 automatic monitoring stations around the city, each measuring sulfur dioxide, carbon monoxide, ozone, nitrogen oxides, and nonmethane hydrocarbons, and 16 manual moni-

Table 2. Costs of Monitoring Selected Pollutants

Pollutant	*Monitoring period*	*Annualized cost (U.S. dollars)*
Particulate matter (PM_{10})	Continuous	19,000
Sulfur dioxide	Continuous	26,000
Nitrogen dioxide	Continuous	27,000
Lead	Daily	20,000
Ozone	Continuous	26,000
Carbon monoxide	Continuous	26,000

Source: USEPA, 1993 data.

toring stations measuring particulates (PM_{10}) and sulfur dioxide. A composite air quality index is prepared and announced daily, and contingency plans are implemented when the index is very high. The performance of the system is audited twice a year by an internationally reputable laboratory. The annual cost of the system is estimated to be less than US$1 million.

Sustainability

Given the costs in time and in human as well as financial resources, it is essential to establish responsibility for the collection of data and maintenance of the information system. Data collection is almost always the most costly component of a monitoring system, and it is unrealistic for an environmental agency or a national statistics office to attempt to collect large amounts of information. To minimize the operating costs of the monitoring group, collection should be the responsibility of the line agencies responsible for various functions such as water supply or transport. The coverage of the data may be less than desirable or optimal, but the system is far more likely to be sustainable in the long term.

It is essential that the environmental monitoring unit have an assured budget to sustain the effort. Reliance on donor funds for setup is acceptable, but the ongoing operations must be funded at a realistic level by the country. Examples of the practical budget problems that have been encountered include lack of fuel to drive project vehicles to sampling sites, inability to pay for long-distance phone calls to regional centers, and lack of an operating budget to pay for basic consumables such as glassware and distilled water.

Difficulties can arise when governments seek grant money for the development of new monitoring systems; such systems tend to be capital-intensive and overly sophisticated and therefore unsustainable in the long run. As awareness of these concerns grows, there is an increasing emphasis in project design on working within realistic institutional and budgetary constraints.

Community Monitoring

Monitoring is usually thought of as technically complex, to be carried out by experts. However, there is increasing interest in developing simple

Table 3. Basic Principles for Designing an Environmental Information System

Principles	*Practical concerns*
Clear objectives	The system should be designed to support specific management objectives. There should be clear, easily understood questions that need to be answered.
Appropriateness	The level of sophistication of the sampling and analysis should match the skills and resources available, as well as the objectives. Achieving this may involve tradeoffs between extent of coverage, level of detail, and quality of the information generated.
Institutional support	The incentives for collection of data and maintenance of the systems must be clearly understood. Agreements must be made up front about the sharing of data and the publication of results.
Quality control	The level of accuracy required of the data must be appropriate to the use foreseen and must be explicit. A quality control system must be established, with sufficient outside involvement to ensure confidence in the results.
Flexibility	The system should be set up on the minimum scale necessary; it can be expanded when the benefits of better information become clear. There should be sufficient flexibility to adjust the system in the light of initial results.
Sustainability	The system must be designed in light of a realistic assessment of the long-term financial and human resources that are likely to be available. It is essential for sustainability to be able to demonstrate to decisionmakers that the system produces useful and relevant information.

systems that can be adopted by communities to monitor their own local environment. These systems can be based on simple technologies (the equivalent of a strip of litmus paper) or can be more sophisticated and involve the training of local technicians in basic sampling and testing procedures. In either case, the involvement of the community in the design and implementation of the system is critical. Experience with these approaches is gradually developing and is likely to expand in Bank projects, with greater involvement of communities and nongovernmental organizations.

What Is a Minimum Data System?

A fundamental question should be asked: what is a minimum data system for a given situation? There is no simple answer, but Table 3 sets out a number of basic principles for the design of an environmental information system.